CONTEMPORARY DIAGNOSIS OF ANTERIOR INTERARCH TOOTH SIZE DISCREPANCY

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ABSTRACT

DOUGLAS E. FORD: Contemporary Diagnosis of Anterior Interarch Tooth Size Discrepancy
(Under the Direction of H Garland Hershey)

The Bolton Analysis has long been accepted in orthodontics as a diagnostic test to detect, localize and quantify anterior interarch tooth size discrepancy (ITSD). Although the Bolton Analysis has served orthodontics well, current restorative modalities, esthetic concepts and other important clinical factors not available or appreciated at the time of Bolton's work warrant a reassessment of the Bolton approach to anterior ITSD diagnosis and treatment. Bolton's methods and assumptions were analyzed to assess use of the Bolton Analysis for contemporary diagnosis and treatment of anterior ITSD. Limitations of the Bolton Analysis were identified and an improved method for contemporary diagnosis of ITSD was proposed.

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LITERATURE REVIEW

> "Nature left to herself, always brings proportion…The proportions of the upper teeth to the lower teeth are as exact as any "[1]
>
> William Gibson Arlington Bonwill, 1899

The concept of a proportional balance between the mesiodistal sums of maxillary and mandibular teeth may have had its origins in the geometric theories of dental articulation proposed by Dr. Bonwill. Dr. Bonwill was a prominent 19th-century dentist credited for developing a geometric theory of occlusion based upon his proposed tripod arrangement of the human mandible forming a four-inch equilateral triangle. Bonwill claimed that the average intercondylar distance, measured from the center of each condyle, was approximately four inches and that the distance from the center of each condyle to the median line at the incisal edges of the mandibular central incisors was also about four inches. These anatomic reference points thus formed an equilateral triangle and became the basis of Bonwill's geometric theory of dental articulation.[1-3] Bonwill's geometric theory of articulation was widely accepted in dentistry and became the basis for an articulator patented by Bonwill[4] and for the Bonwill method of arch predetermination for complete dentures.[3] Bonwill's method for arch predetermination for artificial dentures was adopted for use by orthodontics in the formation of ideal archwires.[5-7]

Gilpatric[8] may have been the first to identify the significance of a relationship between the summed mesiodistal widths of maxillary and mandibular teeth to dental

occlusion. Gilpatric reported that the sum of the mesiodistal widths of teeth in the mandibular arch (measured from buccal groove to buccal groove of the first molars) contains from eight to twelve millimeters less mesiodistal tooth substance than the maxillary arch (measured from buccal groove to buccal groove of the first molars).

Gilpatric also believed that overbite was determined in part by the linear relationship between the summed mesiodistal dimensions of maxillary and mandibular teeth. When a mandibular arch contained only eight millimeters less tooth structure than the maxillary arch, Gilpatric thought overbite would be reduced. When a mandibular arch contained twelve millimeters less tooth substance than the maxillary arch, Gilpatric reasoned that overbite would be increased.

Gilpatric's conclusions were based upon his measurement of over 5,000 cases. He accomplished his measurements using needle point dividers to record the mesiodistal dimensions of teeth. Gilpatric recorded each measurement by pressing the points of the dividers into heavy white paper. This was accomplished for each tooth in the maxillary and mandibular arches. A larger needle-point divider was used to transfer the summed arch lengths to a steel millimeter ruler for quantification. Unfortunately, Gilbert did not publish his data, measures of central tendency or dispersion and statistical analysis was not accomplished.

Although Gilpatric acknowledged, "much discussion relative to disharmony between the upper and lower tooth substance to such an extent that it would lead one to believe that it was of common occurrence."[8] He reported disharmony between the upper and lower tooth substance to be "very rare"[8] in his sample of over 5,000 cases. Still, the possibility of

interarch tooth size discrepancy that might prohibit excellent occlusion was recognized by Gilpatric

Young[9] may have been the first to express the relationship between summed maxillary and mandibular tooth widths as a ratio. Young also attributed variation in overbite to, "…the ratio of tooth material in the mandibular arch to that of the maxillary arch, anterior to the first permanent molars". Young noted that when the combined mesiodistal widths of incisors, canines and premolars in the mandibular arch is large compared to the combined mesiodistal width of the same teeth in the maxillary arch, incisal overbite is reduced. When the ratio of tooth material in the mandibular arch anterior to the first permanent molars is reduced relative to the same teeth in the maxillary arch, Young reasoned overbite would be increased.

Young measured the mesiodistal width of teeth in inches and presented multiple cases to support his conclusions. However, he did not provide data or statistical analysis to support his conclusions. Moreover, Young did not suggest an ideal or average ratio between the maxillary and mandibular tooth widths required for good occlusion. Although Young attributed variation in overbite to the interarch ratio of summed mesiodistal tooth widths, he neither suggested nor acknowledged the possibility of a ratio so discrepant as to prohibit establishment of normal occlusion.

The problem of an interarch tooth size discrepancy significant enough to prohibit establishment of normal occlusion is referenced in some early orthodontic textbooks. Strang in his Text-Book of Orthodontia included images of two cases and wrote:

> "Unquestionable there are a few cases that the orthodontist may find, over a period of years, in which there is more tooth material in one dental arch than the other so that it is impossible to absolutely harmonize the two arches. The author has encountered 3 such cases in thirty years of practice. In one, the left

> upper incisor was nearly 1/16 inch wider than the right and its rotation could not be avoided in the final result. In the second, both upper centrals were huge and could not be accommodated without rotation. In the third case, seen in consultation, there was lack of tooth material in the upper arch…The latter case was studied several years after treatment. The arches were beautifully aligned, the mesiodistal relationship was correct and the overbite normal, but in the upper arch were spaces between all the incisors and there was no way of avoiding these because the teeth were too small. Hence the possibility of inharmony in tooth material and tooth size though rare must be considered. Most cases, however, that on superficial glance, apparently exhibit such a condition, will be found perfectly harmonious when properly treated. The author is convinced that these errors in denture planning by Nature are anomalies of so great infrequency that they may never be encountered by a majority of orthodontists."[10]

Dewey and Anderson in Practical Orthodontia,[11] recognized that extreme cases of disharmony between the upper and lower tooth widths necessitated acceptance of either slight crowding or spacing in one of the arches, or else increased or reduced overbite. Thus, early orthodontic thinkers seemed to believe that while variations in interarch tooth size accounted for differences in overbite, discrepancies significant enough to frustrate attempts to establish normal occlusion were extremely rare.

Perhaps it was not until Ballard[12] published his paper titled, "Asymmetry in Tooth Size: A Factor in the Etiology, Diagnosis and Treatment of Malocclusion" that orthodontists began to appreciate the significance and possibility of tooth size discrepancy as an etiologic factor in malocclusion. Ballard noted the predominant belief in the perfectibility of the human dentition writing:

> "…practitioners prevalently believe that the dental apparatus of man is a potentially perfect machine, harmonious in all its parts, needing only a skillful rearrangement by the orthodontist to render it functionally and esthetically perfect…The inclined planes of the opposing dental arches have often been compared with a system of gears, a mechanical principle in which harmony between component parts is the first essential. When a carefully machined set of gears runs at high speed there exists a state of "balance" which is far from static."[12]

Ballard made measurements on 500 sets of orthodontic casts, collected from three private practices and from the Division of Orthodontics, College of Dentistry, University of California. All casts were made from plaster of Paris impressions. Ballard used fine-pointed dividers and a finely calibrated millimeter ruler to record the greatest mesiodistal crown diameter of each permanent tooth. The greatest mesiodistal diameter of each tooth was measured and compared with the contralateral tooth on each cast. Ballard recorded discrepancies between contralateral teeth of one-half millimeter or larger and discrepancies as large as one-quarter millimeter, but less than one-half. Discrepancies smaller than a quarter millimeter were attributed to errors of measurement and were disregarded.

Ballard reported discrepancies between one or more pairs of contralateral teeth in 448 out of the 500 (90%) cases he measured. 408 of these cases exhibited a discrepancy of 0.5 millimeters or more between left and right teeth. The remaining 40 cases had discrepancies greater than 0.25 millimeters but less than 0.5 millimeters. The maxillary lateral incisors, maxillary first molars, mandibular canines and mandibular first bicuspids were the most frequent teeth to exhibit contralateral discrepancies. Of the 448 discrepant cases, there were only 72 cases which maintained occlusal balance of the buccal segments in spite of the discrepancies in tooth size. Ballard advocated:

> "…judicious stripping of proximal surfaces…where lack of harmony in tooth material lies primarily in the anterior segments, more latitude is provided in correcting lack of balance by stripping than in the buccal segments, where inclined plane relationships impose definite limitations."[12]

In making this statement, Ballard broke from earlier classifications of the human dentition which considered the class of each tooth. Ballard instead classified the teeth within each arch as anterior or posterior. Ballard recognized that the inclined plane relationships of posterior teeth impose greater limitations in correcting lack of interocclusal balance through

interproximal enamel reduction. The anterior teeth were probably considered separately because more latitude is provided in correcting lack of balance by "stripping" than in the buccal segments.

Neff[13] also recognized the possibility for ITSD significant enough to preclude establishment of normal occlusion with an acceptable amount of overbite. He observed that it was not possible to finish some orthodontic cases with proper alignment and ideal overbite. Neff credited Chuck with making a similar conclusion regarding set-up procedures for orthodontic positoners. Chuck[14] noted it was not possible to set up all cases to a standard overbite and still achieve perfect alignment and contact of all teeth. Neff attributed this problem to, "…a variation in proportionate tooth size of the upper and lower anterior teeth." Neff proposed a "…mathematical guide to find each normal occlusions individual anterior overlap." He advocated the use of "three-inch dividers with needle-sharp points" to make direct intraoral measurements of the mesiodistal measurements of the maxillary and mandibular anterior teeth in millimeters prior to the start of treatment. Thus, Neff may have been the first in the United States to propose the use of the relationship of the mesiodistal sum of maxillary and mandibular anterior teeth as a mathematic guide for orthodontic diagnosis to predict post-orthodontic anterior occlusion.

Neff divided the summed mesiodistal widths of the mandibular anterior six teeth into the maxillary sum to obtain a figure he referred to as the anterior coefficient. Neff proposed his anterior coefficient could be used as a guide to a normal occlusion's overbite by comparing the case anterior coefficient to mathematical computations he accomplished based upon the "Hawley-Bonwell triangle". Neff repeatedly used the term "Hawley-Bonwell triangle" in his paper, but was probably referring to the Bonwill-Hawley triangle referenced

earlier in this literature review. Neff considered a 20% overbite to be ideal and calculated a corresponding anterior coefficient value of 1.20. According to Neff's calculations, an anterior coefficient of 1.10 corresponded to an overbite of 0% and an anterior coefficient of 1.55 represented a 100% overbite. Neff claimed to have measured "over two hundred cases" but failed to provide greater detail regarding his sample. In a later paper Neff stated that his sample was based upon measurements of 300 cases of malocclusion measured intraorally and from dental casts. Neff did not report the mean anterior coefficient of his sample or any measures of statistical dispersion other than a range of 1.17 to 1.41. He did report the anterior coefficient values for thirty cases over a range of values along with the indicated overbite according to his mathematical computations using the "Hawley-Bonwell triangle". Neff did not indicate how these thirty cases were selected. Moreover, Neff did not publish data to support or validate his claim that the overbite for a given case could be determined using his anterior coefficient.

In a subsequent paper Neff provided a literature review of the relationship between the summed mesiodistal widths of maxillary and mandibular anterior teeth. He also claimed to have made subsequent observations of "over 600 treated cases". Neff presented in a table the results of, "A more recent survey by the author with all the measurements taken in the mouth" that showed the mandibular anterior teeth are from 73%-85% as large as the maxillary anterior teeth with a mean of 79% from a sample of malocclusions of unspecified size. Neff had previously used the term anterior coefficient to describe the value obtained by dividing the summed mesiodistal widths of the mandibular anterior teeth into the summed mesiodistal widths of the maxillary teeth. In his 1957 paper, he introduced a new term called the anterior percent relation (APR) to describe the percentage larger the summed mesiodistal

widths of maxillary anterior teeth are than the mandibular anterior mesiodistal sum. From his measurements of a sample of three hundred cases of malocclusion, Neff concluded that the maxillary anterior segment is 18 to 36% larger than the mandibular anterior segment with a mean APR of 26.6%, and that an increase of one percentage point in the APR is equal to 2.5 percent increase in overbite.

Lundström[15] provided a review of European investigations on the problem of intermaxillary tooth size discrepancy. Lundström credited the Lux brothers (1930), Ritter (1933), Seipel (1946) and Selmer-Olsen (1949) for investigating the correlation between maxillary and mandibular tooth widths and recording significant correlations. According to Lundström, Ritter calculated a coefficient of $r = 0.67 \pm 0.05$ for one hundred cases he designated as normal and $r = 0.82 \pm 0.03$ for one hundred cases with malocclusion. Seipel was credited by Lundström for having measured 365 "unselected" cases and reported a strong correlation between the maxillary and mandibular mesiodistal tooth widths of incisors, canines and premolars ($r = + 0.77 \pm 0.021$).

Lundström also cited Tonn's 1937 Investigation of the intermaxillary tooth width ratio in fifty cases Tonn considered to have anatomically correct occlusion and twenty cases he described as having apparent disharmony in intermaxillary tooth width. Tonn calculated ratios for each of the four classes of permanent teeth; incisors, canines, premolars and molars (excluding second and third molars). He also calculated a ratio of the summed totals of each class of teeth and published the following mean values and standard deviations:

	Mean (mm)	Standard deviation
I_{1+2} (mandibular:maxillary)	0.74	0.024
C (mandibular:maxillary)	0.87	0.038
P_{1+2} (maxillary to mandibular)	0.96	0.021
M_1 (maxillary to mandibular)	0.92	0.030
Total (mandibular to maxillary)	0.93	0.018

Of the twenty cases with malocclusion eight had intermaxillary tooth width ratios that fell outside three standard deviations of the mean. Of these, six had discrepant incisor ratios and 2 disproportionate premolar ratios. Five of the discrepant cases exhibited abnormally large maxillary teeth, while the sixth had abnormally large mandibular teeth. Tonn's paper was published in German and Lundström did not indicate how Tonn determined that abnormally large maxillary or mandibular teeth were the cause of discrepant ratios. Perhaps, the assumption that discrepancies were due to abnormally large teeth was made because predictable restorative procedures for increasing the mesiodistal dimensions of teeth had not yet been developed so that the only viable options for correcting discrepant ratios was interproximal enamel reduction or extraction. Lundström credits Tonn for advocating finishing orthodontic treatment, in cases with significant disharmony between the maxillary and mandibular tooth widths of such a degree that normal occlusion is not possible, with a degree of crowding or spacing in one jaw, accepting either increased or decreased overbite, or accepting a displacement from the normal posterior interocclusal dental relationship. According to Lundström, Tonn also advocated "interproximal grinding or extraction of premolars in the jaw containing the relatively large teeth."[15]

According to Lundström,[15] Körbitz conducted an investigation of 100 anatomically correct occlusions. Körbitz concluded that the difference between the mesiodistal sum of

maxillary incisors and canines minus the mesiodistal sum of mandibular canines plus half the first premolars should be between 0 and 4 mm to result in an overbite of 0-3.5 mm. Körbitz reported extremes for study metric from -3.3mm to +8.0 mm.

Seipel (1946) provided mean ratios between maxillary and mandibular teeth for each morphological class; incisors, canines, premolars, and molars (excluding third molars), and for the second molar to second molar sum. For the permanent dentition Seipel obtained the following ratios (maxillary:mandibular):

$$I_{1+2} = 1.35,\ C = 1.14,\ P_{1+2} = 0.97,\ M_{1+2} = 0.95\text{: total } 1.06$$

Lundström acknowledged the importance of anomalies in the tooth width ratio to orthodontic therapy. Lundström expressed his belief that the tooth width ratio probably plays a minor role as an etiological factor in malocclusion. He also seemed to suggest the use of deviation from average intermaxillary tooth width ratio as a diagnostic test for ITSD:

> "In a majority of cases the variation in the tooth width ratio probably plays a minor role. In extreme values, however, the treatment must be modified accordingly, and it may then be of value to determine at the outset the deviation from the average intermaxillary tooth width ratio."[15]

Although many of the early American and European investigators of interarch mesiodistal proportionality believed that discrepancies large enough to frustrate orthodontic attempts to achieve good occlusion were rare. More recent investigations estimate the prevalence of interarch tooth size discrepancy (ITSD) among orthodontic patients to range from 5.4%-30.6%[16] and therefore represent a significant problem in orthodontics. Because excellent anterior dental relationships are a fundamental goal of orthodontic treatment, prudent clinicians will attempt to diagnose the presence of ITSD before initiating orthodontic

treatment. Although a diagnostic set-up is the accepted gold standard diagnostic test for detection of ITSD[17,18], because significant investment of time and resources are required, diagnostic set-ups are not widely employed in orthodontic diagnosis.

In 1956, Ballard published an analysis sheet designed for clinical application using the mesiodistal measurements of anterior teeth to evaluate anterior interarch proportionality without accomplishing a diagnostic set-up. Ballard's analysis was based upon a 75 percent proportional relationship of mandibular to maxillary anterior teeth that was supplied by the largest manufacturer of denture teeth.[19]

Ballard was probably not aware that Bolton had submitted a thesis to the University of Washington in 1952, proposing a mathematical analysis using the proportional relationship of the summed mesiodistal dimensions of maxillary and mandibular teeth measured in cases of "excellent" occlusion.[20] Bolton published the results of his thesis more widely in 1958[18] and in 1962[21] presented more completely the clinical application of his analysis with detailed examples. Although other investigators had recognized the significance of ITSD to clinical orthodontics and the value of a mathematical approach to occlusion, Bolton was first for provide a simplified and clinically useful method for diagnosis and treatment of ITSD based upon data obtained from measurements of excellent occlusions.

Bolton measured dental casts he deemed to have excellent occlusion from forty-four orthodontically treated patients (non-extraction) and eleven untreated subjects. The dental casts comprising his sample were selected "from a large number of excellent occlusions…with extreme care"[20] from ten private practices in Washington and Oregon, and from the Department of Orthodontics, University of Washington. Bolton recorded the greatest mesiodistal diameter from first molar to first molar for each dental cast using three-

inch needle pointed dividers and a finely calibrated millimeter ruler. He used these data to establish means and statistical measures of dispersion for two ratios he proposed for use in assessment of interarch relationships to aid in orthodontic diagnosis and treatment planning. The procedure Bolton developed was to measure and record the summed mesiodistal widths of the mandibular teeth (first molar to first molar) and divide this sum by the summed mesiodistal widths of the maxillary teeth (first molar to first molar). He then multiplied this value by 100 to obtain the percentage relationship of mandibular to maxillary teeth and termed this figure the "over-all ratio." The same method was used to calculate a percentage relationship between anterior teeth (canine to canine). Bolton expressed his "ratios" as follows:

$$\text{"over-all ratio"} = \frac{\text{summed mesiodistal widths of mandibular 12 teeth}}{\text{summed mesiodistal widths of maxillary 12 teeth}} \times 100 = 91.3$$

$$\text{"anterior ratio"} = \frac{\text{summed mesiodistal widths of mandibular 6 teeth}}{\text{summed mesiodistal widths of maxillary 6 teeth}} \times 100 = 77.2$$

The emphasis placed upon the arrangement of anterior teeth by patients and dentists has resulted in an increased interest in and clinical application of Bolton's anterior ratio. If the anterior ratio for a given case is greater than Bolton's mean of 0.772, or 77.2 as expressed by the Bolton percentage, a diagnosis of "mandibular excess" is made. A diagnosis of "maxillary excess" is made for case ratios less than the ideal anterior ratio.[18,21]

Once a maxillary or mandibular excess in mesiodistal tooth structure is identified as the cause of ITSD, an algebraic solution for the "correct" mesiodistal tooth mass is possible using one of the mathematic equations that express Bolton's findings for anterior teeth and substituting x for the mesiodistal tooth sum deemed to be excessive, then solving for x to determine the "correct" summed mesiodistal value required to establish interarch

proportional balance. The magnitude of excess ITSD can then be calculated by subtracting the calculated "correct" tooth mass from the actual measured "excessive" tooth mass to indicate the amount of mesiodistal tooth substance reduction required in the "excessive" arch to establish balanced interarch proportion.

Perhaps because he recognized the potential for confusion and errors relating to the mathematic concepts and algebraic solutions used his analysis, Bolton also proposed a tabular method to eliminate the need for algebraic operations.[18,21] The tables published by Bolton are "arranged in two columns, the left column representing a measured maxillary mesiodistal tooth sum and the right column indicating the ideal mandibular counterpart."[21] This made it possible for clinicians to reference the table using the summed mesiodistal widths of a given maxillary arch to determine the ideal corresponding mandibular arch sum, without setting up and solving an algebraic equation.

Bolton's tables were included in a patient analysis sheet that further illustrated how the difference between an actual and "correct" mandibular mesiodistal sum can be used to indicate the reduction in mandibular mesiodistal tooth mass required to resolve a mandibular excess ITSD. If for a given maxillary mesiodistal sum the "correct" mandibular mesiodistal tooth mass was found to be larger than the actual mandibular value, clinicians could instead locate the actual summed mandibular mesiodistal tooth structure measured in one of the right columns of the table to identify the corresponding "correct" maxillary value. For such a case, the difference between the actual and "correct" maxillary sums indicates the amount of maxillary tooth structure reduction required to resolve a maxillary excess ITSD.

Subsequent investigators have evaluated various methods for measuring mesiodistal tooth diameter for Bolton's analysis and the reproducibility and speed of these methods have

been described.[22,23] Tooth size and ITSD among different classes of malocclusion[24-32], gender[32-35] and race[32,35] have also been studied. The analysis developed by Bolton is now so widely accepted as a convenient and clinically useful method for diagnosis and treatment of ITSD that ITSDs are often referred to as "Bolton discrepancies".[25,36-42]

Although the Bolton Analysis has served orthodontics well for more than fifty years, key assumptions of the analysis were necessary because the only viable treatment options for ITSD were extraction, interproximal enamel reduction or a combination of extraction and interproximal enamel reduction. Bonded restorations and esthetic concepts, not available at the time of Bolton's work, warrant a reassessment of the Bolton approach for diagnosis and treatment of anterior ITSD.

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SECTION II

INTRODUCTION

Background

The optimal arrangement of maxillary and mandibular teeth is a subject of great concern to dentists and their patients. In addition to tooth size, shape, inclination, torque and alignment, how teeth fit and function together is integral to optimal dental occlusion. The dental profession, particularly the specialty of orthodontics, has long been interested in the parameters that determine optimal interarch relationships. Because of functional and obvious esthetic implications, much of this attention has been directed to the anterior teeth.

A number of investigators have attempted to quantify the parameters that contribute to optimal anterior dental relationships.[43-48] One area of considerable attention has been the proportional relationship between the mesiodistal widths of the maxillary and mandibular anterior teeth.[13,15,18,19,21,49-51] Patients who lack a proportional balance between the dental arches are described as having anterior interarch tooth size discrepancy (ITSD).[12] Failure to diagnose the presence of anterior ITSD before initiating orthodontic treatment may necessitate the expense and maintenance of unanticipated restorative intervention, unplanned interproximal enamel reduction procedures, or compromised dental relationships and esthetics.

The prevalence of anterior ITSD among orthodontic patients has been estimated to range from 17.4%-30.6%[16] and therefore represents a significant clinical problem. Because

excellent anterior dental relationships are a fundamental goal of orthodontic treatment, prudent clinicians will attempt to diagnose the presence of ITSD before initiating orthodontic treatment. Although a diagnostic set-up is the accepted gold standard diagnostic test for detection of anterior ITSD[17,18], because significant investment of time and resources are required, diagnostic set-ups have never been widely employed in orthodontic diagnosis.

In order to provide a more convenient and less expensive method to detect, localize, quantify and manage ITSD, Bolton proposed a mathematical analysis using the proportional relationship of the summed mesiodistal dimensions of maxillary and mandibular teeth measured in cases of "excellent" occlusion.[18,20,21] Although other investigators had recognized the significance of ITSD to clinical orthodontics and the value of a mathematical approach to occlusion, Bolton was first for provide a simplified and clinically useful method for diagnosis and treatment of anterior ITSD based upon data obtained from measurements of excellent occlusions.

Bolton measured dental casts he deemed to have excellent occlusion from forty-four orthodontically treated patients (non-extraction) and eleven untreated subjects. The dental casts comprising his sample were selected "from a large number of excellent occlusions…with extreme care"[20] from ten private practices in Washington and Oregon, and from the Department of Orthodontics, University of Washington. Bolton recorded the greatest mesiodistal diameter from first molar to first molar for each dental cast using three-inch needle pointed dividers and a finely calibrated millimeter ruler. He used these data to establish means and statistical measures of dispersion for two ratios he proposed for use in assessment of interarch relationships to aid in orthodontic diagnosis and treatment planning. Subsequent investigators have evaluated various methods for measuring mesiodistal tooth

diameter for Bolton's analysis and the reproducibility and speed of these methods have been described.[22,23] Tooth size and ITSD among different classes of malocclusion[24-32], gender[32-35] and race[32,35] have also been studied. The analysis developed by Bolton is now so widely accepted as a convenient and clinically useful method for diagnosis and treatment of ITSD that ITSDs are often referred to as "Bolton discrepancies".[25,36-42]

The procedure Bolton developed was to measure and record the summed mesiodistal widths of the mandibular teeth (first molar to first molar) and divide this sum by the summed mesiodistal widths of the maxillary teeth (first molar to first molar). He then multiplied this value by 100 to obtain the percentage relationship of mandibular to maxillary teeth and termed this figure the "over-all ratio". The same method was used to calculate a percentage relationship between anterior teeth (canine to canine). Bolton expressed his "ratios" as follows:

$$\text{"over-all ratio"} = \frac{\text{summed mesiodistal diameter of mandibular 12 teeth}}{\text{summed mesiodistal diameter of maxillary 12 teeth}} \times 100 = 91.3$$

$$\text{"anterior ratio"} = \frac{\text{summed mesiodistal diameter of mandibular anterior 6 teeth}}{\text{summed mesiodistal diameter of maxillary anterior 6 teeth}} \times 100 = 77.2$$

The continuing emphasis placed upon the arrangement of anterior teeth by patients and dentists has resulted in an increased interest in and clinical application of Bolton's anterior ratio, and is the focus of this investigation.

Mathematic Concepts and Terminology used by Bolton

The Bolton analysis represents a mathematic approach to describe the acceptability of interarch occlusal relationships. Although the mathematic operations used in the analysis are basic, clinicians may still be prone to misinterpret the outcome of the analysis because of misconceptions regarding the mathematic principles employed. In publishing his analysis,

Bolton chose to describe the relationship of the mesiodistal widths of the anterior teeth as a "ratio". Ratios are used to make numerical comparisons between two quantities and are commonly expressed using a colon or the word "to" in order to emphasize the relationship of one quantity to the other. Ratios may also be expressed mathematically as a fraction to describe the relationship between the numerator and denominator. Bolton used the mean mesiodistal dimensions of anterior teeth measured in his sample in order to quantify the relationship of the summed mesiodistal widths between mandibular and maxillary teeth in cases with excellent occlusion. In his publications, Bolton expressed the concept of his anterior ratio as a proportion. A proportion is a mathematical statement that two ratios are equal and is expressed as an equation with a ratio on each side. Bolton's anterior ratio can be expressed as a proportion by introducing an equal sign between the anterior ratio and the Bolton mean of 0.772 and then converting the decimal expression of Bolton's mean anterior ratio to a fraction.

$$\frac{\text{Sum of Mandibular Anterior 6}}{\text{Sum of Maxillary Anterior 6}} = 0.772 \text{ (decimal expression of Bolton's mean anterior ratio)}$$

This can be expressed as:

$$\frac{\text{Sum of Mandibular Anterior 6}}{\text{Sum of Maxillary Anterior 6}} = \frac{77.2}{100} \text{ (The Bolton anterior proportion)}$$

Bolton referred to this proportion as the "anterior ratio" which he expressed as:

$$\frac{\text{Sum of Mandibular Anterior 6}}{\text{Sum of Maxillary Anterior 6}} \times 100 = 77.2$$

Terming this proportion a ratio may have confused some clinicians. Although the mathematical relationship of the mesiodistal sums of mandibular teeth to maxillary teeth as expressed by Bolton was termed the "anterior ratio" it could also be termed, and perhaps

better understood by clinicians, as the anterior percentage, because it considers the summed mesiodistal widths of mandibular anterior teeth as a percentage of the summed mesiodistal widths of the maxillary anterior teeth.

Use of the Bolton Analysis for Diagnosis of Anterior ITSD

Algebraic Method

If the anterior ratio for a given case is greater than Bolton's mean of 0.772, or 77.2 as expressed by the Bolton percentage, a diagnosis of "mandibular excess" is made. A diagnosis of "maxillary excess" is made for case ratios less than the ideal anterior ratio.[18,21] The Bolton Analysis does not consider the possibility of maxillary or mandibular deficiency as the cause of ITSD for reasons that will be presented below. Once a maxillary or mandibular excess in mesiodistal tooth structure is identified as the cause of ITSD, an algebraic solution for the "correct" mesiodistal tooth mass is possible using one of the mathematic equations that express Bolton's findings for anterior teeth and substituting x for the mesiodistal tooth sum deemed to be excessive, then solving for x to determine the "correct" summed mesiodistal value required to establish interarch proportional balance. The magnitude of excess ITSD can then be calculated by subtracting the calculated "correct" tooth mass from the actual measured "excessive" tooth mass to indicate the amount of mesiodistal tooth substance reduction required in the "excessive" arch to establish balanced interarch proportion.

Tabular Method

Perhaps because he recognized the potential for confusion and errors relating to the mathematic concepts and algebraic solutions used his analysis, Bolton also proposed a tabular method to eliminate the need for algebraic operations.[18,21] The tables published by

Bolton are "arranged in two columns, the left column representing a measured maxillary mesiodistal tooth sum and the right column indicating the ideal mandibular counterpart".[21] This made it possible for clinicians to consult a table using the summed mesiodistal widths of a given maxillary arch to determine the ideal corresponding mandibular arch sum, without setting up and solving an algebraic equation. Bolton's tables were included in a patient analysis sheet that further illustrated how the difference between an actual and "correct" mandibular mesiodistal sum can be used to indicate the reduction in mandibular mesiodistal tooth mass required to resolve a mandibular excess ITSD. If for a given maxillary mesiodistal sum the "correct" mandibular mesiodistal tooth mass was found to be larger than the actual mandibular value, clinicians could instead locate the actual summed mandibular mesiodistal tooth structure measured in one of the right columns of the table to identify the corresponding "correct" maxillary value. For such a case, the difference between the actual and "correct" maxillary sums indicates the amount of maxillary tooth structure reduction required to resolve a maxillary excess ITSD. Thus, Bolton's tabular method, like the algebraic method is used to identify either a maxillary or mandibular excess mesiodistal sum that can be removed from the arch deemed to be excessive to achieve improved interarch mesiodistal proportional balance.

Purpose

Although the Bolton Analysis has served orthodontics well for more than fifty years, key assumptions of the analysis were necessary because the only viable treatment options for ITSD were extraction, interproximal enamel reduction or a combination of extraction and interproximal enamel reduction. Bonded restorations and esthetic concepts, not available at the time of Bolton's work, warrant a reassessment of the Bolton approach for diagnosis and

treatment of anterior ITSD. The objectives of this investigation were to; 1) identify assumptions made by Bolton that were necessitated by the limited treatment options for ITSD at the time of his work; 2) to assess the adequacy of the Bolton Analysis for contemporary detection, localization, quantification and treatment of anterior ITSD; and 3) to propose an alternative approach for diagnosis and treatment planning for anterior ITSD that is not biased by the available treatments for ITSD, and will accommodate contemporary ITSD treatment options and better support consideration of other relevant clinical factors.

MATERIALS AND METHODS

Analysis of Bolton's Data

Bolton's thesis[20] and subsequent papers[18,21] were reviewed to identify assumptions made by Bolton in his analysis of anterior interarch tooth size discrepancy that were mandated by ITSD treatment options available at the time of his work. These assumptions were evaluated considering contemporary treatment options for ITSD and other clinical factors relevant to mesiodistal tooth size.

Descriptive summary statistics for the mesiodistal measurements of maxillary and mandibular anterior teeth from the sample selected by Bolton and published in table 1 of his thesis were used in this study (table 1).[20] Mean mesiodistal measurements of maxillary and mandibular anterior teeth were summed and multiplied by two to obtain a mean sum for the maxillary and mandibular anterior teeth. Table 1 also contains the Bolton mean anterior ratio.

This data was used to plot values of maxillary ITSD deficiency and mandibular excess ITSD required to achieve equivalent anterior ratio values (Figure 1). Mandibular ITSDs were generated by starting with the ideal anterior ratio established by Bolton's mean maxillary and mandibular summed anterior mesiodistal tooth measurements (Table 1). Half millimeter increments were added to the mean mandibular anterior mesiodistal sum while holding the mean maxillary anterior mesiodistal sum constant to generate a range of mandibular ITSD values. The mean mandibular anterior mesiodistal sum was then held constant and the maxillary anterior mesiodistal sum was adjusted to achieve equivalent anterior ratios for corresponding values of mandibular excess ITSD. A line representing a hypothetical 1:1 relationship of maxillary anterior ITSD deficiency to mandibular anterior excess ITSD was also plotted to serve as a reference.

Proposed New Method for ITSD Diagnosis and Treatment Planning

The data extracted from Bolton's thesis was also analyzed to determine if an alternate method for consideration of anterior interarch proportional harmony might be developed to address limitations identified for contemporary use of the Bolton Analysis for anterior ITSD diagnosis and management. A new approach to anterior ITSD diagnosis and treatment planning was proposed. The new approach represents a different way of expressing the interarch proportional relationship of maxillary and mandibular anterior teeth. The proposed approach uses a new metric termed the anterior circumference which is produced by adding the mesiodistal tooth widths of maxillary and mandibular anterior teeth. The anterior circumference serves as the denominator for two additional metrics termed the maxillary and mandibular anterior percentages which are expressed mathematically as follows:

$$\text{Mandibular Anterior Percentage} = \frac{\text{summed mesiodistal widths of mandibular anterior teeth}}{\text{summed mesiodistal widths of maxillary and mandibular anterior teeth}} \times 100$$

$$\text{Maxillary Anterior Percentage} = \frac{\text{summed mesiodistal widths of maxillary anterior teeth}}{\text{summed mesiodistal widths of maxillary and mandibular anterior teeth}} \times 100$$

The anterior percent composition describes the percentage of anterior mesiodistal tooth mass of both the maxillary and mandibular arches to the anterior circumference.

RESULTS

A review of Bolton's papers identified four assumptions made by Bolton in his analysis of anterior tooth size discrepancy that were necessitated by the available treatment options for ITSD at the time of his work. These assumptions are:

1) That the anterior ratio can be used to determine the etiology of ITSD
2) That the etiology of anterior ITSD is an excess of tooth mass in the maxillary or mandibular arch.
3) That reductive procedures are the only treatment options to resolve ITSD.
4) That the dental arch opposing the arch indicated by the ratio to be excessive in mesiodistal tooth sum is without discrepancy and therefore "correct".

The line produced by plotting values of maxillary ITSD deficiency and mandibular excess ITSD required to achieve equivalent anterior ratio values presented in figure 1 does not represent a 1:1 relationship. This means that a given mandibular excess ITSD is not equivalent to a maxillary ITSD deficiency of equal but opposite sign.

The maxillary and mandibular anterior percentages obtained using Bolton's mean data (Table 1) are collectively termed the anterior percent composition and are represented mathematically as follows:

$$\text{Mandibular Anterior Percentage} = \frac{\text{summed mesiodistal widths of mandibular anterior teeth}}{\text{summed mesiodistal widths of maxillary and mandibular anterior teeth}} \times 100$$

$$\frac{36.58}{83.96} \times 100 = 43.6\%$$

$$\text{Maxillary Anterior Percentage} = \frac{\text{summed mesiodistal widths of maxillary anterior teeth}}{\text{summed mesiodistal widths of maxillary and mandibular anterior teeth}} \times 100$$

$$\frac{47.38}{83.96} \times 100 = 56.4\%$$

The anterior percent composition defined by Bolton's mean mesiodistal measurements of individual teeth is characterized by a mandibular anterior percentage of 44% and a maxillary anterior percentage of 56% of the anterior circumference. The anterior percent composition describes the percentage of anterior mesiodistal tooth mass of both the maxillary and mandibular arches to the total anterior arch circumference.

DISCUSSION

Assessment of the Bolton Analysis for Contemporary Diagnosis of ITSD

Assumptions of the Bolton Analysis:

A review of Bolton's thesis and subsequent papers indicates the existence of four assumptions that materially affect the clinical use of his data. We hypothesize that these

assumptions were necessitated at least in part by the realization that the only way an ITSD could be treated was by reducing tooth dimension, either by interproximal enamel reduction of extraction. It would appear that because of this singular approach to ITSD treatment, Bolton's analysis assumes that the anterior ratio can be used to determine the etiology of ITSD. Because ratios are used to make relative comparisons between two quantities, a deviation from ideal proportionality does indeed indicate a lack of proportional harmony between the quantities being compared. However, a deviation from an established normative proportional relationship does not provide data to indicate which of the quantities being compared is the cause of the deviation. For example, while a case ratio that is less than the Bolton mean anterior ratio indicates a deviation from ideal interarch proportionality, the smaller case ratio could be due either to a relative increase in maxillary anterior mesiodistal sum, or a relative reduction in mandibular anterior mesiodistal sum. Therefore, the anterior ratio cannot indicate the cause of anterior ITSD. The Bolton analysis for anterior ITSD however is based solely upon the interarch proportional relationship of maxillary and mandibular anterior teeth. No additional diagnostic information is required.

The reason Bolton assumed that the anterior ratio was sufficient to diagnose the etiology of anterior ITSD is because treatment modalities to increase the mesiodistal width of anterior teeth were not available at the time when Bolton developed his analysis. Because of this clinical reality there were no viable treatment options for diagnoses of maxillary or mandibular deficiency. Because the only viable treatments for ITSD were extraction or interproximal enamel reduction a diagnosis of maxillary or mandibular excess mesiodistal sum was required of the Bolton Analysis. Under this limitation, there was only one possible diagnosis for anterior case ratios greater or less than the mean Bolton anterior ratio. Given

the available treatment options for ITSD, Bolton was able to assume the anterior ratio could be used to diagnose the cause of anterior ITSD. However, now that bonded composite resin and porcelain restorations can be used to increase the mesiodistal size of teeth, there is no longer a compelling reason to eliminate maxillary or mandibular deficiency from the differential diagnosis of anterior ITSD. Moreover, the use of the Bolton anterior ratio to localize ITSD is not a valid assumption for contemporary diagnosis and treatment of anterior ITSD because it provides only a relative comparison between maxillary and mandibular mesiodistal tooth sum.

Because predictable treatments to increase mesiodistal tooth size were not yet available, a second assumption that appears to have been made by the Bolton analysis was that the etiology of anterior ITSD is always an excess of either a maxillary or mandibular tooth structure. Although the Bolton Analysis assumes ITSD discrepancy to be the fault of a maxillary or mandibular anterior mesiodistal sum that is excessive, applying the analysis under the assumption that ITSD is instead due to a summed mesiodistal tooth width deficiency, something that the Bolton Analysis does not do, reveals an important shortcoming of the analysis. Applying the Bolton Analysis under the assumption of mesiodistal tooth width deficiency demonstrates that the magnitude of ITSD calculated is dependent upon the arch assumed to be discrepant. This point is perhaps best demonstrated using one of the clinical examples presented by Bolton in his thesis and 1962 paper. For this example, Bolton provided the following values:

Sum of mandibular 6 = 41.5 mm
Sum of maxillary 6 = 48 mm
Anterior Bolton Ratio = 86.45

Because the case anterior ratio of 86.45 is greater than the Bolton 77.2 norm, the Bolton Analysis assumes a mandibular excess to be the cause of ITSD. Under the assumption of mandibular excess the following algebraic solution is accomplished:

Let X = "correct" sum of mandibular anterior 6 teeth
X/48 (actual maxillary 6) x 100 = 77.2
X = 37.06 ("correct" mandibular 6)
41.5 mm (actual mandibular 6) – 37.06 ("correct" mandibular 6) = 4.4 mm
Mandibular excess = 4.4 mm

Assuming a maxillary deficiency however yields the following:

Let X = "correct" sum of maxillary anterior 6 teeth
41.5 (actual mandibular 6)/X x 100 = 77.2
X = 53.7 ("correct" maxillary 6)
53.7 ("correct" maxillary 6) – 48 (actual maxillary 6) = 5.8 mm
Maxillary deficiency = 5.8 mm

It should be noted that for this example, the difference in magnitude of ITSD calculated under an assumption of a mandibular excess versus maxillary deficiency was 1.4 mm. Many clinicians may have assumed a 4.4 mm mandibular excess calculated using the Bolton Analysis to be equivalent to a 4.4 mm maxillary deficiency, but this assumption clearly is not supported by the measured data. If this assumption were made, a clinician may have considered increasing the maxillary mesiodistal sum by 4.4 mm when instead an increase of 5.8 mm would be required to achieve ideal interarch proportional harmony. The difference of 1.4 mm approaches 1.5 mm, which has been suggested to represent a clinically significant ITSD.[52,53]

Clinicians should understand that the Bolton Analysis does not calculate the magnitude of ITSD, but only the magnitude of maxillary or mandibular excess mesiodistal tooth mass that must be reduced in order to establish interarch proportional balance. This

concept may not be immediately intuitive to readers of Bolton's work and may not have been fully appreciated by the many clinicians who have used the analysis over the years since widespread acceptance of the Bolton Analysis. Some clinicians may have incorrectly assumed a mandibular excess of a given value to be equivalent to a maxillary deficiency of equal magnitude.

The reason that reducing the mesiodistal sum of one arch sum is not the same as adding an equivalent amount of tooth mass to the opposing mesiodistal arch sum is because of the fixed proportional relationship between mandibular and maxillary mesiodistal tooth mass established by Bolton's anterior proportion. Under the Bolton proportion, a given change in mandibular tooth mass has a greater impact upon the Bolton ratio than an equal but opposite correction of maxillary tooth substance. Because of the larger absolute dimension of the maxillary arch corrections in maxillary mesiodistal tooth widths must be 1.3 times greater than mandibular adjustments of equal magnitude but opposite sign in order to have an equivalent effect upon the anterior ratio. While this difference is probably negligible for mandibular excess less than1-2 mm, it becomes very significant at mandibular excess ITSDs of greater magnitude, situations in which clinical intervention is most likely (figure 1).

The assumption of maxillary or mandibular excess mesiodistal tooth width as the cause of ITSD was made by Bolton because of a third important assumption of the analysis that could be termed the assumption of reduction. A key assumption of the Bolton Analysis is that reductive procedures will be used to resolve ITSD. Bolton noted:

> "In cases in which a disharmony exists and the ratio results do not fulfill the requirements of 91.0 and 77.0 per cent for the over-all and anterior ratios, respectively, the orthodontist must consider steps to give a finished product which will be in occlusal balance. The steps may range from the stripping of teeth to reduce mesiodistal width to the unusual extraction which will put the tooth-size discrepancy case in harmony. A combination of the two steps is

> often recommended. In the extreme situation the solution may involve the placing of overcontoured restorations to give added width to a tooth or a segment of teeth."[21]

While Bolton acknowledged the potential for restorative treatment to increase the mesiodistal width of a tooth or segment of teeth to improve interarch proportional balance, he considered this to be an "extreme situation." The clinical examples Bolton referenced in his papers do not include a single example where restorations were prescribed to increase mesiodistal tooth width in order to achieve interarch proportional balance. Steadman[49] also noted that the use of fixed prosthodontic restorations to manage anterior ITSD "has never been done to my knowledge" and concluded that"…the advisability of doing so is questionable". Thus, the Bolton Analysis assumes corrective measures to balance interarch mesiodistal tooth size proportion will be reductive interventions applied to the dental arch that is excessive in length.

This assumption of reduction by Bolton was not surprising, because predictable restorative modalities to increase anterior mesiodistal tooth width had not yet been developed. Bonded composite resin restorations were not proposed to resolve ITSD until 1981[54], and bonded porcelain restorations did not become available until the early 1980s.[55,56] This meant that interproximal reduction, extraction, or a combination of extraction and interproximal reduction procedures were the only realistic options for treatment of ITSD available at the time of Bolton's work. Because the only viable treatments for ITSD were interproximal reduction, extraction or a combination of extraction and interproximal enamel reduction, the Bolton Analysis naturally assumed reductive procedures would be used to achieve interarch proportional balance. Contemporary restorative treatment options however render this assumption made by Bolton no longer valid.

Because the assumption of reduction mandated a diagnosis of either maxillary or mandibular excess mesiodistal tooth substance, a fourth significant assumption of the Bolton Analysis is that, in cases with ITSD, the cause of discrepancy is contained within a single arch and the opposing arch is without discrepancy and assumed to be "correct. " Corrective measures are likewise assumed to be directed toward a single "excessive" arch. Even in instances in which extraction of a mandibular incisor is accomplished with subsequent interproximal reduction of maxillary anterior teeth, the initial assumption is that mandibular mesiodistal tooth mass was excessive. Once extraction of a mandibular incisor was accomplished the ratio was recalculated or the Bolton table again referenced so that an excessive maxillary mesiodistal tooth mass could be subsequently reduced with interproximal reduction to further improve interarch proportional balance. Thus, using the Bolton Analysis even in instances where corrections are accomplished in both arches results in a sequence of single arch reductive procedures to improve interarch proportional balance.

Contemporary restorative modalities make combining additive restorative interventions in one arch with reductive procedures in the corresponding arch a feasible treatment strategy for ITSD. Therefore, the assumptions that the anterior ratio can be used to indicate ITSD that is caused by a single discrepant dental arch with excessive mesiodistal anterior tooth substance and that treatment intervention to improve interarch proportional balance will be limited to reductive procedures directed toward the arch deemed to be "excessive" are no longer valid. Moreover, there is also no valid reason to assume that the dental arch opposing the arch indicated by the anterior ratio to be excessive should be assumed to be "correct".

Another shortcoming of the Bolton Analysis is that adjustments in mesiodistal tooth mass to improve interarch proportional balance that involve both dental arches are not easily accomplished using the Bolton Analysis because either multiple algebraic solutions or repeated and potentially confusing references to the Bolton tables are required. The practicality and accuracy of accomplishing a series of algebraic calculations or sequential references to the Bolton Tables are important considerations now that reduction of mesiodistal tooth mass within a single discrepant arch is no longer the only viable treatment for ITSD.

Additional Relevant Clinical Factors:

A number or clinical considerations and esthetic concepts relevant to anterior mesiodistal tooth size have been developed since Bolton proposed his analysis for interarch tooth size discrepancy. Unfortunately, the Bolton Analysis does not readily facilitate consideration of these additional factors that might indicate, limit or at least merit consideration before altering anterior mesiodistal tooth size. Other important clinical considerations might include; tooth shape[57,58], interproximal enamel thickness[59-62], crown width[63-67], the height to width relationship of individual crowns[58,63,68-70], open gingival embrasures[71-74], apparent contact dimension[47,58], "golden" or other lateral proportional guides for the maxillary anterior teeth.[75-80] Patient desires and finances might also be important considerations for ITSD treatment planning. Unfortunately, the Bolton analysis does not readily support consideration of these patient and contemporary esthetic guidelines. Therefore the value of the Bolton Analysis for contemporary diagnosis and treatment planning for ITSD is reduced.

Proposed New Method for ITSD Diagnosis and Treatment Planning

A new approach to anterior ITSD diagnosis and treatment planning was proposed. The new approach represents a different way of expressing the interarch proportional relationship of maxillary and mandibular anterior teeth for contemporary ITSD diagnosis and treatment planning. The proposed approach uses a new metric termed the anterior circumference which is produced by adding the mesiodistal tooth widths of maxillary and mandibular anterior teeth. The anterior circumference serves as the denominator for two additional metrics termed the maxillary and mandibular anterior percentages. The anterior percent composition describes the percentage of anterior mesiodistal tooth mass of both the maxillary and mandibular arches to the anterior circumference. The maxillary and mandibular anterior percentages obtained using Bolton's mean data (Table 1) are represented mathematically as follows:

$$\text{Mandibular Anterior Percentage} = \frac{\text{summed mesiodistal widths of mandibular anterior teeth}}{\text{summed mesiodistal widths of maxillary and mandibular anterior teeth}} \times 100$$

$$\frac{36.58}{83.96} \times 100 = 43.6\%$$

$$\text{Maxillary Anterior Percentage} = \frac{\text{summed mesiodistal widths of maxillary anterior teeth}}{\text{summed mesiodistal widths of maxillary and mandibular anterior teeth}} \times 100$$

$$\frac{47.38}{83.96} \times 100 = 56.4\%$$

The anterior percent composition defined by Bolton's mean mesiodistal measurements of individual teeth is characterized by a mandibular anterior percentage of 44% and a maxillary anterior percentage of 56% of the anterior circumference. The values

for these new metrics can be used as an aid in treatment planning for anterior ITSD that is not biased by the treatment options for ITSD and better supports consideration of patient factors and esthetic guidelines relevant to anterior mesiodistal tooth size.

The use of this proposed new analysis will be demonstrated using the case presented earlier in this paper and taken from Bolton's thesis and 1962 paper.[20,21] For this example, Bolton provided the following values:

Sum of mandibular 6 (Mn6) = 41.5 mm
Sum of maxillary 6 (Mx6) = 48 mm
Anterior Bolton Ratio = 86.45

Recall that because the case anterior ratio of 86.45 is greater than the Bolton 77.2 norm, the Bolton Analysis assumes a mandibular excess to be the cause of ITSD. Under the assumption of mandibular excess the algebraic solution indicated a mandibular excess of 4.4 mm. Assuming a maxillary deficiency, something the Bolton Analysis does not do, however yielded a Maxillary deficiency of 5.8 mm. Applying the new approach to ITSD diagnosis yields:

Anterior Circumference = Mn6 + Mx6 = 41.5 + 48 = 89.5
Mandibular Percentage = Mn6/Total Arch Circumference x 100 = 41.5/89.5 x 100 = 46.4 %
Maxillary Percentage = Mx6/Total Arch Circumference x 100 = 48/89.5 x 100 = 53.6%

For this case, the anterior percent composition is represented by a mandibular anterior percentage of 46.4% and a maxillary anterior percentage of 53.6%. The mean values for the anterior percentages established using Bolton's data for the mean mesiodistal measurements of anterior teeth are 44% and 56% which indicates that relative to the total anterior circumference, the mandibular anterior percentage is 2.4% to large and the maxillary anterior percentage is 2.4% to small. Corrective measures to improve proportional harmony will

therefore be directed at reducing the mandibular anterior mesiodistal sum, increasing the maxillary anterior mesiodistal sum or a combination of mandibular anterior sum reduction and increasing the maxillary anterior mesiodistal sum. Because there is a 2.4% discrepancy for each arch, the total discrepancy is 4.8%. This value can be used to calculate the millimeter interarch discrepancy as follows:

$$X/89.5 \times 100 = 4.8\%$$

Solving for X indicates a 4.3 mm interarch discrepancy

The 4.3 mm value provided by the new method represents a true measure of ITSD not merely the amount of mesiodistal tooth substance that must be removed from an excessive maxillary or mandibular anterior sum to establish interarch proportional harmony. Because the anterior percent composition indicated a mandibular anterior percentage greater than the mean and a maxillary anterior percentage less than the mean, corrective interventions to improve interarch proportionality should be directed as follows:

1. Reducing the mandibular anterior mesiodistal sum
2. Increasing the maxillary anterior mesiodistal sum
3. A combination of mandibular anterior mesiodistal sum reduction and maxillary anterior mesiodistal sum augmentation

The entire 4.3 mm ITSD can be removed from the mandibular mesiodistal sum, added to the maxillary anterior mesiodistal sum or split between the anterior segments of the arches as mandibular reductions and maxillary additions as other relevant clinical factors might indicate. For example, the entire 4.3 mm could be removed from the mandibular anterior mesiodistal sum to achieve normative values for the anterior percent composition as follows:

Sum of mandibular 6 (Mn6) = 41.5 mm
Sum of maxillary 6 (Mx6) = 48 mm

Corrected Mn6 sum = 37.2 mm
Corrected anterior circumference = 37.2 + 48 = 85.2
Corrected Mandibular Percentage = 37.2/85.2 x 100 = 44%
Corrected Maxillary Percentage = 48/85.2 x 100 = 56%

Similarly, augmenting the maxillary anterior mesiodistal sum by 4.3 mm could also be accomplished to achieve normative values for the anterior percent composition:

Sum of mandibular 6 (Mn6) = 41.5 mm
Sum of maxillary 6 (Mx6) = 48 mm

Corrected Mx6 sum = 52.3 mm
Corrected anterior circumference = 41.5 + 52.3 = 93.8
Corrected Mandibular Percentage = 41.5/93.8 x 100 = 44%
Corrected Maxillary Percentage = 52.3/93.8 x 100 = 56%

Alternatively, the 4.3 mm value for interarch tooth size discrepancy can be divided as other clinical factors might indicate to achieve interarch proportional balance. For example, consider reducing the mandibular anterior sum with interproximal enamel reduction by 2.3 mm and augmenting the maxillary anterior sum by 2 mm for a net 4.3 mm correction. The results of this treatment strategy are as follow:

Sum of mandibular 6 (Mn6) = 41.5 mm
Sum of maxillary 6 (Mx6) = 48 mm

Corrected Mn6 sum = 41.5 – 2.3 = 39.2 mm
Corrected Mx6 sum = 48 + 2 mm = 50 mm
Anterior circumference correction = 89.5 -2.3 + 2 = 89.2
Corrected Mandibular Percentage = 39.2/89.2 x 100 = 44%
Corrected Maxillary Percentage = 50/89.2 x 100 = 56%

Note that proposed adjustments to maxillary and mandibular mesiodistal sums must be accounted for in the corrected anterior circumference.

The measure of ITSD provided by the new approach serves as a useful treatment planning aid for consideration of potential treatment strategies. Possible treatments for ITSD

are not determined by the measure of ITSD generated by the new analysis, but rather as other individual case factors might warrant. Two cases with identical anterior composition values might ultimately be managed in very different ways. Although this new approach to assessment of anterior interarch mesiodistal proportionality offers potential advantages, future investigations will be required to validate the use of this approach to anterior ITSD diagnosis and management.

CONCLUSIONS

The following conclusions can be made from this assessment of the Bolton Analysis for contemporary diagnosis and treatment of anterior ITSD.

1. The Bolton Analysis is not adequate for contemporary diagnosis and treatment of ITSD because key assumptions of the analysis were necessitated by 1950s ITSD treatment options. These assumptions have been invalidated by bonded restorations.
2. A given mandibular excess is not equivalent to a maxillary deficiency of equal magnitude, nor is a given maxillary excess equivalent to a mandibular deficiency of equal magnitude.
3. Bolton's data can be used in a different way for ITSD diagnosis and treatment planning that is not biased by ITSD treatment options, accommodates dual arch corrections and better supports consideration of other relevant clinical factors.

Table I. Summary data for the mean mesiodistal measurements of anterior teeth from Bolton. Mean anterior sums were obtained by adding the mean mesiodistal measurements For each anterior tooth and multiplying this value by 2.

	Maxillary Teeth			**Mandibular Teeth**		
	Central	**Lateral**	**Canine**	**Central**	**Lateral**	**Canine**
Mean (mm)	8.82	6.96	7.91	5.42	5.94	6.93
S. D.	0.42	0.48	0.46	0.31	0.26	0.37
Mean Sum x 2	**Mean Mx Anterior Sum** 47.38			**Mean Mn Anterior Sum** 36.58		
Mn 6 x 100 = Mx 6	**Mean Anterior Ratio** = 77.2					

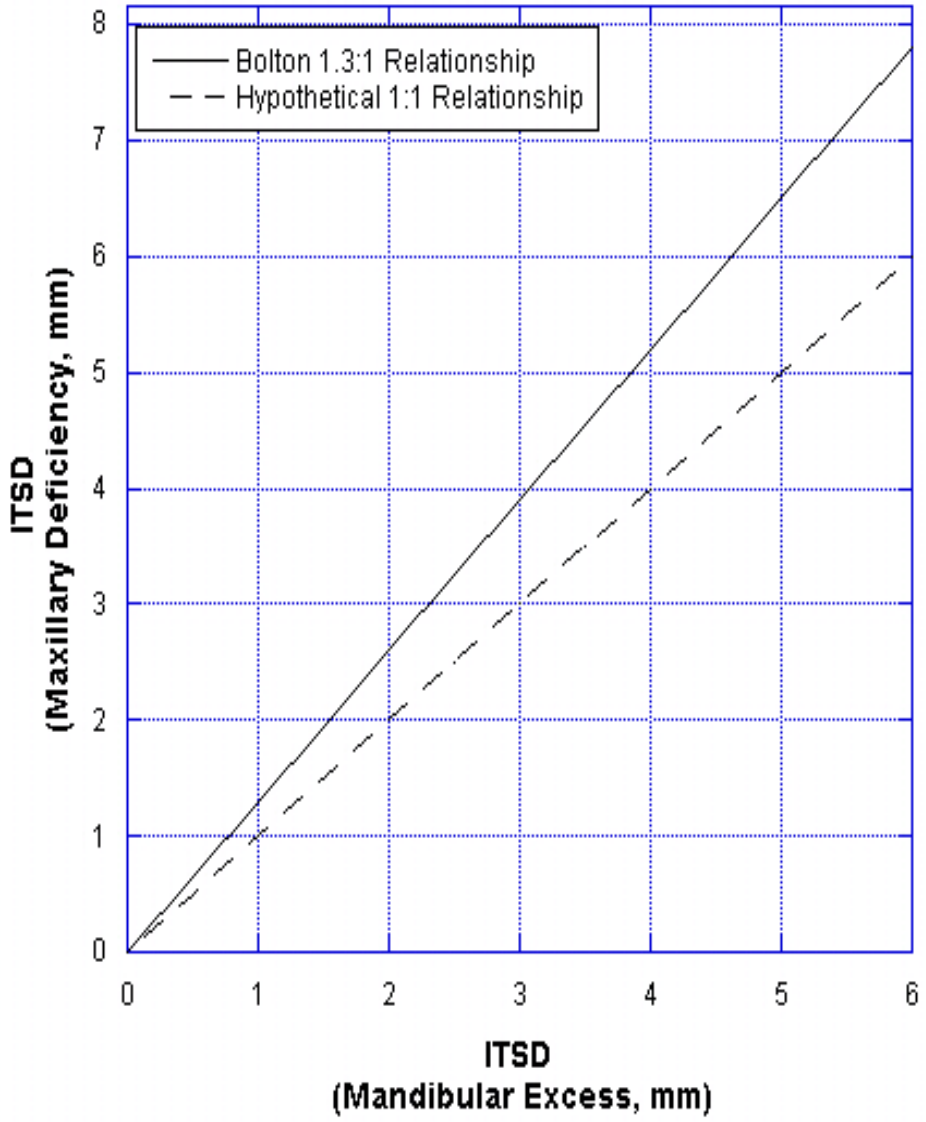

Figure 1. Values of maxillary ITSD deficiency and mandibular excess ITSD required to achieve equivalent anterior ratio values compared to a hypothetical 1:1 relationship between maxillary ITSD and mandibular ITSD.

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