CORRELATION OF SEQUENCE OF ERUPTION AND CROWDING

Genevieve M. Lange, DDS

An Abstract Presented to the Graduate Faculty of Saint Louis University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dentistry

2011
Abstract

Introduction: A wide range of research has focused on factors that predict and affect crowding. The sequence of eruption is an important aspect of occlusal development. Previous research has primarily focused on examining specific sequences of eruption for simple didactic purposes. Little research has been done to examine specific sequences and the effect they might have on the dental arches. Purpose: The purpose of this project was to attempt to establish a correlation between specific sequences of eruption of the maxillary and mandibular canine, first premolar and second premolar and the amount of crowding present in specific areas of the dental arch. The project’s intent was also to correlate other factors such as intermolar width and arch depth to specific sequences of eruption. Methods and Materials: Using panoramic radiographs this study evaluated eruption patterns of 28 patients from a single private practice located in St. Louis, Missouri. Specifically, the area of the maxillary and mandibular canine, first premolar and second premolar was assessed. Secondly, the corresponding dental casts were scanned and analyzed for crowding in these specific areas. Variables such as intermolar width,
arch length and arch depth were also measured and correlated to specific sequences of eruption. **Results:** Kruskal-Wallis statistical analysis revealed no significant finding for the maxillary arch, however significance was found for the mandibular arch for two variables: overall crowding and R segment canine, first premolar, second premolar (345) crowding. A Mann-Whitney test found significance between cases with the sequence canine, first premolar, second premolar versus cases with the sequence first premolar, canine, second premolar for overall 5-5 crowding. More specifically, descriptive statistics revealed more overall crowding was associated with patients that have the sequence of eruption: first premolar, canine, second premolar compared to the sequence: canine, first premolar, second premolar. **Conclusion:** Based on these findings, it can be concluded that individual variation in sequence of eruption can play an important role in orthodontic treatment planning and can have a direct clinical application in early treatment. Further studies are warranted to elucidate the relationship between sequence of eruption and crowding with a larger sample.
CORRELATION OF SEQUENCE OF ERUPTION AND CROWDING

Genevieve M. Lange, DDS

A Thesis Presented to the Graduate Faculty of Saint Louis University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dentistry

2011
COMMITTEE IN CHARGE OF CANDIDACY:
Professor Eustaquio Araujo,
    Chairperson and Advisor
Professor Rolf G. Behrents
Assistant Professor Ki Beom Kim
DEDICATION

This thesis is dedicated to all of the individuals who have supported me throughout my educational journey to become an orthodontist. To my wonderful parents whose support and guidance have helped me reach my dreams and goals. I love them both and greatly appreciated their tireless love and support. To my sisters and all my dear friends, who have always been there for me, sculpting me into the person I am today. To my amazing boyfriend, A.J., who I am so fortunate to have met while here at SLU and whose bright smile and calm demeanor have gotten me through this hectic last year of residency. And finally, to the faculty and residents at SLU. This incredible experience would not have been the same without each and every one of you. Keri, I feel so blessed to have shared this experience with you. I am so lucky to have met such a great friend and will miss you dearly.
ACKNOWLEDGEMENTS

This research project would not have been possible without the dedication and guidance of the following people:

Dr. Eustaquio Araujo, my mentor and chairperson, for your constant help and guidance in preparation of this thesis. You have not only provided me with an immense knowledge of orthodontics, but also have taught me a great deal about myself. I have the deepest respect for you and thank you for your constant encouragement.

Dr. Rolf Behrents, I am forever grateful for giving me the opportunity to be a part of the program at SLU and also for your help with this thesis. SLU has been one of the best experiences of my life.

Dr. Kim, for serving on my committee. Thank you for your support and approachability while working on my thesis as well as in clinic.

Dr. Heidi Israel, who performed all my statistical analysis and kindly explained exactly what it meant.

Dr. Richard Goldberg, for graciously allowing me to access all his records for use in my thesis.

Dr. Gus Sotiropoulos, for being a friend and an inspiration.
# TABLE OF CONTENTS

**List of Tables** ................................................. v

**List of Figures** ................................................. vi

**CHAPTER 1:** INTRODUCTION. ................................. 1

**CHAPTER 2:** REVIEW OF LITERATURE

  Development of Occlusion. ................................. 3
     Characteristics of Deciduous and
     Mixed Dentition ......................................... 4
  Patterns of Eruption ...................................... 9
  Sequence of Eruption .................................... 11
  Variations in Eruption Sequence ....................... 15
  Factors Affecting Sequence of
     Eruption .................................................. 16
  Changes in Dental Arch Dimension ..................... 17
     Arch Width ................................................. 17
     Intermolar Width ...................................... 20
     Arch Length ............................................. 21
     Arch Depth ............................................... 23
  Characteristics of Permanent
     Occlusion .................................................. 25
  Crowding .................................................... 27
  Prediction and Methods of Measuring
     Crowding .................................................. 30
     Methods of Measuring Space Available ............. 30
     Methods of Measuring Tooth Width ................. 31
     TSLA of Mixed Dentition .............................. 32
     TSLA of Permanent Dentition ....................... 36
  References .................................................. 38

**Chapter 3:** JOURNAL ARTICLE

  Abstract ..................................................... 43
  Introduction ............................................... 45
  Methods and Materials .................................. 47
     Patient Sample ......................................... 47
     Measurement of Dental Models ....................... 51
  Statistical Analysis ..................................... 56
  Results ..................................................... 56
  Discussion .................................................. 62
  Conclusions ............................................... 70
  Literature Cited .......................................... 71

**Vita Auctoris** .................................................. 74
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.1</td>
<td>Eruption sequence.</td>
<td>14</td>
</tr>
<tr>
<td>Table 2.2</td>
<td>Mixed dentition analysis.</td>
<td>35</td>
</tr>
<tr>
<td>Table 3.1</td>
<td>Grouping of sample.</td>
<td>50</td>
</tr>
<tr>
<td>Table 3.2</td>
<td>Distribution of sample.</td>
<td>50</td>
</tr>
<tr>
<td>Table 3.3</td>
<td>Descriptive statistics for maxillary crowding variables for all groups.</td>
<td>57</td>
</tr>
<tr>
<td>Table 3.4</td>
<td>Descriptive statistics for mandibular crowding variables for all groups.</td>
<td>57</td>
</tr>
<tr>
<td>Table 3.5</td>
<td>Test statistics for maxillary sample.</td>
<td>58</td>
</tr>
<tr>
<td>Table 3.6</td>
<td>Test statistics for mandibular sample.</td>
<td>58</td>
</tr>
<tr>
<td>Table 3.7</td>
<td>Mann-Whitney Results.</td>
<td>59</td>
</tr>
<tr>
<td>Table 3.8</td>
<td>Descriptive statistics for mandibular Group 1.</td>
<td>60</td>
</tr>
<tr>
<td>Table 3.9</td>
<td>Descriptive statistics for mandibular Group 2.</td>
<td>60</td>
</tr>
<tr>
<td>Table 3.10</td>
<td>Descriptive statistics for mandibular Group 3.</td>
<td>61</td>
</tr>
<tr>
<td>Table 3.11</td>
<td>Descriptive statistics for mandibular Group 4.</td>
<td>61</td>
</tr>
</tbody>
</table>
**List of Figures**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1</td>
<td>Primary molar relationship.</td>
<td>5</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Diagram of early mesial shift.</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Diagram of late mesial shift.</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Occlusal relationship of the primary and permanent molars.</td>
<td>8</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Average transverse arch changes from birth to 25 years.</td>
<td>19</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Measurement of intermolar width.</td>
<td>20</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>Male and female arch length changes.</td>
<td>22</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Arch depth measurement</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Measure of total arch length</td>
<td>54</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Measure of arch length segment 345</td>
<td>54</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Measures of intermolar width and arch depth</td>
<td>55</td>
</tr>
</tbody>
</table>
Chapter 1: Introduction

Crowding is one of the most common reasons patients seek orthodontic treatment. Growth of the jaws, variation in the relationship of mesio-distal crown diameters of permanent teeth and their predecessors and migration of teeth within the dental arches affect the amount of space available. Variations in sequence of eruption have been studied for many years and the importance has been noted. However, most literature has focused on examining specific sequences of eruption for simple didactic purposes. Little research has been done to examine how specific sequences of eruption might interact with the space available in the dental arches. Space analysis is of vital interest when treatment planning for orthodontic purposes. Moorrees\(^1\) states that “exactly how the leeway space is utilized depends on the sequence of shedding and eruption of the maxillary and mandibular posterior teeth and the molar occlusion.” It is fair then to look further into this statement and pose the question of exactly what sequence of shedding and eruption of teeth affects the utilization of leeway space and consequently causes crowding? Is there one sequence of eruption over another that utilizes leeway space more positively, thus making more space available and in essence result in less crowding? Therefore, the purpose
of this study is to evaluate variations in the sequence of eruption of the cuspid and premolars and correlate these sequences with the sites and amount of crowding after eruption. The development of occlusion, including sequence of eruption, and other factors known to influence crowding, will be addressed in this literature review.
Chapter 2: Review of Literature

Development of Occlusion

The development of the occlusion involves a combination of processes, that begins with the formation of the primary dentition continues during the mixed dentition and finally concludes with the completion of the permanent dentition.

In the first year of life, human growth is more rapid than at any other time. The dentition is also developing at a rapid rate.² Twenty primary teeth normally erupt between the ages of approximately 4 and 30 months. Although timing of eruption of primary teeth are variable, eruption tends to occur slightly earlier in the mandibular arch than in the maxillary arch. The sequence of eruption is typically the central incisor, lateral incisor, first molar, canine, and then second molar. All primary teeth are usually into occlusion by the age of 3 years. Deciduous arches are generally ovoid and as primary teeth erupt, spacing between teeth can be present and is considered normal.³ These spaces are required for proper alignment of permanent teeth.

The mixed dentition is defined as the transition period from the primary to the permanent dentition. This stage begins around the age of 6 with the eruption of the
first molars followed by the lower central incisors. During this period, noteworthy changes occur in the dentition. By approximately 12-13 years of age, all the permanent dentition eruption, with the exception of the third molars, has been completed.

Characteristics of Deciduous and Mixed Occlusion

Baume\textsuperscript{4} suggests two categories for primary dentition: Type I, continuously spaced dentition and Type II, closed dentition. Occlusal relationships in mixed dentition correspond to those in permanent dentition. When studying primary first molar relationships, a “flush terminal plane” relationship is categorized as normal. A flush terminal plane refers to the distal surfaces of occluding second primary molars in the same vertical plane. When the permanent first molars erupt, their Angle classification will be determined by this initial primary relationship. A “distal step relationship” of the primary dentition is equivalent of Angle’s Class II. A “mesial step” is an equivalent of a Class I or Class III (Figure 2.1).
According to Baume in type I spaced primary dentition with a flush terminal plane relationship, the permanent molars will utilize this space (primate space) available to shift mesially emerging into a Class I relationship. Baume refers to this as “early mesial shift”. (Figure 2.2)

In type II closed primary dentition and a straight terminal plane, because no primate spaces are available, permanent molars erupt into an edge to edge position. When the primary second molars exfoliate, the permanent
maxillary and mandibular molars tend to shift mesially into the excess space provided by the difference in mesio-distal dimensions of the primary second molars and the succeeding second premolar (leeway space). The mandibular molars tend to migrate slightly more mesially than the maxillary molar, making the initial “terminal flush plane” relationship, now into a Class I. This phenomenon is termed “late mesial shift”. (Figure 2.3)

Figure 2.2 Diagram of early mesial shift
Figure 2.3 Diagram of late mesial shift

Bishara\(^5\) studied the outcome of different deciduous molar relationships in 121 patients on subsequent permanent first molar relationships and found similar conclusions as Baume. He reported that a distal step relationship in the primary occlusion progressed to a full or partial Class II molar relationship. A terminal plane relationship developed into a Class I in 56% of cases and Class II in 44% of cases. A 1 mm mesial step produced a Class I in 76%
of cases, Class II in 23% of cases and Class III in 1% of cases. A 2 mm mesial step resulted in Class I in 68% of cases, Class II in 13% of cases and Class III in 19% of cases (Figure 2.4).

Figure 2.4 Occlusal relationship of the primary and permanent molars (Adapted from Proffit).§

Leeway space was first described by Nance and it is an important feature of the transition from mixed to permanent dentition. Proffit as well as other investigators state
that the leeway space is approximately 2.5mm per side in the mandible and about 1.5mm per side in the maxilla. Much of the adjustment from the mixed dentition to the permanent dentition relies on the proper utilization of the leeway space. Since it is assumed that the permanent canine is larger than its predecessor, it will tend to use some of this space. Moorrees’ studies conclude that “exactly how the leeway space is utilized depends on the sequence of shedding and eruption of the maxillary and mandibular posterior teeth and the molar occlusion.” As Moorrees states, the patterns and sequence of eruption of permanent teeth is an important part of occlusal development.

**Patterns of Eruption**

During the transition from primary to permanent dentition, Moyers describes that the tooth proceeds through four stages of development during its path into the dental arch. First, the position of the tooth germ is mainly determined by genetics. Second, prior to eruption, the tooth buds migrate mesially before appearing in the oral cavity. Third, upon entering the oral cavity the teeth find a final position by both eruptive mechanisms and the pressured from surrounding tissues. Lastly, post-eruption,
when the tooth is in occlusion with the opposing arch, additional systems of forces may alter its final position.

In looking at these stages, a reasonable question to ask is, does lack of available space alter these eruptive patterns? And, if so, in which stage of this model does crowding manifest? Kindaichi\(^8\) believed that rotations of teeth occurred prior to eruption. In his study, radiographs of 37 skull mandibles from children 10 months to 7 years were studied. Results showed that permanent mandibular incisors were rotated in 60.8% of cases and the most common type of rotation seen (44.6%) was that in which the mesial aspect was directed lingually. No rotation of the central incisors was seen in 39.2% of cases. The least common observation (16.2%) was the type of rotation in which the distal aspect of the central incisor was turned lingually. Therefore, it is fair to assume that some irregularity exists prior to eruption into the arch.

Although this is an interesting theory, the majority of research has focused on crowding as it pertains to the teeth post-emergence. At the transition from primary to permanent dentition, the first and most noticeable site of crowding is the lower anterior incisors. Proffit\(^6\) termed this occurrence “incisor liability.” According to Moorrees,\(^9\) the maxillary arch has just enough space to
accommodate the incisors. In the mandibular arch, however, when the lateral incisors erupt, there is on average 1.6 mm less space available for the four mandibular incisors than is required to perfectly align them. He then goes on to explain how an average 2 mm of crowding can be reduced to 0 mm by age 8:

1.) A slight increase in the width of the dental arch across the canines. As growth continues the teeth erupt not only upward but also slightly outward.

2.) A slightly more labial positioning of the permanent incisors relative to the primary incisors. Proffit\textsuperscript{6} states this may contribute 1 to 2 mm of additional space.

3.) Repositioning of the canines in the mandibular arch. As the permanent incisors erupt, the canine teeth not only widen out slightly but move slightly back into the primate space, increasing the intercanine width.

Sequences of Eruption

The sequence of eruption of the primary and permanent dentition has been studied extensively for the past several decades. Up to this point in time, most studies have focused on specific sequences of eruption from an anthropological standpoint.
Massler and Schour\textsuperscript{10} divided the eruption of the permanent teeth into three basic groups:

1.) Group one includes the permanent first molar and all of the permanent incisors. These teeth erupt within one year of each other.

2.) Group two consists of the permanent cuspid, premolars and second molars

3.) Group three is limited to the third molars

In 1953, Lo and Moyers\textsuperscript{11} comprehensively studied the sequence of eruption, intraorally and from roentenograms, in 236 Canadian school children. The authors attempted to determine the most frequent sequence of eruption seen in that population and whether the sequence of eruption affects the final occlusion (according to Angle’s classification).

In the maxillary arch, eighteen different sequences were noted. The most frequent sequence, seen 48.72 percent of the time, was 6 1 2 4 5 3 7. The 6 1 2 4 3 5 7 sequence appeared 16.01% of the time; 6 1 2 4 5 7 3 sequence was seen in 11.8% of cases; 6 1 2 3 4 5 7 sequence observed 5.93% of the time and the 6 1 2 4 3 7 5 sequence just 5.51% of the time.

In the mandibular arch, seventeen eruption sequences were observed. The most common sequence was found to be
6 1 2 3 4 5 7, occurring in 45.77 percent of the cases studied. The sequence 6 1 2 3 4 7 5 was seen in 18.64% of cases, 6 1 2 4 3 5 7 in 8.47%, 6 1 2 3 7 4 5 in 5.93%, and 6 1 2 4 5 3 7 in 5.93%.

Table 2.1, adapted from Lo and Moyers, compares the work of several researchers where different sequences of eruption were evaluated using a wide range of samples. With regard to the sequence of eruption in relation to occlusion, Lo and Moyers found that the combination of sequences (most frequently seen), 6 1 2 4 5 3 7 for the maxilla and 6 1 2 3 4 5 7 for the mandible, produced the highest percentage of Class I occlusions.
Table 2.1 Eruption sequence (Adapted from Lo and Moyers)\textsuperscript{11}

<table>
<thead>
<tr>
<th>Author</th>
<th>Arch</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noyes, Schour and Noyes (1948)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Hopewell-Smith (1913)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Widdowson (1928)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Churchill (1935)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Broomell (1902)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Humphreys and Wellings (1923)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Massler and Schour (1941)</td>
<td>Upper</td>
<td>6 1 2 4 3 5 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 3 5 7</td>
</tr>
<tr>
<td>James and Pitts (1912)</td>
<td>Upper</td>
<td>6 1 2 4 3 5 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 3 5 7</td>
</tr>
<tr>
<td>Diamond (1935)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Hill and Steggerda (1942)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>1 6 2 3 4 5 7</td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Hellman (1942)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>1 6 2 3 4 5 7</td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Lo and Moyers (1953)</td>
<td>Upper</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>6 1 2 4 5 3 7</td>
</tr>
<tr>
<td>Nanda (1960)</td>
<td>Upper</td>
<td>6 1 2 4 3 5 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>1 6 2 3 4 7</td>
</tr>
<tr>
<td>Studiviant el al. (1962)</td>
<td>Upper</td>
<td>6 1 2 4 3 5 7</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>1 6 2 4 3 5 7</td>
</tr>
</tbody>
</table>
Variations in Eruption Sequence

In a study by Garn and Smith, basic descriptive data was reported on the frequency of pairwise eruption sequences determined in cross-sectional examination based on 6,000 children. They found that the most common sequence in the maxilla was 6 1 2 4 3 5 7 and 6 1 2 3 4 5 7 in the mandible. Any sequence in disagreement from this was considered a “variant.” The authors then divided eruption into two major phases. The eruption of 6 1 2 was considered phase I and the eruption of 3 4 5 7 was phase II. It was found that teeth in phase I rarely reverse with those in phase II. More variants were found in the mandible. In the mandible, three high level variants exist between 1 and 6, 4 and 3, and 7 and 5. In the maxilla, only two variants appear at high levels both of these involving the canine: between 3 and 4 and 5 and 3.

Several reasonably normal variations in eruption sequence have clinical significance. Proffit describes the importance of variation in:

1.) Eruption of second molars ahead of premolars in the mandibular arch. It can tend to decrease the space for the second premolar and may lead to its being blocked out of the arch.
2.) Eruption of canines ahead of premolars in the maxillary arch. If the canine erupts at about the same time as the first premolar, the canine will be forced labially. Labial positioning of maxillary canines often occurs when there is an overall lack of space in the arch, because this tooth is usually the last to erupt. But displacement of the canine can also be an unfortunate consequence of an eruption sequence abnormality.

3.) Asymmetries in eruption between the right and left side.

Factors affecting Sequence of Eruption

Gordon and Kuskin\textsuperscript{13} found that timing of eruption depends upon four factors:

1. Endocrine factors
2. Non endocrine factors, such as familial tendencies, chronic diseases, rickets and acute infections
3. The mentality of the infant in the first six months of life
4. Chronologic relationship between the time of inception of the influencing factor and the normal time of teething.
Other factors are:

1. Oral physiologic conditions, e.g., density of bone, thickness of keratinized tissue, amount of calcification of the predecessor, rate of resorption of the primary tooth

2. Oral pathologic conditions, e.g., dental caries, periodontal infections, ankylosis of teeth, abscesses, etc.

3. Hereditary factors

Changes in Dental Arch Dimensions

Arch Width

The growth of the dental arches generally precedes the eruption of the teeth and further there is similarity in the maxillary and mandibular arch width changes. Sillman found that from birth to four years of age much of the transverse growth of the jaw is completed. Width changes in the maxilla are greater than in the mandible, promoting the correct transverse relationship for normal occlusion. Several studies have shown that arch width increase can vary in individuals from 2 to 4 years of age, however it seems to be directly related to the eruption of the permanent teeth. Barrow and White found that one should
expect small amounts of width increases until the permanent canines erupt. After this time, some decrease in arch width, in both the anterior and posterior regions, is seen. Several researchers\textsuperscript{16,18} support this theory and further explain that there is a rapid increase in intercanine width from six to nine years of age, corresponding to the eruption of the permanent incisors and canine. In studies by Moorrees\textsuperscript{1}, there is a decrease in intercanine width from 10 to 12 years of age which remains stable into adulthood. More recently, Bishara\textsuperscript{15} states that the majority of arch width decreases occur by late adolescence and early adulthood but slight dimensional changes do continue into mid-adulthood. (Figure 2.5)
Figure 2.5 Average transverse arch changes from birth to 25 years (Adapted from Sillman)\textsuperscript{14}
**Intermolar Width**

Moyers\(^{19}\) atlas defines intermolar width as the distance from centroid of the right first permanent molar to the centroid of the left first permanent molar (Figure 2.6).

![Figure 2.6 Measurement of intermolar width (Adapted from Moyers)\(^{19}\)](image)

In 1952, Barrow\(^{18}\) and White performed a detailed analysis of developmental changes of several regions of the dental arches. The data consisted of 528 sets of serial casts of 51 children. A relevant finding of this study is that that the maxillary and mandibular dental arches in general only slightly increase in width from ages 4 to 17. The authors state that this increase in width is likely due to remodeling of the alveolus and transverse jaw growth. From ages 7 to 11 the average increase in intermolar width
was 1.8 mm in the maxillary arch and 1.2 mm in the mandibular arch. From 11 to 15 years old there was decrease in intermolar width of 0.4 mm in the maxillary arch and 0.9 mm in the mandibular arch. After the age of 15 more than half of the cases show a decrease in intermolar width. It was also noted that the decrease in intermolar width seen is most likely due to mesial drift of the first permanent molars after the loss of the primary molars. Sillman\textsuperscript{14} and Moorrees and Reed \textsuperscript{16} have reported different findings than Barrow. Sillman\textsuperscript{14} reported that intermolar width increased from 3-12 years of age at the rate of 0.5 mm per year in the maxilla and 0.2 mm per year in the mandible, with no significant changes thereafter. Moorrees and Reed\textsuperscript{16} found significant mandibular intermolar distance increases between the ages of 9 and 14 and thereafter remained constant.

**Arch length**

According to several studies by Moorrees\textsuperscript{1,20,21}, some changes take place within the arches as permanent teeth erupt:

1.) A small decrease in arch length reflects closure of interdental space between deciduous canines and molars as permanent molars erupt.
2.) Arch length increases during the emergence of the permanent maxillary incisors and only a slight increase with the emergency of the mandibular incisors.

3.) A second decrease in arch length occurs by the replacement of the deciduous molars and canine by the premolars and permanent canine, due to the difference in tooth size of the successor and by mesial migration of the permanent molars into the leeway space (See figure 2.7)

Figure 2.7 Male and female arch length changes (Adapted from Moorrees)
Referring to figure 2.7, arch length is greatest at age three, at three years of age the primary dentition is complete. The next significant change that occurs is upon the exfoliation of the primary second molars at approximately 10 years of age. With the loss of primary teeth the space that is lost is mesial to the first molars. The arch length will partially stabilize by age 14, concurrent with the eruption of the permanent second molars.

Several studies have found that the on average the maxillary arch length will decrease by approximately 1.5 mm per side and 2.0 mm preside in the mandibular arch.\textsuperscript{1,14}

Arch Depth

Arch depth is defined as the distance from the midpoint of the most labial points of the central incisors to the second deciduous molars or second premolars at the distal midpoints\textsuperscript{10}. (Figure 2.8)
1950, Speck\textsuperscript{22} studied photographs of dental arches in a series of 49 patients and he concluded that arch depth was greater in all patients during the stage of deciduous dentition compared to that of the permanent dentition. In a study by Knott,\textsuperscript{23} maxillary and mandibular casts of 29 patients were evaluated for size and form of the dental arches from 9 years of age to adolescence. Among other variables, maxillary and mandibular arch width and arch depth changes were analyzed over this time period. Significant findings were a mean decrease in maxillary dental arch depth from 9 to 15 years old of 1.5 mm and a mean decrease of 3.0 mm for the mandibular arch. Between 12 to 15 years old, both arches show some decrease in arch
depth, ranging up to 3.0 mm. Sillman\textsuperscript{14} found the same result as Knott where there is a decrease in arch depth of 1.5 mm in the maxilla and 2 mm in the mandible. DeKock\textsuperscript{24} studied arch depth and width longitudinally from 12 years of age to adulthood in 26 subjects. He found that in all cases arch overall depth decreased from 12 to 26 years of age. However most of the decrease in males and females was seen from ages 12 to 15. Moorrees and Reed\textsuperscript{16} further explain that there is an increase in arch depth as the incisors erupt in the maxilla, however there are minimal changes in the mandible. Following this stage, there is a decrease in arch depth after the shedding of the deciduous second molars, averaging for a mean decrease in overall arch depth.

Characteristics of Permanent Occlusion

In 1899, Edward Angle\textsuperscript{25} was the first to establish classifications of occlusion. Angle classification is based primarily on the mesio-distal relation of the jaws and dental arches to each other and to the skull. He considered the maxillary first molar in relation to the mandibular first molar as the “key to occlusion.” He postulated that if the mesiobuccal cusp of the maxillary molar occludes with the buccal groove of the mandibular
first molar and the teeth were arranged in a smoothly curving line of occlusion, a normal Class I occlusion would exist. Occlusion of the dental arch was divided into three classes. A Class I, or neutro-occlusion, was defined as normal occlusion where the mesiobuccal cusp of the maxillary first molar articulates within the mesiobuccal groove of the mandibular first molar. A Class II, or disto-occlusion, was defined as abnormal occlusion where the mandibular first molar articulates distal to the mesiobuccal cusp of the maxillary first molar. A Class III, or mesio-occlusion, was defined by the mesiobuccal groove of the mandibular first molar located mesial to the mesiobuccal cusp of the maxillary first molar.

Although Angle’s classification has been modified and at times scrutinized, after a century of use, it is still accepted and the most widely used classification system to date.

Many variables influence the final position of the teeth in the permanent occlusion. It is rare to find a perfectly normal Class I occlusion that would not be indicated for adjustments. Among these variables previously discussed, eruption sequence and timing are factors to be considered.
Crowding

Crowding is one of the most prevalent malocclusions and one of the most common reasons patients seek orthodontic treatment. Nance\textsuperscript{7} describes crowding as the difference between the space needed in the dental arch and the space available in that arch. A common term for crowding in the field of orthodontics is tooth size arch length discrepancy (TSALD). TSALD is the difference in arch length versus the total tooth size, which predictably will equal negative or positive space available. Negative space available will result in crowding and positive space available will result in spacing between the teeth.\textsuperscript{6}

Factors that affect crowding are total space available within the dental arches, size of the teeth and arch dimension among many more factors. Extensive research has been done on these factors and their correlation to crowding or spacing.

Various investigators have focused on tooth size and arch length dimensions in relation to crowding and spacing. Lundstrom\textsuperscript{27}, Moorrees and Reed\textsuperscript{28}, Faslicht\textsuperscript{29}, Garn\textsuperscript{12} and Doris et al.\textsuperscript{30} all came to the same basic conclusion that arches with crowding had larger teeth (mesio-distal width) than those with less or no crowding. In a recent study by Puri et al.\textsuperscript{31} the extent to which tooth size contributes to
dental crowding and spacing was analyzed. From their results, it was again confirmed that the mesio-distal crown dimensions of individual teeth, and the combined sum of incisors, canines and premolars was larger in crowded arches compared to normal and spaced dental arches.

Howe and his co-investigators\(^2\) continued to study tooth width dimensions but also thought to investigate arch dimensions and how variations in dimension contribute to crowding. In this study, 104 pairs of dental casts were evaluated, 50 exhibited gross dental crowding and 54 exhibited little or no crowding. Results in this study were contradictory to the previous studies mentioned in reference to tooth size. The difference in tooth size between groups was not significant, but the arch perimeter in the non-crowded groups was significantly larger than the crowded group. Therefore, arch length was a larger contributor to crowding than tooth size. Howe et al. also reported that in the non-crowded group, significantly larger intermolar widths were found. Radnizic\(^3\), Mills\(^4\) and McKeown\(^5\) also studied arch dimensions, particularly arch width, in relation to crowding. All found that an inverse relationship exists between arch width and crowding.

Sampson and Richards\(^6\) decided to look further into dental arch parameters in an effort to predict crowding.
They investigated a sample of 47 Class I children and evaluated pre-eruptive tooth positions and several dental arch parameters. Crowding, radiographic relationship of the lower permanent second molar, first molar, second bicuspid, primary second molar and dental arch dimensions (molar arch width, canine arch width and arch depth) were evaluated in mixed and permanent dentition stages.

They reported that crowding was related directly to tooth size and inversely to molar arch width, canine arch width and arch depth. However, these parameters were noted not to be predictive of anterior crowding. Crowding seemed to be related more to changes in arch depth and molar arch width, rather than changes in intercanine arch width. The investigators also found that the radiographic variables they assessed did not provide useful predictive information regarding changes in anterior crowding.

Sayin and Tukkahraman\textsuperscript{37} performed a more extensive investigation on different arch parameters and how they relate to crowding. Mandibular casts of 60 children in early and mixed dentition were analyzed on the basis of crowding. Factors such as space available for the mandibular permanent incisors, total incisor width, deciduous intercanine width, deciduous intermolar widths, permanent intermolar width, and total arch length were
correlated with the amount of crowding present within the dental arch. The data showed that significant inverse correlations were found between crowding and available space, deciduous intercanine width, deciduous intermolar width, permanent intermolar width, and interalveolar width.

Prediction and Methods of Measuring Crowding

It is well documented in orthodontic literature that space analysis involves comparing the amount of space available for the alignment of teeth and the amount of space required to place them in the correct position. Approaches to measure tooth mass, as well as the estimated space available and space required will now be reviewed.

Methods of Measuring Space Available

To measure the space available in the dental arch, determining arch perimeter is necessary. This can be accomplished by

1.) Dividing the dental arch into segments, using straight line approximations.\textsuperscript{38,39}

2.) Contouring a piece of brass wire to the line of occlusion and then straightening it out to obtain the measurement.\textsuperscript{7,40,39}
3.) Using computerized approaches based on the above principles.\textsuperscript{6}

Methods of Measuring Tooth Width

Throughout history, several authors have used various ways to measure the width of individual teeth, whether it is in the mixed or permanent dentition. Some methods that have been used are measuring directly intra-orally,\textsuperscript{41} from study models\textsuperscript{6,28,41-43} and Xerox prints and photographs of the occlusal plane.\textsuperscript{44,45}

Hunter and Priest\textsuperscript{41} found that teeth measured on dental casts are more accurate than measurements taken directly in the mouth.

Sliding calipers with a vernier scale or bow dividers in conjunction with a millimeter rule were typically used to measure the individual widths of the teeth.\textsuperscript{30} Hunter and Priest\textsuperscript{41} found the sliding calipers to be more accurate than the dividers. Moorrees and Reed\textsuperscript{28} went further and tried to standardize the location of measurement on the models. The best method appears to employ sliding calipers with a vernier scale to the nearest 0.1 mm, measuring the greatest mesiodistal diameter at the contact point parallel to the occlusal surface of the teeth.
In a more recent study by Zilberman, he compared the accuracy of measuring tooth width on casts with the aid of calipers or computerized analysis (OrthoCAD). Results showed that measurement with digital calipers on plaster models produced the most accurate and reproducible results and recommended it as the most suitable instrument for scientific work. The computerized analyses via OrthoCAD showed high accuracy and reproducibility but was inferior to those measurements done on plaster casts with digital calipers.

**Tooth-Size Arch Length Analysis (TSLA) of Mixed Dentition**

According to Gianelly one way to obtain space for the alignment of teeth is to start treatment in the mixed dentition stage of development in order to use the leeway space for alignment. Several authors have described different ways to predict the size of unerupted teeth, specifically the canine, first premolar and second premolar, for the purpose of estimating potential spacing/crowding that will exist within the dental arches.

In 1947, the Nance analysis takes the sum of the erupted permanent central and lateral incisor widths plus the sum of the widths of the permanent unerupted premolars and canines taken from the radiographs to obtain the total
space required. This total is then compared with total space available.

In 1958, Moyers\textsuperscript{48} devised an analysis using only the sum of the widths of the lower central incisors. However his method makes allowance for different levels of probability.

Hixon and Oldfather\textsuperscript{42} devised an analysis similar to Nance. The sum of the mesio-distal diameters of the permanent incisors added to the width of the unerupted canine and premolars taken from the radiograph is then compared to prediction charts to obtain the estimated value of the unerupted teeth.

Tanaka and Johnston\textsuperscript{43} used a regression equation to predict the sizes of the unerupted canines and premolars. The equation takes one half of the sum of the mesio-distal widths of the permanent central and lateral mandibular incisors plus 11 mm for the maxillary and plus 10.5 mm for the mandibular teeth. They determined that the number that results from this equation predicts the width of the unerupted premolars and canines at the seventy-fifth percentile level.

In 1979, Gardner\textsuperscript{49} compared the analyses by Nance, Moyers, Hixon and Oldfather and Tanaka and Johnston to test their accuracy (Table 2.2). This study, along with another
investigation by Kaplan et al.,\textsuperscript{50} found that the Hixon-Oldfather method was proved to be the closest to ideal. However, this method only predicts the size of the unerupted canine and premolars in the mandibular arch. Gardner’s results show that Tanaka and Johnston and Moyers analyses are widely accepted and can be considered reliable methods for prediction. These predictions are also more readily applied by a spectrum of clinicians.\textsuperscript{51,52}
<table>
<thead>
<tr>
<th>Author</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nance (1947)</td>
<td>Space required = incisors + sum of unerupted teeth from periapicals</td>
</tr>
<tr>
<td>Moyers (1958)</td>
<td>Space available = lower incisors + value for 3’s, 4’s, and 5’s on prediction chart</td>
</tr>
<tr>
<td>Hixon Oldfather (1958)</td>
<td>Measured value = maximum M-D width of permanent mandibular central and lateral incisors + M-D width of unerupted premolars measured on periapicals. Take “measured value” to determine estimated value from prediction chart. Space required = lower incisors + estimated value (for both sides)</td>
</tr>
<tr>
<td>Tanaka and Johnston (1974)</td>
<td>Space available = lower incisors + value for 3’s, 4’s and 5’s on prediction chart Maxillary teeth = ( \frac{1}{2} ) width of mandibular incisors + 11 mm Mandibular teeth = ( \frac{1}{2} ) width of mandibular incisors + 10.5 mm</td>
</tr>
</tbody>
</table>
Tooth-size Arch Length Analysis (TSLA) of Permanent Dentition

Several authors have described approaches to assess dental arch perimeter discrepancies in the permanent dentition. Nance (1947), Huckaba (1964), Beasley (1971) and van der Linden (1974) describe a method of assessing tooth-size arch length discrepancy, as space available minus space required. This method involves measuring the size of each individual tooth, from, but not including, the first left permanent molar to first right permanent molar (space required). The perimeter of the arch is calculated, as previously discussed, by constructing points along the alveolar ridge that dictate the space available within the arch from first molar to first molar. These figures are then compared in the following equation to estimate crowding or spacing:

\[
\text{Space available} - \text{Space required} = \text{Discrepancy (crowding/spacing)}
\]

Although crowding is multi-factorial and unpredictable at times, the sequence of eruption of the cuspid and premolars may offer some clue to causes of potential crowding. The present study examines the hypothesis that impending crowding might be predictable based on different sequences of eruption of the permanent teeth. The hypothesis of the study is that crowding of the permanent
teeth is affected by the variation in the order of eruption involving the canines and premolars.
References


Chapter 3: Journal Article

Abstract

Introduction: A wide range of research has focused on factors that predict and effect crowding. The sequence of eruption is an important aspect of occlusal development. Previous research has primarily focused on examining specific sequences of eruption for simple didactic purposes. Little research has been done to examine specific sequences and the effect they might have on the dental arches. Purpose: The purpose of this study was to evaluate a correlation between specific sequences of eruption of the maxillary and mandibular canine, first premolar and second premolar and the amount of crowding present in specific areas of the dental arch. The project’s intent was also to correlate other factors such as intermolar width and arch depth to specific sequences of eruption. Methods and Materials: Using panoramic radiographs this study evaluated eruption patterns of 28 patients from a single private practice. Specifically, the area of the maxillary and mandibular canine, first premolar and second premolar was assessed. Secondly, the corresponding dental casts were scanned and analyzed for crowding in these specific areas. Variables such as intermolar width, arch length and arch depth were also
measured and correlated to specific sequences of eruption.  

**Results:** Kruskal-Wallis statistical analysis revealed no significant finding for the maxillary arch, however significance was found for the mandibular arch for two variables: overall crowding and right segment canine, first premolar, second premolar (345) crowding. A Mann-Whitney test found significance between cases with the sequence canine, first premolar, second premolar versus cases with the sequence first premolar, canine, second premolar for overall 5-5 crowding. More specifically, descriptive statistics revealed more overall crowding was associated with patients that have the sequence of eruption: first premolar, canine, second premolar compared to the sequence: canine, first premolar, second premolar. **Conclusion:** Based on these findings, it can be concluded that individual variation in sequence of eruption can play an important role in orthodontic treatment planning and can have a direct clinical application in early treatment. Further studies are warranted to elucidate the relationship between sequence of eruption and crowding with a larger sample.
**Introduction**

One of the major responsibilities of orthodontists is to guide dental growth and development of the child so that adverse conditions are reduced as much as possible. During the stage of occlusal development, there are many opportunities to guide and intercept malocclusion. Crowding is one of the most frequently occurring types of malocclusion.\(^1\) According to the most recent National Health and Nutrition Examination and Survey (NHANES III), almost 50% of the children in the United States have mild crowding in the mixed dentition, which tends to worsen into adolescence and adulthood. About 33% of the population reported moderate (4 mm or more) and 15% reported severe crowding (7mm or more).\(^2\) One of the major goals of interceptive orthodontics is to prevent excessive crowding from occurring. Consequently, knowing potential sources of crowding is vital for orthodontic treatment planning. Extensive research has found that crowding is multifactorial and has identified factors that affect it.

Literature to date has focused primarily on factors contributing to crowding. Several studies\(^3-8\) have examined the tooth size arch length relationship but have generated a wide range of results. The majority of studies came to the same basic conclusion that arches with crowding had
larger teeth (mesio-distal width) than those with less or no crowding.

Howe et al.\textsuperscript{9} not only evaluated tooth size and crowding, but also looked at the relationship of crowding and arch dimension. Contrary to previous studies, the authors found no association between crowding and tooth size, but did find a relationship between crowding and arch length. The non-crowded sample had significantly larger arch widths than the crowded sample. Many others\textsuperscript{10-12} have obtained similar findings when evaluating arch dimension in relation to crowding.

Proffit states that “variations in eruption sequence have clinical significance and should be recognized.”\textsuperscript{1} Unfortunately, research has primarily focused on examining specific sequences of eruption for simple didactic purposes. In 1953, Lo and Moyers\textsuperscript{13} attempted to determine the most frequent sequence of eruption seen in a specific population and whether the sequence of eruption affects the final occlusion. The authors also compared the work of several other researchers where different sequences of eruption are evaluated based on a wide range of samples. Garn and Smith\textsuperscript{14} went further to study variations in sequence of eruption in a cross-sectional examination,
noting the most common sequences found as well as the most common variations seen.

The sequence of eruption is an important aspect of occlusal development observed by clinicians. However little to no research has been accomplished that examines specific sequences and their effect on the dental arches, specifically crowding. Therefore, the purpose of this study is to attempt to make a correlation between specific sequences of eruption of the maxillary and mandibular canine, first premolar and second premolar and the amount of crowding present in those specific areas of the dental arch as well as overall crowding. Furthermore, other variables, such as intermolar width and arch depth, will be studied in relation to specific sequences of eruption.

**Materials and Methods**

**Patient Sample**

The records of 28 patients, including plaster models of maxillary and mandibular arches and radiographs, were analyzed. All records were gathered from the archives of a single private practice orthodontist.

The patients were selected based on the completeness of records in which radiographs (panoramic or full mouth radiographs) were available to document specific sequences
of eruption and models that included most if not all the erupted permanent teeth.

The inclusion criteria also required the availability of radiographs visibly showing the sequence of eruption of the maxillary and mandibular permanent cuspid, first premolar and second premolar. Additionally needed were initial plaster models with most if not all of the permanent teeth present (excluding second and third molars) and post-treatment final models, to be used if the patient’s initial casts had primary or unerupted permanent teeth present. Exclusion criteria included cases with pathology, congenitally missing or extracted permanent teeth and any cases that had interceptive or early treatment performed between the time of the radiograph in which the sequence was documented to the pour of the initial model used for analysis.

The sample was divided into 8 groups based on specific sequences of eruption for the right and left side of the arch separately for the maxilla and mandible. (Refer to Table 3.1)

For the maxilla, group one consisted of the right and left side of the arch each having the same sequence of eruption in the following order: first premolar, second premolar, canine (4, 5, 3). Previous research notes this
order as the most typical eruption sequence seen in the maxillary arch. In group two, the right and left side of the arch had the same eruption sequence of 4, 3 and 5. This sequence is the second most common sequence seen. In group three, the right and left sides of the arch differ in sequence. The right side had the sequence 4, 5, 3 and the left side has the sequence 4, 3, 5. In group four it was the opposite. The right side had the sequence 4, 3, 5 and the left side 4, 5, 3.

For the mandibular arch, group one, the right and left side had the same sequence of eruption, canine, first premolar, second premolar (3, 4, 5); this was also the most common sequence seen in previous research for the mandibular arch. Group two had the same sequence per side however the order is 4, 3, 5, this was the second most typical sequence seen. Group three had different sequences of eruption for the right and left sides. The right side was 3, 4, 5 and the left side was 4, 3, 5. Group four consists of the opposite of group three, the right side had the sequence 4, 3, 5 and the left side had 3, 4, 5. Refer to Table 3.2 for the sample distribution.
**Table 3.1** Grouping of sample

<table>
<thead>
<tr>
<th>Maxillary Arch Grouping</th>
<th>Sequence of eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Right 453 Left 453</td>
</tr>
<tr>
<td>Group 2</td>
<td>Right 435 Left 435</td>
</tr>
<tr>
<td>Group 3</td>
<td>Right 453 Left 435</td>
</tr>
<tr>
<td>Group 4</td>
<td>Right 435 Left 453</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mandibular Arch Grouping</th>
<th>Sequence of eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Right 345 Left 345</td>
</tr>
<tr>
<td>Group 2</td>
<td>Right 435 Left 435</td>
</tr>
<tr>
<td>Group 3</td>
<td>Right 345 Left 435</td>
</tr>
<tr>
<td>Group 4</td>
<td>Right 435 Left 345</td>
</tr>
</tbody>
</table>

**Table 3.2** Distribution of sample

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Maxilla (N)</th>
<th>Mandible (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Group 2</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Group 3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Group 4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>28</td>
</tr>
</tbody>
</table>
Measurement of Dental Models

The sequence of eruption of the maxillary and mandibular cuspid, first premolar and second premolar was recorded for each patient. As previously mentioned, based on the sequence of eruption, the maxilla and mandible would be placed into the proper group.

Each set of models was scanned into a computer base using the ESM Digital Solutions Scanner and software. A full scan of each maxillary and mandibular model was completed and then a partial scan of the models in occlusion was taken. The maxillary and mandibular full scans were then superimposed on the partial occlusal scan to obtain a final full scan of the models. The scans were automatically loaded into the Shape Ortho analyzer software associated with the scanner. This software was used to make measurements on the models. Individual tooth width, arch length, arch length of the canine and premolar segment, arch depth and intermolar width were the variables measured on each set of computerized models. From these measurements, total arch crowding and right and left canine, first and second premolar segment crowding could be calculated. Individual mesio-distal tooth width measurements were made by selecting individual contact points from first molar to first molar with accuracy of
0.020 mm. An employee and developer of the ESM Solutions Scanner and Ortho Analyzer software trained the operator that preformed the data measurements previously described.

If the initial model scanned had one or several permanent teeth unerupted, the patient’s final set of models were used to measure the width of the individual teeth missing from the initial cast. A digital caliper calibrated to the nearest 0.01 mm was used to measure the tooth on the cast. This value was then entered into the program as the exact width of that particular tooth. According to Zilberman et al.\textsuperscript{15} and others\textsuperscript{16,17}, both computerized and direct cast measurement using a boley gauge are acceptable methods of recording tooth width.

Arch length was measured by constructing a “made to fit” arch form along the defined occlusal plane, adapted from the mesial of the first molar, over the fossa of posterior teeth, cusp tips of the canines, idealized anterior segment between the two canines, to the mesial of the opposite molar (Figure 3.1). This measurement gives the value of the total space available for all permanent teeth excluding molars. A segmented arch length was also constructed along the alveolar ridge from the distal of the second premolar to the distal of the lateral incisor. This arch length measurement is the available space for the
permanent cuspid, first premolar and second premolar (Figure 3.2).

Arch depth was measured from the midpoint of the most labial points of the central incisors to the mandibular second deciduous molars or premolars at the distal midpoints. Intermolar width was measured as the distance between the right first molar and the left molar at the centroids (Figure 3.3). These two methods of recording arch depth and intermolar width has been show to be accurate and repeatable in previous literature.18

A conventional tooth size-arch length (TSAL) assessment was preformed to quantify crowding. Crowding was measured by subtracting the space available (arch length) to space required (the sum of widths of the teeth measured). This is the traditional assessment used by orthodontists to quantify crowding.19-22 A separate TSAL was preformed for the right and left cuspid, first premolar and second premolar segment.
Figure 3.1 Measure of total arch length (space available)

Figure 3.2 Measure of arch length segment 345
Reliability was established by randomly choosing 10% of the sample to re-measure one month after the data was entered into the ESM Scanner Ortho Analyzer software. A reliability analysis (intercorrelation coefficient) was performed to compare the initial to the repeated measures. When performing the data analysis, Cronbach’s alpha needed to be greater than 0.8 for reliability. For all variables, reliability coefficients were found to range from 0.997 to 1.00. Therefore, all data was reliable.
Statistical Analysis

Statistical calculations were completed for the model analysis, and for the main purpose of this study, a correlation analysis of different sequences of eruption with variables associated with crowding. ESM Solutions Scanner, Microsoft Excel 2003 and a statistical software program (SPSS, version 15.0, SPSS Inc., Chicago, IL) were utilized for the statistical analysis.

Descriptive statistics were calculated for all maxillary and mandibular groups. Statistical analysis was then carried out to identify relationships between all group combinations and all variables measured.

Due to the low sample size in groups three and four for the maxilla and mandible, the non-parametric, Kruskal-Wallis one-way analysis of variance was initially applied. The Mann-Whitney test was subsequently applied between groups to any of the significant variables found from the initial correlation test.

Results

Descriptive statistics all groups and variables measured are listed in Tables 3.3 and 3.4.
### Table 3.3 Descriptive statistics for maxillary crowding variables for all groups

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crowding 5-5</td>
<td>28</td>
<td>-0.65</td>
<td>4.16</td>
<td>-8.58</td>
<td>5.68</td>
</tr>
<tr>
<td>Arch depth</td>
<td>28</td>
<td>27.64</td>
<td>2.54</td>
<td>23.19</td>
<td>33.76</td>
</tr>
<tr>
<td>Intermolar width</td>
<td>28</td>
<td>46.22</td>
<td>2.18</td>
<td>41.77</td>
<td>50.47</td>
</tr>
<tr>
<td>L 345 crowding</td>
<td>28</td>
<td>-1.32</td>
<td>1.84</td>
<td>-6.32</td>
<td>0.86</td>
</tr>
<tr>
<td>R 345 crowding</td>
<td>28</td>
<td>-1.61</td>
<td>2.09</td>
<td>-7.00</td>
<td>0.94</td>
</tr>
</tbody>
</table>

### Table 3.4 Descriptive statistics for mandibular crowding variables for all groups

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crowding 5-5</td>
<td>28</td>
<td>-2.23</td>
<td>3.23</td>
<td>-8.51</td>
<td>3.40</td>
</tr>
<tr>
<td>Arch depth</td>
<td>28</td>
<td>23.30</td>
<td>2.26</td>
<td>18.63</td>
<td>27.30</td>
</tr>
<tr>
<td>Intermolar width</td>
<td>28</td>
<td>41.28</td>
<td>2.08</td>
<td>38.20</td>
<td>47.23</td>
</tr>
<tr>
<td>L 345 crowding</td>
<td>28</td>
<td>-1.13</td>
<td>1.35</td>
<td>-3.53</td>
<td>1.52</td>
</tr>
<tr>
<td>R 345 crowding</td>
<td>28</td>
<td>-1.40</td>
<td>1.97</td>
<td>-7.09</td>
<td>2.05</td>
</tr>
</tbody>
</table>

According to the initial Kruskal-Wallis statistical analysis run, no significant variables were found for the
maxillary groups, therefore a Mann-Whitney test was not needed.

In the mandibular arch, two variables, total crowding 5-5 and crowding for the right 345 segment, were found to be significant. (Table 3.5 and 3.6)

**Table 3.5 Test statistics for maxillary sample**

<table>
<thead>
<tr>
<th></th>
<th>Crowding 5-5</th>
<th>Arch Depth</th>
<th>Intermolar width</th>
<th>L 345 crowding</th>
<th>R 345 crowding</th>
</tr>
</thead>
<tbody>
<tr>
<td>P value</td>
<td>.774</td>
<td>.386</td>
<td>.399</td>
<td>.277</td>
<td>.399</td>
</tr>
</tbody>
</table>

**Table 3.6 Test statistics for mandibular sample**

<table>
<thead>
<tr>
<th></th>
<th>Crowding 5-5</th>
<th>Arch Depth</th>
<th>Intermolar width</th>
<th>L 345 crowding</th>
<th>R 345 crowding</th>
</tr>
</thead>
<tbody>
<tr>
<td>P value</td>
<td>.039</td>
<td>.964</td>
<td>.720</td>
<td>.154</td>
<td>.031</td>
</tr>
</tbody>
</table>

*P < 0.5 for significance, significant results shown in bold

A Mann-Whitney test was then performed between all mandibular groups for these two significant variables. Significance was found between groups 1 and 2 for overall 5-5 crowding, between groups 1 and 4 for overall 5-5 crowding and crowding in the R 345 segment, and between groups 2 and 4 for the R 345 segment crowding. (Table 3.7)
When examining the descriptive statistics for the mandibular arch between groups, more crowding is observed in Group 2 than in Group 1, supporting our initial hypothesis that a significant difference in crowding exists between specific sequence of eruption of the canine, first premolar and second premolar. More specifically the sequence involving the first premolar, canine, second premolar (4,3,5) correlates to more crowding when compared to the sequence, canine, first premolar, second premolar (3,4,5) (Tables 3.8 and 3.9).
Table 3.8 Descriptive statistics for mandibular Group 1

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum (mm)</th>
<th>Maximum (mm)</th>
<th>Mean (mm)</th>
<th>Std. Dev (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crowding 5-5</td>
<td>12</td>
<td>-6.42</td>
<td>3.30</td>
<td>-0.88</td>
<td>2.63</td>
</tr>
<tr>
<td>R 345 Crowding</td>
<td>12</td>
<td>-3.02</td>
<td>2.05</td>
<td>-0.55</td>
<td>1.35</td>
</tr>
<tr>
<td>L 345 Crowding</td>
<td>12</td>
<td>-2.94</td>
<td>1.52</td>
<td>-0.64</td>
<td>1.40</td>
</tr>
<tr>
<td>Intermolar Width</td>
<td>12</td>
<td>39.52</td>
<td>47.23</td>
<td>41.72</td>
<td>1.98</td>
</tr>
<tr>
<td>Arch Depth</td>
<td>12</td>
<td>18.63</td>
<td>26.17</td>
<td>23.16</td>
<td>2.07</td>
</tr>
</tbody>
</table>

Table 3.9 Descriptive statistics for mandibular Group 2

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum (mm)</th>
<th>Maximum (mm)</th>
<th>Mean (mm)</th>
<th>Std. Dev (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crowding 5-5</td>
<td>11</td>
<td>-8.51</td>
<td>3.40</td>
<td>-3.42</td>
<td>3.41</td>
</tr>
<tr>
<td>R 345 Crowding</td>
<td>11</td>
<td>-4.55</td>
<td>1.19</td>
<td>-1.64</td>
<td>1.69</td>
</tr>
<tr>
<td>L 345 Crowding</td>
<td>11</td>
<td>-3.53</td>
<td>0.03</td>
<td>-1.90</td>
<td>1.26</td>
</tr>
<tr>
<td>Intermolar Width</td>
<td>11</td>
<td>38.78</td>
<td>46.34</td>
<td>41.05</td>
<td>2.18</td>
</tr>
<tr>
<td>Arch Depth</td>
<td>11</td>
<td>19.55</td>
<td>27.30</td>
<td>23.53</td>
<td>2.59</td>
</tr>
</tbody>
</table>

Refer to Tables 3.10 and 3.11, for descriptive statistics for Group 3 and Group 4.
Table 3.10 Descriptive statistics for mandibular Group 3

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum (mm)</th>
<th>Maximum (mm)</th>
<th>Mean (mm)</th>
<th>Std. Dev (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crowding 5-5</td>
<td>3</td>
<td>-2.43</td>
<td>-1.44</td>
<td>-.45</td>
<td>1.94</td>
</tr>
<tr>
<td>R 345 Crowding</td>
<td>3</td>
<td>-1.26</td>
<td>-.49</td>
<td>-.87</td>
<td>.39</td>
</tr>
<tr>
<td>L 345 Crowding</td>
<td>3</td>
<td>-1.10</td>
<td>.07</td>
<td>-.32</td>
<td>.67</td>
</tr>
<tr>
<td>Intermolar Width</td>
<td>3</td>
<td>38.76</td>
<td>41.45</td>
<td>40.48</td>
<td>1.50</td>
</tr>
<tr>
<td>Arch Depth</td>
<td>3</td>
<td>20.20</td>
<td>26.65</td>
<td>23.17</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Table 3.11 Descriptive statistics for mandibular Group 4

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum (mm)</th>
<th>Maximum (mm)</th>
<th>Mean (mm)</th>
<th>Std. Dev (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crowding 5-5</td>
<td>2</td>
<td>-6.88</td>
<td>-5.96</td>
<td>-6.42</td>
<td>.65</td>
</tr>
<tr>
<td>R 345 Crowding</td>
<td>2</td>
<td>-7.09</td>
<td>-5.02</td>
<td>-6.05</td>
<td>1.46</td>
</tr>
<tr>
<td>L 345 Crowding</td>
<td>2</td>
<td>-1.15</td>
<td>-1.04</td>
<td>-1.10</td>
<td>.078</td>
</tr>
<tr>
<td>Intermolar Width</td>
<td>2</td>
<td>38.20</td>
<td>44.05</td>
<td>41.13</td>
<td>4.14</td>
</tr>
<tr>
<td>Arch Depth</td>
<td>2</td>
<td>22.09</td>
<td>23.99</td>
<td>23.04</td>
<td>1.34</td>
</tr>
</tbody>
</table>
Discussion

Dental arch crowding is multifactorial and the relative importance of likely factors seems to vary unpredictably. A number of studies use a wide range of parameters to quantify and predict crowding. Dental arch dimension, specifically intermolar width, arch depth, arch length and sequence of eruption were evaluated in this study and correlated to crowding.

Radnizic, Mills, McKeown and Sayin et al. all found an inverse relationship between arch depth and intermolar width and crowding. More specifically, Howe et al. reported that “non-crowded” cases had significantly larger intermolars widths.

This seems to follow the reasoning that as the molars migrate mesially into a narrower arch, decreasing intermolar widths and arch depth, arch length is decreased and subsequently there is less room for the teeth within the dental arch.

Contrary to previous studies, our results show no correlation between group 2, proving to have significantly more crowding than group 1, and arch depth or intermolar width.

Leeway space and the utilization of leeway space is an important part of the transition from mixed to permanent
dentition. Sampson and Richards\textsuperscript{24} state that various contact points are formed between the lateral and canine based on timing and sequence of eruption. They noted that incisor crowding seemed to be greatest when the canine erupts buccally and interferes with alignment of the lateral incisor. Nanda\textsuperscript{25} states that if the space required by the permanent cuspids is inadequate then the permanent cuspid will be diverted from its normal eruption path by interference from the mesial aspect of the first primary molar. If the permanent cuspid erupts after the mandibular first premolar, typically not the most common sequence observed, it most likely will erupt in a labial position. Based on this statement, it would be logical to ask if variations in sequence predict more or less crowding post-eruption. However, little to no research has focused on specific sequences of eruption and the correlation to crowding, which leads to the question of interest in this study.

In the maxilla it was found that the majority of cases (18 out of 28) fell into Group 1, sequence: first premolar, second premolar and then the cuspid (4, 5, 3). Previous research by Lo and Moyers\textsuperscript{13} among others also finds this sequence to be the most common. Lo and Moyers\textsuperscript{13} and Garn and Smith\textsuperscript{14} also found that little variation exists in the
maxillary when it comes to sequence of eruption in the posterior segment. This theory supports how the sample was distributed in this study. No significant findings were observed for the maxillary sample. A low sample number in Groups 2, 3 and 4 may likely have contributed to these non-significant findings.

Another possible reason as to why no significant results existed for the maxilla may be that the sequence of eruption proceeds from the back to the front of the arch. When the canine is erupting, if less space is available, the canine can push the upper incisors forward creating more space. This sequence and anatomical position of the maxilla utilizes leeway space more efficiently and gives the canine options to “create” space by moving forward. To verify this reasoning, future investigation of maxillary incisor inclination would need to be added as a variable.

In the mandible the most common sequence observed is typically different from the maxilla, i.e., cuspid, first premolar and then second premolar. Cases were almost equally split between Groups 1 and 2. Although the most common sequence of eruption seen for the mandible is characterized by Group 1, several authors have found that variations in this particular segment are common.\textsuperscript{13,14}
Significant findings for the mandibular arch were found for two variables, crowding 5-5 and right segment 345 crowding. The primary finding in this study is that overall crowding 5-5 was found to be significant between Groups 1 and 2, validating our hypothesis that significant difference results between variations in sequence of eruption of the canine, first premolar and second premolar. More specifically, looking at the descriptive statistics, more crowding is seen in Group 2 (mean = -3.42 mm) than in Group 1 (mean = -.88). The right segment 345 crowding was found significant between Groups 1 and 4 which makes sense from the results we see between Groups 1 and 2. When the sequence is first premolar, canine, second premolar, more crowding is seen overall as well as in that particular section of the arch. It is unknown as to exactly why the left segment 345 did not prove to be significant between Groups 1 and 3 (which is the equivalent to right segment 345 between Groups 1 and 4), however looking at descriptive statistics for group 4, the sample (N = 2) proved to have a very high amount of crowding overall (mean = -6.42 mm) as well as for right segment 345 (mean = -6.05 mm) compared to Group 3 overall crowding (mean = -.45) and left segment 345 (mean = -.32).
Although there is no previous research to support these findings, logical reasoning for these results will be discussed.

Sampson and Richards\textsuperscript{24} note that in the mandible, incisor crowding is seen when the canine erupts in a buccal position, signifying insufficient space available. The authors also state that some of this incisal crowding may be transferred to the premolar region, but most of time stays in the canine area. It is logical to reason that this is the case, due to the natural development of occlusion, whereby the mandibular teeth erupt confined within the parameters of the maxillary arch. With the lower arch constricted within the maxilla, the lower teeth do not have the same ability to create space by moving forward as the maxillary arch does. Instead space is to be gained backwards, utilizing essential leeway space, and potentially causing crowding.

Moorrees\textsuperscript{26} states that the utilization of leeway space depends on the sequence of shedding and eruption of the maxillary and mandibular teeth. In the mandibular arch, the permanent central incisors erupt slightly buccal compared to the primary dentition and the lateral incisors erupt slightly lingual to the central incisors. This immediately creates irregularity in the mixed dentition.\textsuperscript{26,27}
Much of this initial crowding is later relieved by laterally forcing out and ultimately shedding of the primary canine. Nystrom and Peck\textsuperscript{28} deduced that if there is space discrepancy, the lateral incisors will drift into this space, the canine will erupt buccally and cause a higher degree of crowding.

When the sequence, canine, first premolar, second premolar is observed in the lower arch, the canine erupts into the space created by the shedding of the primary canine, and moves slightly distal, making a small amount of space for those crowded incisors. The first and second premolars then erupt into the space available, utilizing the leeway space. With this eruption sequence, it is logical that less crowding is seen. When the tooth-size space available ratio is poor, the cuspid may be impeded in its eruption by the first primary molar, or the exfoliation of the first primary molar may be accelerated and the first premolar erupts before the canine.\textsuperscript{29} When this sequence is observed, there is no space for the canine to move distally, resulting in more crowding. The first molar and second premolar then have the opportunity to move into the leeway space.

In contrast to the maxillary arch, the second premolar is typically the last succedaneous tooth to erupt in the
mandible, and there may not be space due to shortening of the arch by mesial movement of the first molars. When this occurs the second premolar may get pushed lingually out of occlusion, causing increased irregularity.

It is uncertain as to why the right segment 345 was found to be significant for crowding and the left side segment was not. Even though overall crowding was found to be significant between Groups 1 and 2, this does necessarily mean crowding will manifest in the region of the canine and premolars. According to Groves\textsuperscript{2} and Vaden et al.\textsuperscript{30}, the majority of irregularity is found in the lateral incisor - canine contact, then the central – lateral incisor contact. Thus, crowding would not be significant in the area of the canine and premolars (3,4,5) when comparing different sequences of eruption, instead the segment of the lateral and canine should instead be the variable investigated.

Unfortunately, it is very difficult to predetermine which mixed dentitions will change favorably and which will worsen and benefit from interceptive orthodontic therapy. The present study suggests that in the stage of mixed dentition, it would be prudent to observe panoramic radiographs for the sequence of eruption of the canine, first and second premolars. If the sequence in the lower
arch is that of the first premolar, canine and then second premolar, it is expected that less space is available and crowding may result. Interceptive treatment should be implemented to prevent arch length loss and minimize potential crowding.

A source of space maintenance such as a lower lingual holding arch (LLHA) or lip bumper should be planned so as to make sure there is not unwanted mesial migration of the molars. The leeway space can then be used for rest of the dentition and to unravel unwanted crowding. Another option to entertain that is less predictable is at first notice of an unfavorable sequence of eruption, extraction of the primary teeth, namely the canine, is suggested so that the permanent canine may accelerate its eruption into the arch before the first premolar, forcing the teeth to erupt in a more favorable sequence.

Further investigation with a larger sample size, as well as correlating crowding of the lateral – canine segment, instead of the canine and premolar area, to sequence of eruption, is recommended.
Conclusions

1. The sequence of eruption of canine and premolars in the maxillary arch seen most frequently (64%) was in order of: first bicuspid, second bicuspid, canine.

2. The sequence of eruption: canine, first premolar, second premolar, in the mandibular arch was observed in 43% of the cases. The other sequence most frequently seen (39%) was: first premolar, canine, second premolar.

3. More variation in sequence is seen in the mandible than in the maxilla.

4. More crowding is seen in the lower arch when the eruption sequence is that of the first premolar, canine, second premolar compared with the sequence canine, first premolar then second premolar.

5. Due to the limitations of the sample, future investigation with larger sample size would possibly provide more valuable information.


VITA AUCTORIS

Genevieve Marie Lange was born at Barnes Jewish Hospital in Saint Louis, Missouri on July 23, 1981 to Tony H. Lange and Cathy A Lange. She is the oldest of three children.

She grew up in Saint Charles, Missouri and graduated from Duchesne High School in May of 1999. She then attended the University of Missouri in Columbia, Missouri where she obtained a Bachelor of Science degree in 2003. In July of that same year, she followed her urge to broaden her horizons and moved to the West Coast. In 2008, she graduated with honors from University of Southern California with a Doctorate of Dental Surgery degree. With a desire to specialize, her formal education culminated in a residency program for Orthodontics and Dentofacial Orthopedics at the Center for Advanced Dental Education at Saint Louis University. She was thrilled to move back to the Midwest to spend time with her family. Here she expects to receive a Masters of Science in Dental Research and a specialty certificate in Orthodontics in January 2011.

Upon graduation, Gena plans to stay in Saint Louis and join the Saint Louis Orthodontic Group as an associate.