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Interarch tooth-size discrepancies in patients with normal occlusions

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INTERARCH TOOTH-SIZE DISCREPANCIES IN PATIENTS WITH NORMAL OCCLUSIONS

by

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For my amazing wife, Emily, my brilliant son, Jack, and my loving parents, Joyce and Larry. Your contributions to my life are without measure.

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INTRODUCTION

The goal of orthodontic treatment is straightforward. To attain this goal a practitioner must simply place the teeth in proper interdigitation with correct overbite and overjet. (Smith, Buschang, and Watanabe, 2000) Unfortunately, actually reaching the goal is much more complicated than simply knowing the goal. Each patient has her own set of infinite variables that can affect the outcome. Often a patient has biological limitations that make it impossible to reach an ideal outcome without the loss or gain of tooth structure through various methods such as extraction and composite buildups. One of these oft encountered limitations is interarch tooth-size discrepancy which refers to the tooth-size proportion of the maxillary teeth to the mandibular teeth. If the proportion of the maxillary to the mandibular teeth is not similar it becomes very difficult, if not impossible, to align the teeth in a way that allows for an ideal result.

It can be useful for an orthodontist to determine if there is an interarch tooth-size discrepancy (ITSD) before treatment begins. This allows the practitioner to develop the treatment plan in a way that will take ITSD into account during the treatment instead of trying to manage it at the end. Several methods have been used to make the determination of ITSD. Of these methods the one most commonly used is the Bolton analysis (Smith, Buschang, and Watanabe, 2000). The analysis, developed by W.A. Bolton and published in 1958, involves finding a ratio of size between the maxillary and mandibular teeth by measuring the mesiodistal width of each tooth, excluding the second and third molars (Bolton, 1958) By measuring 55 casts with excellent occlusions Bolton developed two ratios for determining an ITSD. One of the ratios was made by comparing the twelve teeth from first molar to the contralateral first molar while the other ratio involved the anterior teeth from canine to canine. Since Bolton’s seminal article, many researchers have expanded on his work to apply his analysis to various populations of patients. The newer articles have examined ITSD between gender, ethnicity and malocclusion groups

(Othman and Harradine, 2006). Additional studies have examined the impact of extractions on the analysis and whether digital models are as reliable as plaster models.

While Bolton's analysis has had wide ranging impact on the field of orthodontics, it is not without controversy. Many orthodontists agree proper tooth-size relations are important for excellent occlusion but they have widely varying opinions on the need to document ITSD before treatment, the frequency with which it occurs and the amount of discrepancy that is clinically significant (Othman and Harradine, 2006). There have also been various challenges Bolton's original study. One such challenge relates to the sample that was used. Casts of 55 subjects with 'excellent occlusion' selected from 10 different private practices and the University of Washington were used, 44 of which had gone through non-extraction orthodontic treatment (Bolton, 1958). The selected casts were culled 'from a large number of excellent occlusions' (Bolton, 1958). Other than the more in-depth details given on select example cases there is little known about the sample subjects. No information was given on the sex or racial background of the subjects. The qualifying criterion of 'excellent occlusion' was not defined, nor an explanation given for why one set of casts was selected from the larger sample of excellent occlusions and another cast was not selected. It would be very difficult to limit selection bias in the sample used as different orthodontists have differing opinions on what makes an excellent occlusion including criteria such as overbite, overjet, torque, inclination and several other factors.

While orthodontists may argue if the cases in Bolton's study had excellent occlusion, most would probably agree that his subjects, based on the photos of example cases, were at least good to very good occlusions (Bolton, 1958). This allowed Bolton to get an average ratio that allows for good occlusal relationships. However, by not including subjects with less than ideal occlusions there is no sufficient way to determine which ITSD ratios would rule out excellent occlusions (Othman and Harradine, 2006). This helps explain why several recent studies have a high proportion of subjects that are beyond two standard deviations of Bolton's mean (Johe, et. al, 2010; Crosby and Alexander, 1989; Freeman, Maskeroni, Lorton, 1996).

With the exception of one study examining a population of school children, almost all Bolton analysis studies have been conducted on patients in orthodontic populations, either before or after treatment (Othman and Harradine, 2006; Bernabě, Major and Flores-Mir, 2004). This is an inherently bias population as only people who actively seek orthodontic treatment, and therefore are almost assured to have some degree of malocclusion, are included as subjects. This population of orthodontic subjects is good to examine patients that are undergoing orthodontic treatment but may not be representative of occlusions of the general population.

The measurement of ITSD is an important part of any orthodontic treatment plan. Orthodontists have long used the Bolton analysis, but it is not without flaws. This study aims to improve on the analysis by limiting sample bias as much as possible and determining the limits at which an ITSD becomes clinically significant.

Purpose of this Study

1. Use the University of Iowa Meredith Growth Study to limit selection bias in selecting subjects to measure and compare the mesiodistal widths of maxillary and mandibular teeth.
2. Determine mean ratios and standard deviations of ITSD of subjects that fit defined parameters of normal occlusion.
3. Determine the limits of ITSD ratios that can still qualify as normal occlusions

LITERATURE REVIEW

Early History of Interarch Tooth-Size Discrepancy Analyses

G.V. Black (1902) is generally regarded to have done the first formal research on the mesio-distal widths of teeth. The mean dimensions found in his study are still found in present day research. In 1923, Young appears to be one of the first people to notice inter-arch asymmetries (Lundstrom, 1954). He noticed that two cases with normal posterior occlusion had differing overbite. He measured the widths of the central incisors to the second premolars in both arches and found that the patient with end-to-end occlusion had maxillary teeth that were 10.9 millimeters (mm) larger than the mandibular teeth while the patient with larger overbite had a difference of 17.0mm. However, Young's new idea of tooth-size discrepancies being an etiologic factor in malocclusion was not given much thought until Ballard (1944) wrote on intra-arch asymmetries. He measured 500 sets of casts and compared the mesio-distal widths of a tooth with its contralateral partner. More than 90% of patients had discrepancies between the left and right side of an individual arch of .25mm or more with over 80% having discrepancies of .5mm or more. Ballard suggested interproximal stripping of teeth to even out arches with larger asymmetries.

In 1949 Neff published his research comparing the widths of the maxillary and mandibular anterior teeth to create a ratio that he called the anterior coefficient. He credited Kesling (1945) and his invention of the tooth positioner with popularizing the serious examination of ITSD. To create a tooth positioner teeth are individually sectioned from a plaster model of a patient's dental arches and replaced, with wax holding it together, into an ideal position. A rubber mold is then made of this idealized cast and a patient wears it for several weeks to help move the teeth into the new setup. In the creation of these positioners Kesling and other orthodontists came to the realization that it was impossible to idealize some patients' setups. When patients were placed with ideal posterior occlusion there was excess overjet or spaces in one of the arches and if the anterior was idealized then the posterior was not seating properly. Neff (1949) credited Dr. George Chuck with theorizing that ITSD may be the cause of this discrepancy. To examine ITSD, Neff measured over 200 casts and found a range of 1.17 to 1.41 for the anterior coefficient. A higher anterior coefficient tended to have more overbite and he reported a coefficient of 1.20-1.22 to be ideal and attain an overbite of 20%. By Neff's calculation a coefficient of 1.10 allowed for an overbite of 0%, 1.40 was 55% and 1.55+ was 100%. To be sure Neff's study was not without error. No mention of his sample was made other than it was over 200 hundred cases, he did not perform basic statistics to obtain a mean or standard deviation and did not give strong evidence to support his claim that a coefficient of 1.20 would lead to 20% overbite, which in his view was the ideal amount. However, with the anterior coefficient Neff had created one of the first mathematical formulas for determining an ITSD before orthodontic treatment is initiated.

Ballard, Neff and Kesling's work helped create a shift in the view of the importance of ITSD in the field of orthodontics. In 1899 W.G. Bonwill, in his paper that tried to develop a geometric theory of occlusion, stated that, "Nature left to herself, always brings proportion…The proportions of the upper teeth to the lower teeth are as exact as any" (As cited in Ford, 2009). This theory of nature always being the most precise standard to live up to was pervasive in early orthodontics and was seen in the strict non-extraction period started by Edward Angle. By 1933 the idea of ITSD being a problem in orthodontic finishing was still seen as a minimal, incredibly rare occurrence. In the first edition of his *Textbook of Orthodontia*, Strang (1933) stated that:

> Unquestionably 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... 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.

However by the fourth edition of *Textbook of Orthodontia* (Strang and Thompson, 1958), because of the early seminal work on ITSD, the paragraph on inharmony of tooth material or tooth size read very differently:

> Unquestionably there are quite a few cases that the dentist and orthodontist may find over a period of years, in which there is more tooth material in one dental arch than in in the other so that it is impossible to absolutely harmonize the two arches. The author has encountered several of these cases in his practice… The authors are convinced that there are a greater number of cases of inharmony in the overall amount of tooth material in one dental arch than in the other than has been emphasized in the past. Consequently the orthodontist should be constantly on the alert to detect such a problem previous to beginning treatment… If the orthodontist suspects such an abnormality to be present, he is advised to…reset them in proper occlusion, according to the technique suggested by Dr. H. D. Kesling in the June, 1946, number of The American Journal of Orthodontics and Oral Surgery. By such a procedure, positive evidence is available.

The Bolton Analysis

By the time Wayne A. Bolton was in his orthodontic residency in the early 1950’s, the diagnostic setup developed by Kesling had become an important diagnostic tool. Unfortunately the diagnostic setup was an incredibly time consuming process. This motivated Bolton to develop an ITSD analysis that could be accomplished mathematically versus manually with the diagnostic setup (Staley and Reske, 2011). The ITSD analysis Bolton developed was originally used for his master’s thesis in 1952 but was not widely published until 1958. (Bolton, 1958). Bolton stated that his primary purpose was to ‘analyze a group of excellent occlusions and determine whether or not mathematical ratios could be set up between lengths of dental arches, as well as between segments of dental arches.' His hope was that this simpler method of measuring tooth size would help in treatment planning and in determining the functional and esthetic outcomes of orthodontic cases. With his analysis he became the first person to develop a simple, clinically useful method for measuring ITSD.

In Bolton's introduction he pointed to Ballard and Neff's earlier studies as important work in the examination of ITSD. He began his material and methods section by describing the subject casts that were used. His study used 55 casts which he determined had excellent occlusions. The casts were chosen from a larger selection of excellent occlusions that were gathered from ten different private practices and the department of orthodontics at the University of Washington. Most of the cases had been orthodontically treated and of the final 55 chosen for the study 44 of them were treated (non-extraction) and the eleven remaining cases were untreated. Three-inch needle-pointed dividers were used to measure the mesiodistal width of all the teeth except second and third molars. The dimensions were measured to the nearest ¼mm. The sum of the twelve maxillary teeth was totaled and compared to the sum of twelve mandibular teeth. He called the ratio comparing the twelve teeth of each arch the "over-all ratio." The ratio was defined as:

$$\frac{\text{Sum mandibular “12”}}{\text{Sum maxillary “12”}} \times 100 = \text{overall ratio}$$

The same method was used to set up a ratio between the maxillary and mandibular anterior teeth. The ratio was defined as:

$$\frac{\text{Sum mandibular “6”}}{\text{Sum maxillary “6”}} \times 100 = \text{anterior ratio}$$

Bolton also measured the degree of overbite, overjet, angles of the maxillary and mandibular incisors to the occlusal plane, incisor length, and cusp height. However, he could not find many clinically useful correlations from most of these measurements and spent little time examining them further other than overbite.

For the overall ratio Bolton found a mean of 91.3% (Bolton, 1958). The range went from 87.5 to 94.8 with a standard deviation of 1.91. Therefore, according to Bolton's research, if the overall ratio for a given patient is greater than 91.3% it can be said that the patient has "mandibular excess." A ratio of less than 91.3% would be indicative of "maxillary excess." A case with significant mandibular excess may not have enough overjet to properly finish a case by having spaces between the incisors when the posterior is in proper interdigitation or may be Class II in the posterior in the anterior teeth are properly aligned. A case with maxillary excess would have the opposite problem with excess overjet. For the anterior ratio the mean was 77.2% while the range was 74.5-80.4 with a standard deviation of 1.65. Having both ratios may help a clinician determine which section of an arch is in excess and therefore help with the decision of which teeth should have tooth structure removed or composite buildups placed to establish the correct interarch proportions.

If an ITSD is found, Bolton's formula can be used to algebraically determine what the proportionally correct mesiodistal tooth width would be. (Bolton, 1958) For example if an overall maxillary excess is found the actual mandibular sum can be divided by .913 to determine what the "correct" maxillary sum would be. Several cases were shown as examples of how to use the analysis. By figuring out which arch was in excess, and by how much, he could determine if stripping interproximal tooth structure was possible or if perhaps extractions would suit his goal of correct interarch tooth-size proportions. Bolton also mentioned that overcontoured posterior restorations may be used to help correct ITSD, something that would later become a much more important practice in orthodontics when composite anterior restorations became viable options. The final case showed an example of a manmade ITSD. An "overzealous dentist" was faulted for placing overcontoured restoration that created asymmetry in the interarch relations.

Bolton stressed the clinical importance of the ease and quickness with which the analysis could be completed, although he still suggested doing a diagnostic setup if the analysis found a large discrepancy so that the ITSD could be more adequately visualized. In 1953, a year after its creation, the analysis was used as part of the diagnostic procedure on every orthodontic case at the University of Washington.

In 1962 Bolton published a follow-up clinical application article to the 1958 article (Bolton, 1962). The first part of the paper had a short literature review and a sizeable portion of the 1958 article was included for background information. The remainder of the article focused on the clinical use of the analysis with a focus on various extraction patterns. Bolton also mentioned two clinical features that could affect the anterior ITSD, one of which was the extreme labial angulation of the incisors and the other was an extreme labiolingual thickness of the incisors. Bolton summed up his article with more confidence in his analysis than his previous paper as in the newer article he said there was rarely a need for diagnostic setups when the ITSD analysis is done properly. Since Bolton introduced his analysis in the late 1950's it has become an important diagnostic tool for orthodontists around the world. The Bolton analysis has become so widely accepted that ITSD are now often called Bolton discrepancies (Staley and Reske, 2011).

Studies on Various Aspects of Interarch Tooth-Size Discrepancies

Methods of Measurement

In the past 25 years numerous studies have expanded on Bolton's research in a variety of ways. Studies have focused on varying aspects of ITSD including methods of measurement, prevalence, race, gender, extractions and malocclusion type. The traditional method of measurement, used by Bolton and Neff, was the needle point divider (Bolton, 1958; Neff, 1949). The needle point divider (Figure 1) can be used intraorally or on study casts. The divider can be measured directly with a ruler or holes can be punched into graph paper and then measured. Another commonly used instrument is the caliper (Shellhart et al., 1995). There are several types of calipers that can be used including Boley gauges, dial calipers or digital calipers. (Calipers, Wikipedia). The calipers are functionally identical but have different ways to read the results. Boley calipers (Figure 2) are vernier-type calipers in which a moveable jaw slides along a fixed jaw with a calibrated scale that can be used to measure the distance that the jaws have been separated. Boley calipers are specific up to .01 mm. Dial calipers (Figure 3) record the final fraction of the measurement on a dial on the face of the instrument, allowing for a measurement that is easier to read than the Boley gauge. Digital calipers (Figure 4) are arguably the simplest and most popular type of caliper as a single value is displayed on the screen and can be integrated with computer software. This may reduce any transfer or calculation errors associated with manual methods (Ho and Freer, 1999). Shellhart et al. compared the intra- and interrater reliability of the needle point divider to the Boley gauge (Shellhart et al., 1995). They found that the Boley gauge had a higher frequency of significantly repeated measures than the needle point divider and therefore the Boley gauge may be slightly more reliable for conducting the Bolton analysis. The same study also examined the effects of crowding on measurement error and found that casts with more than 3 mm of crowding had significantly more measurement errors.

In the past decade the increasing popularity of digital models has led to several studies on the accuracy of measuring ITSD of computerized models compared to plaster models. Tomassetti et al. was one of the first to compare the manual measurement method to computerized methods (Tomassetti et al., 2001). Three methods of computerized ITSD measurements, QuickCeph, Hamilton Arch Tooth System, and OrthoCad, were compared to the current gold standard of manual measurements with vernier calipers. No statistically significant error was found between any of the methods but clinically significant differences (>1.5 mm) were present for each method. Each of the digital measurements was quicker than the manual method.

Further research has found that measurements from digital models are not significantly different than plaster models (Stevens et al., 2006; Leifert et al., 2009). The digital models were significantly faster to measure and accurate enough to allow for an orthodontist to make the same diagnoses and treatment planning decisions that she would have made with plaster models. Mullen et al. compared the plaster casts and emodels of 30 patients (Mullen et al., 2007). No significant difference was found between the Bolton ratios calculated using plaster models and emodels. The mean difference was 0.05 ± 1.87. The Bolton ratio measurement was just as accurate with emodels as the traditional method of using calipers to measure plaster casts. On average the digital measurements were 65 seconds faster than the manual method. They concluded that emodels are adequate replacements for plaster models by being just as accurate and faster to measure.

Another commonly practiced method of measuring ITSD is “eyeballing” the models and estimating the ITSD. Proffit suggests a quick way to estimate ITSD is to compare the maxillary laterals to the mandibular laterals in width. If the maxillary laterals have widths that are equal to or less than the mandibular laterals then a mandibular excess is likely (Proffit, 2007). He also states that the maxillary second premolars should be of roughly equal size. However, Othman and Harradine found that visual estimation is a poor method of measuring ITSD as orthodontists missed over half of the patients with a discrepancy of more than 2mm or 3mm (Othman and Harradine, 2007). Orthodontists were better at picking out cases that did not have significant discrepancies but still guessed incorrectly on 30% of those cases.

Prevalence

The prevalence of ITSD has long been in dispute in the orthodontic community. This was seen early on in the previously mentioned change in Strang’s textbooks as the newer editions were much more willing to accept clinically significant ITSD than the first edition. The 4th edition of Proffit’s textbook puts the prevalence at 5% (Proffit, 2007).

However, there is no research or evidence used as a source to justify the prevalence at 5%. Presumably, the number was used to denote patients that are more than two standard deviations from Bolton's norms assuming his data was normally distributed.

Recent orthodontic research on ITSD prevalence has had varied results but the prevalence of patients with ITSD over two standard deviations from the mean is often stated to be above 5%, especially in the anterior (Othman and Harradine, 2006). Crosby and Alexander measured 109 casts from their orthodontic population to determine the prevalence of a clinically significant ITSD (Crosby and Alexander, 2009). The mean anterior and overall ratios were similar to Bolton's however there was a much wider range of variability than was in Bolton study. They found that 22.9% of patients had an anterior ratio than was more than two standard deviations (SD) from the mean, which is roughly a 3-4mm ITSD (Johe, et al., 2010). Freeman et al also found a mean ratio almost identical to Bolton's when they measured 157 pretreatment casts, however similar to Crosby and Alexander higher variation was found with 30.6% of patients having anterior ITSD over 2 SD and 13.5% with overall ratios beyond 2 SD (Freeman, Maskeroni and Lorton, 1996).

Johe et al examined 306 pretreatment casts from varying ethnicities, sex and malocclusion groups (Johe et al., 2010). They found 17% of patients had clinically significant ITSD (2 SD or more) which is similar to those found by Othman and Harradine (17.4%), Uysal et al (21.3%), Bernabe et al (20.5%), and Araujo and Souki (22.7), but were lower than the findings of the aforementioned Freeman et al (30%), O'Mahony et al (37.9%), and Santoro et al (28%). The prevalence of clinically significant ITSD found by Johe et al was 12% which was similar to those found by Freeman et al (13.5%) and Uysal et al (15.3%) (Othman and Harradine, 2007; Uysal, et al., 2005; Bernabe, et al., 2005; Araujo and Souki, 2003; Freeman, Maskeroni and Lorton, 1996; Santoro, et al., 2000; O'Mahony, et al., 2011). Johe attributed the higher ITSD prevalence in these studies compared to Bolton's study to the varying ethnic and genetic sample population. Almost all of the studies examining the prevalence of ITSD concluded that the use of a Bolton analysis prior to orthodontic treatment is recommended as anywhere from 13-30% of patients can have a clinically significant ITSD.

Sex Differences

Previous studies have found that males tend to have larger teeth than females (Bishara, et al, 1989). However it appears that even though males may have larger teeth, the maxillary and mandibular teeth are proportioned similarly to females. Research on sex differences in ITSD has had varied results but most studies have found that there is little to no sex differences in prevalence or magnitude of ITSD (Johe, et al., 2010). Smith et al was one of a few studies to find that males had a larger ratio than females but the differences were small and much less than one SD from the Bolton norms (Smith, Buschang, and Watanabe, 2000). Johe et al found no significant differernces in sexual dimorphism in ITSD and neither did Akyalcin et al, Araujo and Souki, Tamimi and Hashim, O'Mahony et al or Nie and Lin (Akylacin et al, 2006; Araujo and Souki, 2003; Tamimi and Hashim, 2005; O'Mahony et al, 2011; Nie and Lin, 1999). Therefore most studies have concluded that there is little impact of gender on ITSD.

Racial/Ethnic Differences

Similar to gender differences, research examining racial and ethnic differences in ITSD has had varied results. The demographics of the subjects in Bolton's original sample were not reported in his paper, which implies potential selection bias (Bolton 1958). Some recent studies have suggested that Bolton's results are most similar to those found in white females which coincides with the fact orthodontic that most patients treated in the 1950's were white females (Othman and Harradine, 2006). In 1972 Lavelle found blacks had the highest overall and mandibular ITSD ratios while whites had the lowest ratios with people of eastern Asia descent between the two groups. (Lavelle, 1972). Smith et al found that blacks had the highest overall Bolton ratio of 93.4% while Hispanics had a ratio of 93.1% and whites were at 92.3% (Smith, Buschang, and Watanabe, 2000). They attributed the differences primarily to the posterior segments. Johe et al did not find statistical significant differences in the overall ITSD between blacks, whites and Hispanics but did find that blacks have a significantly higher prevalence of clinically significant anterior ITSD (29%) than whites (14%) or Hispanics (13%) (Johe, et al., 2010).

Numerous studies have tried to establish ITSD ratio norms similar to Bolton for specific populations. Published studies have been conducted to examine Iranian, Jordanian, Chinese, Nigerian, Turkish, Spanish, Japanese, Thai, India, Irish and Peruvian populations ITSD norms (Al-Khateeb and Abu Alhaija, 2006; Kachoei, Ahangar-Atashi and Pourkhamneh, 2011; Ta, Ling and Hägg, 2001; Adeyemi, Bankole and Denloye, 2010; Uysal and Sari, 2005; Paredes, Gandia and Cibrian, 2006; Endo et al., 2008; Manopatanakul and Watanawirun, 2011; Sharma, Kumar, Singla, 2011; O'Mahony et al., 2011; Bernabé, Major and Flores-Mir, 2004). The study by Paredes et al on the ITSD in Spanish populations is fairly representative of most of the studies (Paredes, Gandia and Cibrian, 2006). They used 100 casts from a population of patients from the orthodontic clinic at a Spanish university. An overall ratio of 91.97 and an anterior ratio of 78.32 were found compared to Bolton's ratios of 91.3 and 77.2 respectively. It was mentioned that this difference was statistically significant but did not mention anything about clinical significance. They also found 22% of patients had anterior discrepancies and 5% had overall discrepancies over two SD.

Malocclusion Type Differences

Researchers, starting with Lavelle in 1972, have also been interested in determining if patients with differing malocclusion groups have different norms of ITSD

(Lavelle, 1972). Lavelle found that patients with Angle Class III malocclusions tend to have higher ITSD than Class I or II patients. Araujo and Souki examined 300 patients, 100 in each malocclusion group, and found that Class I and III patients had greater ITSD than Class II patients (Araujo and Souki, 2003). They also found Class III patients had more anterior ITSD than Class I and II patients. However, many studies have found no differences in ITSD based on malocclusion group. Crosby and Alexander studied 109 patients and found no differences in ITSD between malocclusion groups (Crosby and Alexander, 1989). Smith et al, Johe et al and Uysal et al also found no differences in ITSD based on malocclusion type with respective sample sizes of 180, 306 and 560 (Smith, Buschang, and Watanabe, 2000; Johe, et al., 2010; Uysal, et al., 2005). Therefore most evidence suggests that malocclusion type does not affect ITSD with a possibility that Class III patients may tend to have slightly larger incidence of discrepancies.

Effect of Extractions on ITSD

In his 1962 clinical application paper Bolton suggested that extraction of 4 premolars would alter the overall ratio (Bolton, 1962). He said the resulting ratio would be between 87-89%. It was also suggested that removing the mandibular second premolars may be more beneficial in certain cases as removing the normally larger second premolars may reduce an ITSD. To examine this Kayalioglu et al selected 53 ideal patients, based on peer assessment and cephalometric norms, that had four premolars extracted (Kayalioglu, Toroglu, and Uzel, 2005). They found an overall ratio for the 10 remaining teeth as 89.28 +/- 1.07% and suggested that it be used as the norm for four premolar extraction patients. Endo et al also found that the overall ratio reduced with premolar extraction (Endo, et al., 2010). They suggested carefully examining extraction options and possibly determining what the overall ITSD ratio would be after a variety of extraction options to determine which extraction pattern would be the best option for the patient.

Magnitude of ITSD that is Clinically Significant

Many of the studies examining ITSD have used 2 SD as the level at which ITSD is clinically significant (Johe, et al, 2010, Crosby and Alexander, 1989). Othman and Harradine argue that while this makes sense statistically it may not be a good measure of clinically significant ITSD (Othman and Harradine, 2007). They argue that Bolton's sample is not representative of the amount of variation in the general population because he used only ideal occlusions, a narrow sample that may not follow a normal distribution. They suggest using actual measurement numbers to help in determining clinical significance. Bernabe et al had used 1.5mm as their cutoff point, basing it on Profitt's textbook, of clinical significance and found that 35.6% of patients in their study had clinically significant ITSD (Bernabĕ, Major and Flores-Mir, 2004). Othman and Harradine argued that a difference of 1.5mm may be slightly small as it means only .75mm difference per side of the arch (Othman and Harradine, 2007). Their paper used 2mm as a cutoff point, simply by stating that 1mm per side "seems a reasonable minimum for intervention to change the size of teeth". With a cutoff of 2mm they found that 24-28% of patients had clinically significant ITSD. Endo et al also recommended a 2mm cutoff of significance (Endo et al., 2009).

MATERIALS AND METHODS

This investigation was designed as a retrospective, cross-sectional study to measure the interarch tooth-size discrepancy on patients with “normal” occlusions. Normal occlusion is defined as Class 1 molars with mild crowding/spacing. The groups were further divided based on magnitude of crowding/spacing with one group consisting of patients with <2mm of crowding/spacing and 2-4mm of crowding/spacing.

Subject Selection

The subjects for this study were culled from the Iowa Growth Study conducted by Howard V. Meredith and L.B. Higley beginning in 1946 (Meredith and Knott, 1973). The study consisted of 130 subjects. Ninety-seven percent of the subjects were of northwestern European ancestry and the remaining 3% were of central or southeastern European lineage. Dental casts were made twice every year until age 12, annually until age 17 and periodically through adulthood on patients that remained in the study. The sample was described as follows,

> All members of the sample resided in or near Iowa City, Iowa, and were voluntary participants in a long-term research program begun in 1946 at the State University of Iowa. Enrollment for study was based on willingness to participate and likelihood of continuing residence in the community. The subjects were physically normal children unselected in respect to cephalic or faciodental characteristics (Meredith and Knott, 1973).

The initial list of subjects with normal occlusion within the Iowa Growth Study was determined by a previous thesis conducted by Kuntz in which the subjects were separated into groups based on Angle molar classification and amount of crowding/spacing (Kuntz, 1993). The subjects selected had normal occlusions which were defined as Class 1 molars with mild crowding/spacing. For the purpose of this study the groups were further divided based on magnitude of crowding/spacing with one group consisting of patients with <2mm of crowding/spacing and 2-4mm of crowding/spacing with the measurements conducted. Any subjects that had orthodontic treatment were eliminated along with casts that did not have measureable, undamaged and/or unrestored permanent teeth. These qualifications reduced the sample size from 68 to 56. The sample included casts from 32 males and 24 females. Of those there were 31 patients (17 male and 14 female) with <2mm of crowding/spacing and 25 patients (15 male and 10 female) with 2-4mm of crowding/spacing.

Measurements

A Mitutoyo Absolute IP67 digital caliper (Figure 4) capable of measuring to the nearest 1/100 of a millimeter was used to make all measurements on the casts (Mitutoyo Corporation, Japan). For each subject the mesiodistal widths of the incisors, canines, premolars and first molars were measured and recorded on an Excel spreadsheet (Microsoft, Redmond, Wash). The teeth were measured at their widest mesiodistal points which correspond to the contact points in properly aligned teeth (Figures 5, 6, 7 and 8).

The preferred age of measured cast was shortly after the eruption of all the permanent teeth (Figures 9 and 10). This allowed for a full complement of permanent teeth and lessened the time for restorations to be placed or interproximal wear. When interproximal restorations were already in place in a tooth before the rest of the permanent teeth had erupted casts from when the patient was younger were searched to find the teeth before restorations were placed and were then measured. Each cast was measured by the primary investigator, Jordan Poss, twice, with at least 24 hours between the first and second measurement of a cast. Ten casts, 5 male and 5 female, were selected at random for intrarater reliability tests to be performed. Those same 10 casts were also measured by another orthodontic resident, Laura Bonner, for interrater reliability.

The mean width for each tooth from the 2 measurements was calculated and then the Bolton ratio was computed for each subject:

(Sum of mandibular 12/Sum of maxillary 12) × 100 = Overall ratio

(Sum of mandibular 6/Sum of maxillary 6) × 100 = Anterior ratio

The standard of clinical significance used most by previous papers is a Bolton discrepancy of +/-2 SD, using the original Bolton data, and is therefore the standard used for clinical significance in this study. The frequency of patients +/-1 or +/-2 SD was calculated.

Overview of Statistical Methods

Descriptive statistics were computed. A two-sample t-test was used to detect the differences between the genders and between two crowding groups under different conditions. The Shapiro-Wilk test was used to check for the normality of the variables.

A p-value of less than 0.05 was used as a criterion for statistical significance. SAS for Windows (v9.3, SAS Institute Inc, Cary, NC, USA) was used for the data analysis.

Measurement of Reliability

Intraclass correlation coefficients were computed as a measure of agreement between the two duplicated measurements which were made on the same subject by a single observer or by the two observers. An intraclass correlation coefficient above .8 represents strong agreement.

In addition, a paired-samples t-test was used to determine whether a significant difference existed between two measurements made on the same subjects either by a single observer by the two observers.

All tests employed a 0.05 level of statistical significance. SAS for Windows (v9.3, SAS Institute Inc, Cary, NC, USA) was used for the data analysis.

A total of 10 subjects, including 5 males and 5 females, were included. Twenty four teeth per subject were measured twice by the primary investigator (J.P.), and measured once by a second observer (L.B.). Therefore, assessments of intra- and inter-observer reliability were conducted.

Intra-observer Agreement

Intraclass correlation coefficient was computed to assess intra-observer agreement of cast measurements. Overall, there was very strong evidence that the intraclass correlation differed from zero ($p<0.0001$ for each instance), and the correlation coefficients ranged from 0.98 to 0.99 indicated a strong agreement between two measurements made by J.P. for each tooth measured.

Inter-observer Agreement

An average of two measurements which were made by J.P. was calculated and was then used to evaluate the inter-observer agreement.

Intraclass correlation coefficient was used to assess inter-observer agreement in tracing of cast measurements which were made by J.P. and L.B. Overall, there was very strong evidence that the intraclass correlation differed from zero ($p<0.0001$ for each instance), and the correlation coefficients ranged from 0.90 to 0.99 for each tooth indicated a strong agreement between two observers for each tooth measured.

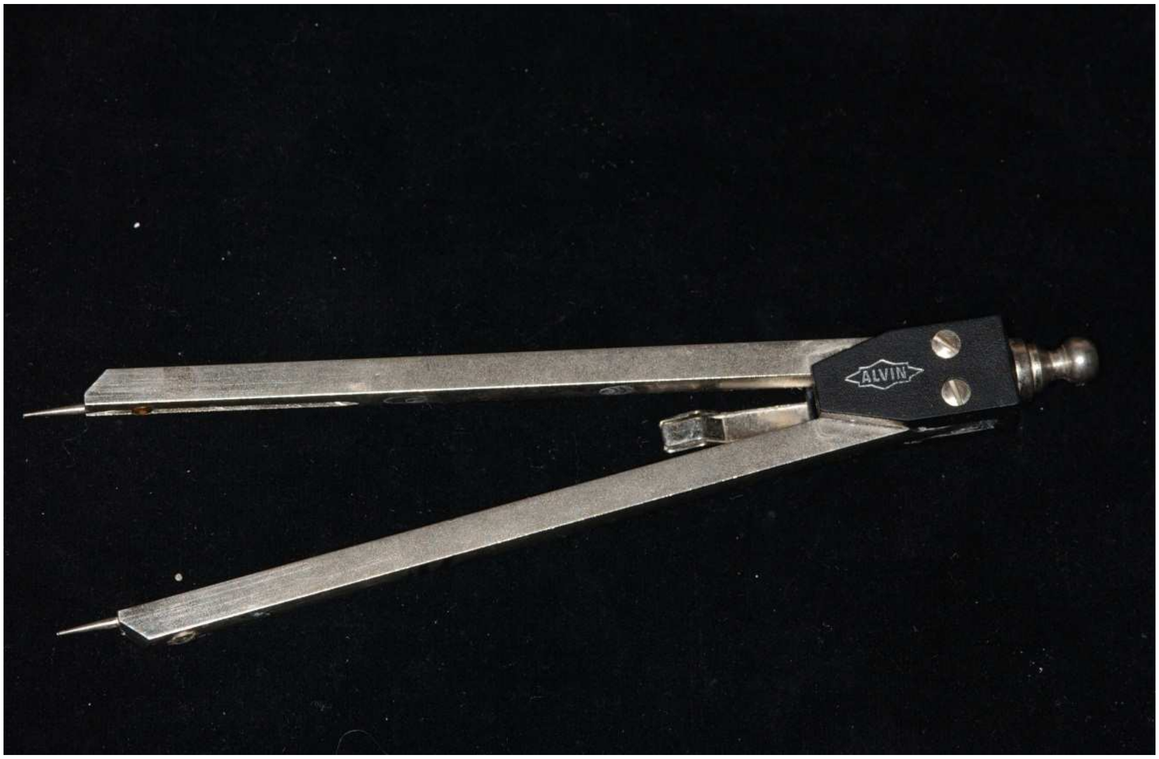

Figure 1: Needle point divider

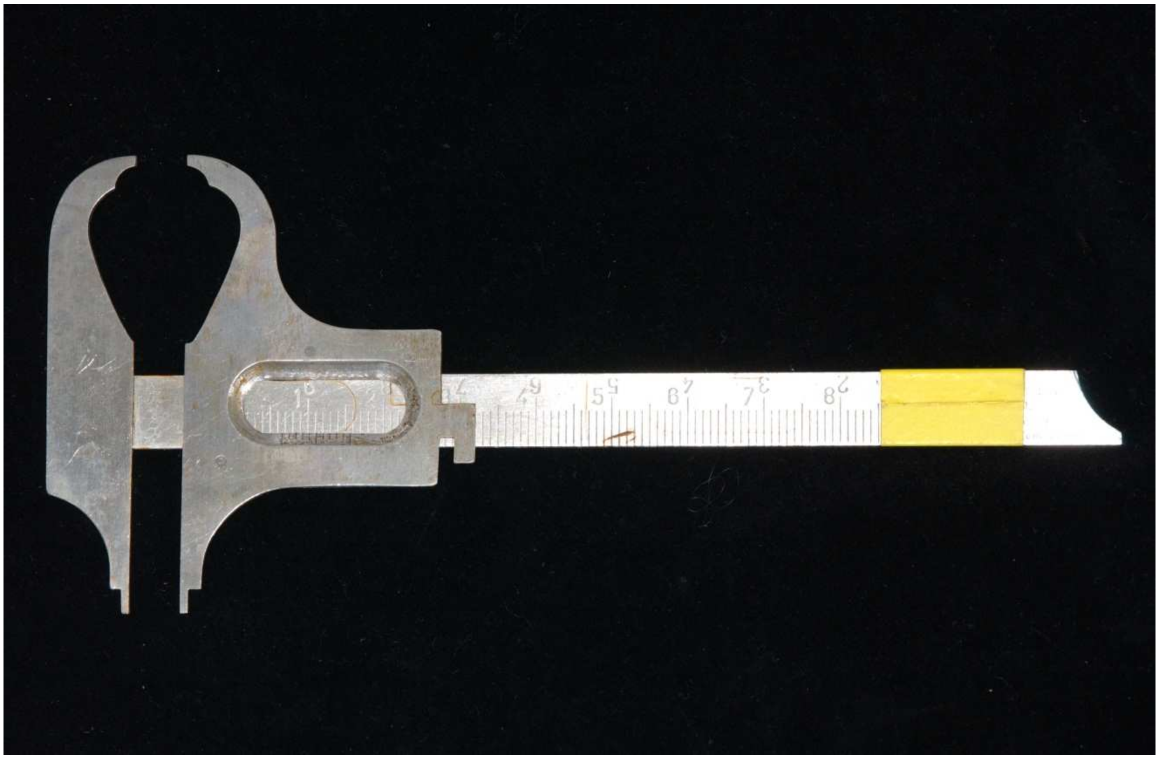

Figure 2: Boley gauge

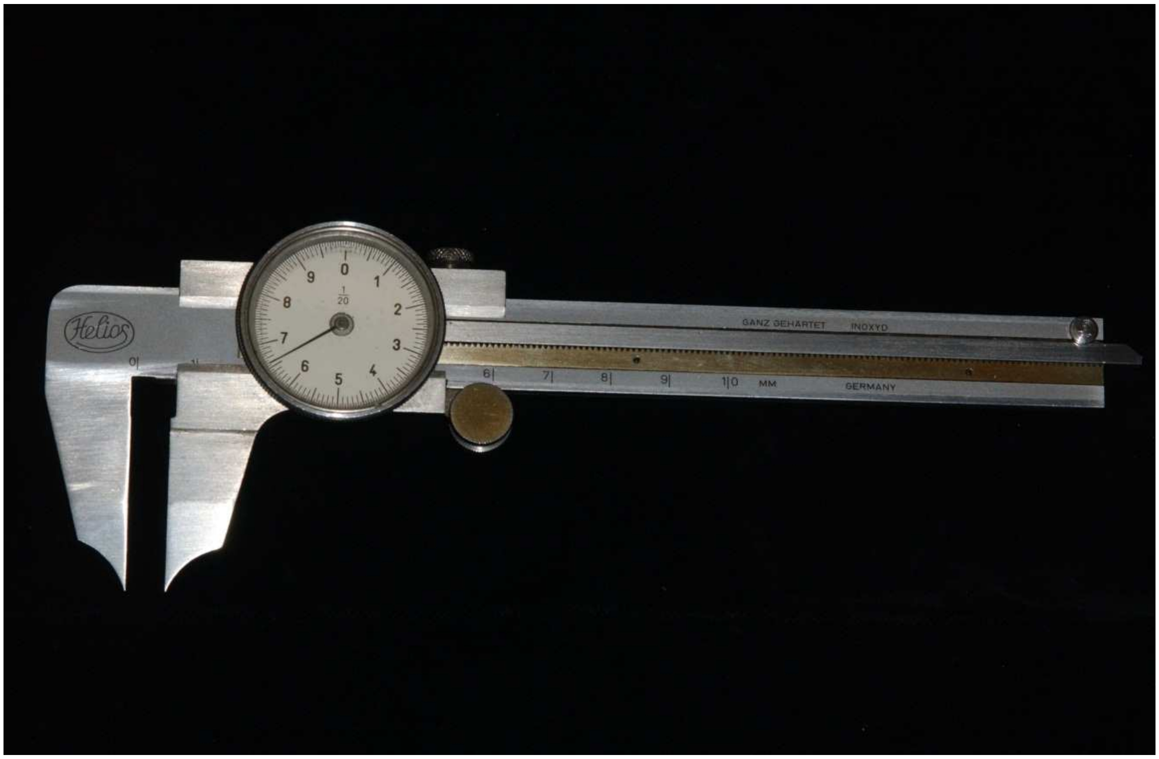

Figure 3: Dial calipers

Figure 4: Digital calipers

Figure 5: Measuring mesiodistal width of a mandibular incisor

Figure 6: Measuring with digital caliper readout

Figure 7: Measurement locations of a typical maxillary cast

Figure 8: Measurement locations of a typical mandibular cast

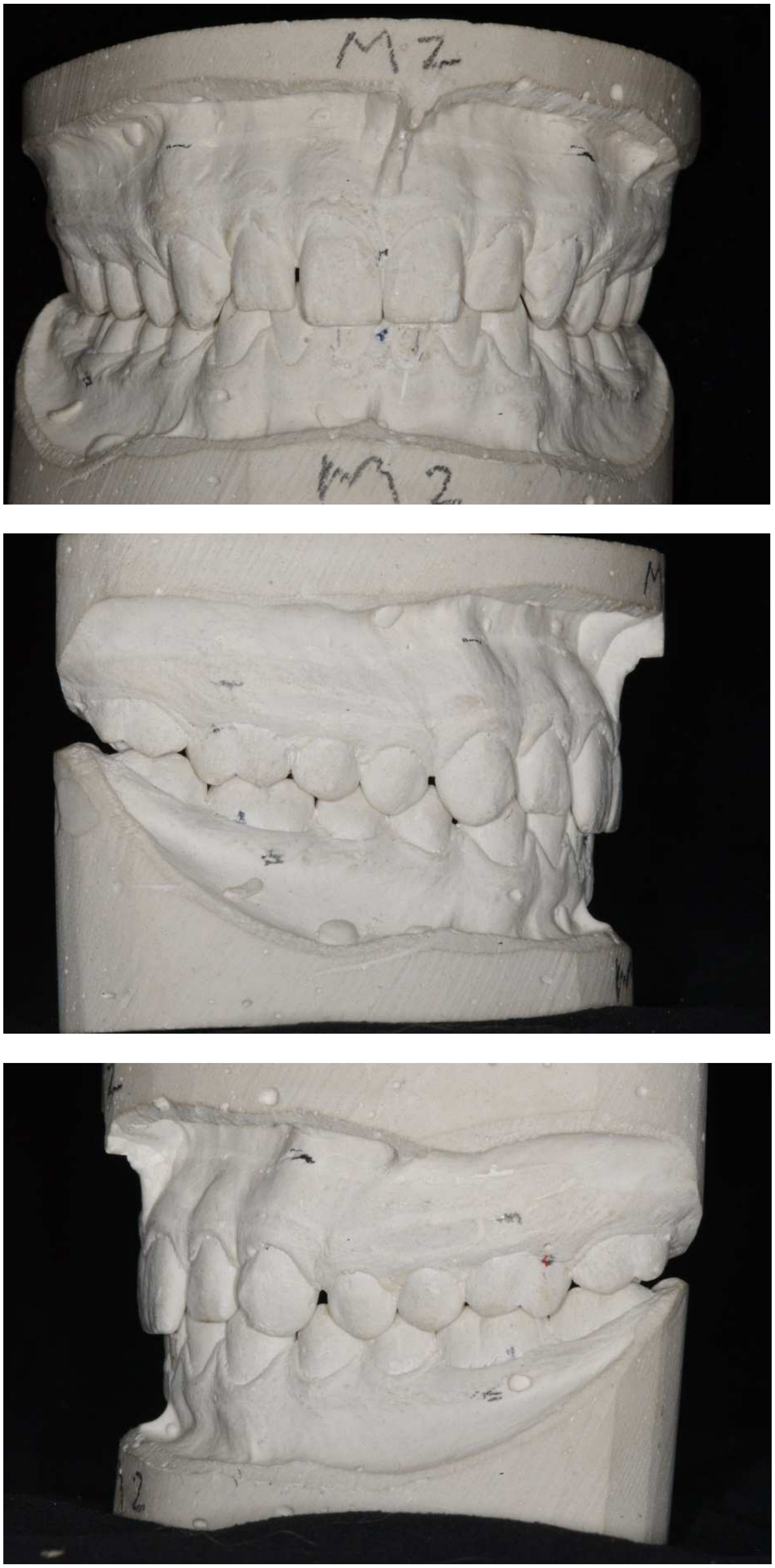

Figure 9: Frontal and lateral views of typical cast used in this study

Figure 10: Occlusal views of typical casts used in this study

RESULTS

Overall ITSD Ratios

All subjects had a combined mean overall ITSD ratio of .914, a SD of .021 and a range of .875-.960. Broken down by gender the females had a mean of .912, a SD of .018 and a range of .875-.948 while the males had a mean of .915, a SD of .022 and a range of .875-.960 (Table 1A).

The overall ITSD ratios were also separated into groups based on amount of crowding/spacing (<2mm and >2mm) and gender. The <2mm group had a combined mean overall ratio of .912, a SD of .016 and a range of .882-.945. Broken down by gender the females with <2mm had a mean of .912, SD of .014 and a range of .893-.940 while the males had a mean of .912, SD of .017 and a range of .882-.945 (Table 1B).

The >2mm group had a combined mean overall ratio of .916, a SD of .026 and a range of .875-.960. Broken down by gender the females had a mean of .911, a SD of .024 and a range of .875-.948 while the males had a mean of .919, a SD of .027 and a range of .875-.960 (Table 1C).

For all subjects there were 28.57% of casts that were outside 1 SD from the mean and 3.57% that were outside of 2 SD. Females had 29.17% of subjects were outside 1 SD and 4.17% fell outside of 2 SD while males had 34.38% outside of 1 SD and 0% outside of 2 SD. Those with <2mm of crowding had 41.94% outside 1 SD and 3.23% outside of 2 SD while those with 2-4mm of crowding had 40% outside 1 SD and 0% outside of 2 SD.

Anterior ITSD Ratios

All subjects had a combined mean anterior ITSD ratio of .778, a SD of .025 and a range of .714-.863. Broken down by gender the females had a mean of .780, a SD of .020

and a range of .738-.817 while the males had a mean of .776, a SD of .029 and a range of .714-.863 (Table 1A)

The anterior ITSD ratios were also separated into groups based on amount of crowding/spacing (<2mm and >2mm) and gender. The <2mm group had a combined mean anterior ratio of .776, a SD of .020 and a range of .740-.810. Broken down by gender the females with >2mm had a mean of .782, a SD of .020 and a range of .755 while the males had a mean of .772, a SD of .020 and a range of .740-.810 (Table 1B).

The >2mm group had a combined mean anterior ratio of .780, a SD of .031 and a range of .714-.863. Broken down by gender the females had a mean of .777, a SD of .022 with a range of .738-.807 while the males had a mean of .782, a SD of .036 and a range of .714-.863 (Table 1C).

For all subjects there were 26.79% of casts that were outside 1 SD from the mean and 3.57% that were outside of 2 SD. Females had 41.67% of subjects were outside 1 SD and 4.17% fell outside of 2 SD while males had 25% outside of 1 SD and 6.25% outside of 2 SD. Those with >2mm of crowding had 29.03% outside 1 SD and 0% outside of 2 SD while those with 2-4mm of crowding had 24% outside 1 SD and 8% outside of 2 SD.

<u>Overall and Gender Comparisons</u>

No significant differences in overall ratios were found between the two crowding groups for all subjects, female subjects, and males subjects ($p>0.05$ in each instance) (Table 2A).

No significant differences in anterior ratios were found between the two crowding groups for all subjects, female subjects, and males subjects ($p>0.05$ in each instance) (Table 2A).

No significant differences in overall ratios were found between the genders for all subjects, subjects with 2mm or less amount of crowding, and subjects with 2-4mm amount of crowding ($p>0.05$ in each instance) (Table 2B).

No significant differences in anterior ratios were found between the genders for all subjects, subjects with 2mm or less amount of crowding, and subjects with 2-4mm amount of crowding ($p>0.05$ in each instance) (Table 2B).

Comparisons to Bolton's Original Data

No significant differences in overall ratios were found between Bolton's data and this study's data for all subjects ($p=0.7934$), subjects with 2mm or less amount of crowding ($p=0.7963$), or subjects with 2-4mm amount of crowding ($p=0.6083$).

No significant differences in anterior ratios were found between Bolton's and this study's data for all subjects ($p=0.9786$), subjects with 2mm or less amount of crowding ($p=0.9857$), or subjects with 2-4mm amount of crowding ($p=0.9715$).

There were 26.79% of subjects that were more than 1 SD away from Bolton's mean overall ratio and 7.14% that were over 2 SD For the anterior ratio there were 33.92% of subjects over 1 SD and 16.07% of subjects over 2 SD.

Table 1. Descriptive statistics of overall ratio and anterior ratio for all subjects

A. Overall

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	56	0.914	0.021	0.875	0.960	0.912
Anterior_ratio	56	0.778	0.025	0.714	0.863	0.778

B. By Gender

Gender=Female

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	24	0.912	0.018	0.875	0.948	0.909
Anterior_ratio	24	0.780	0.020	0.738	0.817	0.780

Gender=Male

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	32	0.915	0.022	0.875	0.960	0.914
Anterior_ratio	32	0.776	0.029	0.714	0.863	0.774

****

Table 2. Descriptive statistics of overall ratio and anterior ratio for subjects with 2mm or less amount of crowding

A. Overall

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	31	0.912	0.016	0.882	0.945	0.912
Anterior_ratio	31	0.776	0.020	0.740	0.817	0.777

B. By Gender

Gender=Female

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	14	0.912	0.014	0.893	0.940	0.911
Anterior_ratio	14	0.782	0.020	0.755	0.817	0.782

Gender=Male

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	17	0.912	0.017	0.882	0.945	0.912
Anterior_ratio	17	0.772	0.020	0.740	0.810	0.773

****

Table 3. Descriptive statistics of overall ratio and anterior ratio for subjects with 2-4mm amount of crowding

A. Overall

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	25	0.916	0.026	0.875	0.960	0.914
Anterior_ratio	25	0.780	0.031	0.714	0.863	0.779

B. By Gender

Gender=Female

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	10	0.911	0.024	0.875	0.948	0.905
Anterior_ratio	10	0.777	0.022	0.738	0.807	0.778

Gender=Male

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Overall_ratio	15	0.919	0.027	0.875	0.960	0.915
Anterior_ratio	15	0.782	0.036	0.714	0.863	0.779

Table 4. Comparisons of overall ratio and anterior ratio between the two crowding groups

Variables	**Levels of Crowding**		
	Group1 2mm or Less	**Group2 2-4mm**	***P*-value**
A. All Subjects (N=31 for Group1; N=25 for Group2)			
Overall ratio Mean (std)	0.912 (0.016)	0.916 (0.026)	0.4910
Anterior ratio Mean (std)	0.776 (0.020)	0.780 (0.031)	0.6297
B. Females (N=14 for Group1; N=10 for Group2)			
Overall ratio Mean (std)	0.912 (0.014)	0.911 (0.024)	0.8986
Anterior ratio Mean (std)	0.782 (0.020)	0.777 (0.022)	0.5326
C. Males (N=17 for Group1; N=15 for Group2)			
Overall ratio Mean (std)	0.912 (0.017)	0.919 (0.027)	0.3534
Anterior ratio Mean (std)	0.772 (0.020)	0.782 (0.036)	0.3370

Table 5. Comparisons of overall ratio and anterior ratio between the genders

Variables	**Gender**		
	Female	**Male**	***P*-value**
A. All Subjects (N=24 for Female ; N=32 for Male)			
Overall ratio			0.5193
Mean (std)	0.912 (0.018)	0.915 (0.022)	
Anterior ratio			0.6308
Mean (std)	0.780 (0.020)	0.777 (0.029)	
B. Subjects with 2mm or Less Amount of Crowding (N=14 for Female; N=17 for Male)			
Overall ratio			0.9600
Mean (std)	0.912 (0.014)	0.912 (0.017)	
Anterior ratio			0.1564
Mean (std)	0.782 (0.020)	0.772 (0.020)	
C. Subjects with 2-4mm Amount of Crowding (N=10 for Female; N=15 for Male)			
Overall ratio			0.4467
Mean (std)	0.911 (0.024)	0.919 (0.027)	
Anterior ratio			0.6814
Mean (std)	0.777 (0.022)	0.782 (0.036)	

DISCUSSION

The 1958 publication of Bolton's seminal ITSD study has long been the gold standard in orthodontics to determine clinical ITSD (Staley and Reske, 2011). The study was, however, not without limitations especially with regards to its case selection and demographic reporting. No study to date had been conducted on calculating ITSD on a group of untreated subjects with an objectively defined normal occlusion. Our results found no statistically significant differences from Bolton's original study. Bolton's mean for the overall ratio was 91.3%, a SD of 1.9% and a range of 87.5% to 94.8% (Bolton, 1958). Our results were remarkably similar with an overall ratio of 91.4%, a SD of 2.1% and a range of 87.5% to 96.0%. Bolton's mean for the anterior ratio was 77.2%, a SD of 1.65% and a range of 74.5% to 80.4%. Similar to the overall ratio, the anterior ratio was also remarkably similar with a mean of 77.8%, a SD of 2.5% and a range of 71.4% to 86.3%. Our sample had slightly more variability than Bolton, but it did not differ significantly from Bolton's sample.

The sample was split into two groups with one being less than 2mm of crowding/spacing and the other one having 2-4mm of crowding/spacing. Our results indicated that there was not a statistically significant difference in Class I cases with mild (<2mm) crowding/spacing versus moderate (2-4mm) crowding/spacing.

Similar to most previous studies, we found that there was no statistically significant difference in ITSD between the genders (Johe, et al., 2010). This was true with all groups included and when they were broken into mild and moderate crowding/spacing groups.

Bolton's original ratios have been reaffirmed in many subsequent studies including the largest ITSD study, with 306 subjects of varying sex, ethinicity and malocclusions, which found no statistically significant differences from Bolton's mean overall or anterior ratios (Johe, et al., 2010). Our study also found no such differences. This consistency over the decades may suggest that ideal ITSD is a mathematical constant that, no matter how big the teeth are, to get the maxillary teeth to overlap the mandibular teeth around an arc in the proper anteroposterior and vertical dimensions the mandibular teeth must be roughly 91-92% as wide as the maxillary teeth.

We found that 28% of our subjects had overall ITSD discrepancies over 1 SD compared with Bolton's original standard deviations and 7.14% over 2 SD. These numbers are similar to Bolton's and are close to expected normal distribution percentages of 33% and 5% respectively. When compared to previous studies that used 2 SD to indicate a discrepancy it is similar to Bernabe et al. (5.4%) and somewhat less than Johe et al. (12%), Santoro et al. (11%), and Freeman et al. (13.5%). (Bernabe, et al., 2005; Freeman, Maskeroni and Lorton, 1996; Santoro, et al., 2000; Johe, et al., 2010).

For anterior ITSD discrepancies our study found 33.9% of subjects had anterior ITSD discrepancies over 1 SD based on Bolton's data and 16.1% over 2 SD. Previous research had found the most variation on prevalence compared with Bolton on patients with anterior discrepancies over 2 SD. Our study also found the most variation in this area with 16.1% of patients over 2 SD compared to the expected 5%. This number was similar to other recent ITSD studies such as Bernabe et al. (20.5%) and Johe et al. (17%) and somewhat lower than Freeman et al. (30.6%) and Santoro et al. (28.0%) (Bernabe, et al., 2005; Freeman, Maskeroni and Lorton, 1996; Santoro, et al., 2000; Johe, et al., 2010). Overall our study shows similar prevalence of ITSD discrepancies as Bolton's data with the exception of anterior ITSD over 2 SD. The lowered prevalence of significant ITSD discrepancies in our study compared to most other recent studies may be a result of our sample being very similar, both in era in which samples were collected and in ethnicity, to Bolton's sample.

Limitations of the Study

As with any research project, there are several inherent limitations that exist for this study. The sample was obtained from the Iowa Growth Study that originated in the 1940's. Over 70+ years the records continue to be in very good shape, but there are several models that have been slightly chipped or damaged. At times it could be difficult to determine if a tooth had an interproximal restoration by using the casts. If an interproximal restoration was present previous models were examined until prior to the restoration being placed. On a couple of occasions the only time there was no restoration was shortly after eruption of a tooth. The mesiodistal dimensions were sometimes difficult to ascertain if complete eruption was not completed and a concerted effort was made to be as accurate as possible in these situations.

The generalizability of the study may be somewhat limited due to the homogeneity of the sample group which consisted entirely of Caucasians, with 97% of them having northwestern European descent. Although, as previously mentioned, ideal ITSD tend not to vary between ethnicities, there tends to be small variations in variability between ethnicities (Johe, et al., 2010).

Another limitation of the study may result from the age of the records that were used. Using the same Iowa Growth Study used in this study, Warren, Bishara and Yonezu found significant secular differences in the arch length and tooth size of the children in the growth study compared to the currently ongoing Iowa Fluoride Study.

> Our findings suggest that there has been an increase in TSALD in the deciduous dentition of contemporary children compared with children from 50 years earlier in both sexes, particularly girls. As reported previously, arch lengths were significantly smaller in contemporary children, and tooth sizes were similar but slightly larger. As a result, TSALD and crowding seem to have increased in prevalence from earlier times. Further research is needed to determine whether the increase in crowding has also occurred in the mixed and permanent dentitions and to further establish these possible secular trends. (Warren, Bishara, and Yonezu, 2003).

While these secular trends towards increased crowding may affect orthodontics as a whole there is probably minimal effect on ITSD. Both the maxillary and mandibular teeth were, on average, larger in the current study versus the older growth study meaning that there was probably little to no change in the ratio between the two groups.

Future Research

Many studies have examined ITSD, mainly in the same context and procedure as Bolton used in 1952. Future research into ITSD should be focused on the applicability of ITSD measurements to clinical outcomes. The buccolingual inclination of teeth is an important part of allowing teeth to fit properly. Even if a patient has an ideal ITSD, his teeth still may not fit properly if the inclination of the maxillary and mandibular teeth do not properly match. Using radiographs, particularly cone beam computed tomography, to determine average inclinations of normal occlusions would be valuable information to help determine a proper plan of treatment for a patient.

The buccolingual dimension of teeth has not yet been taken into account with ITSD. The buccolingual thickness of teeth, particularly the lingual marginal ridges of the maxillary incisors, plays a role in how anterior teeth fit together. If, for example, an ethnic group tends to have thicker teeth in the buccolingual dimension this may account for some increased variation in ITSD in regard to overjet within the group and compared to other ethnic groups.

The effects of extractions on ITSD have mainly been studied with the extraction of four first premolars. The effects of Class II or Class III masking with extractions of maxillary or mandibular premolars have yet to be examined.

There is also further need to validate the Bolton analysis with finished clinical outcomes. Few, if any, studies have examined ITSD before treatment and determined if the predictive value matched the final outcome. While mesiodistal tooth width is important it may be that inclination or buccolingual thickness of the teeth is just as, or even more, important.

CONCLUSION

Intermaxillary tooth-size discrepancies play an important role in development of normal occlusions with proper form, function and esthetics. Having the ability to predict these discrepancies before treatment allows an orthodontist to adjust treatment plans to provide the most efficient and effective way to help a patient. This study examined a defined sample of normal occlusions that were selected with minimal bias. The determined overall ITSD ratio of 91.4% +/- 2.1% and anterior ratio of 77.8% +/- 2.5% are remarkably similar to the original Bolton analysis that is still frequently used in orthodontics today. There were no significant differences found between gender or the amount of crowding. The prevalence of subjects with clinically significant ITSD (over 2 SD) was 7.4% for the overall ratio and 16.1% for the anterior ratio. The results of this study validates and strengthens the findings of Bolton's study and support the use of the Bolton analysis in the determination of ITSD before orthodontic treatment as a tool to assist in the development of an orthodontic treatment plan.

APPENDIX

Table A1. Statistical report

I. An Overview of Statistical Methods

Descriptive statistics were computed. A two-sample t-test was used to detect the differences between the genders and between two crowding groups under different conditions. The Shapiro-Wilk test was used to check for the normality of the variables.

A p-value of less than 0.05 was used as a criterion for statistical significance. SAS for Windows (v9.3, SAS Institute Inc, Cary, NC, USA) was used for the data analysis.

II. Statistical Results

A total of 56 subjects were included in the study, comprising 31 with 2mm or less amount of crowding (Group1) and 25 with 2-4mm amount of crowding (Group2). Within Group1, 14 were females and 17 were males, while there were 10 females and 15 males in Group2. Descriptive statistics of overall ratios and anterior ratios are summarized in Tables 2A trough 2C under different conditions. Additionally, Table1 reports the descriptive statistics of over jet measurements.

A. No significant differences in overall ratios were found between the two crowding groups for all subjects, female subjects, and males subjects ($p>0.05$ in each instance).

B. No significant differences in anterior ratios were found between the two crowding groups for all subjects, female subjects, and males subjects ($p>0.05$ in each instance).

C. No significant differences in overall ratios were found between the genders for all subjects, subjects with 2mm or less amount of crowding, and subjects with 2-4mm amount of crowding ($p>0.05$ in each instance).

D. No significant differences in anterior ratios were found between the genders for all subjects, subjects with 2mm or less amount of crowding, and subjects with 2-4mm amount of crowding ($p>0.05$ in each instance).

E. No significant differences in overall ratios were found between Bolton's data and Jordan's data for all subjects ($p=0.7934$), subjects with 2mm or less amount of crowding ($p=0.7963$), and subjects with 2-4mm amount of crowding ($p=0.6083$).

F. No significant differences in anterior ratios were found between Bolton's and Jordan's data for all subjects ($p=0.9786$), subjects with 2mm or less amount of crowding ($p=0.9857$), and subjects with 2-4mm amount of crowding ($p=0.9715$).

G. The results for the percentage of subjects fall outside of 1 or 2 standard deviation;

(1) For all subjects

a. Overall ratio**:** 28.57% of them fall outside 1 standard deviation, 3.57% fall out 2 standard deviation.

Table 6 cont.

Table A1 cont.

b. Anterior ratio: 26.79% of them fall outside 1 standard deviation, 3.57% fall out 2 standard deviation.

(2) For subjects who had 2mm or less amount of crowding

a. Overall ratio**:** 41.94% of them fall outside 1 standard deviation, 3.23% fall out 2 standard deviation.

b. Anterior ratio: 29.03% of them fall outside 1 standard deviation, 0% fall out 2 standard deviation.

(3) For subjects who had 2-4mm amount of crowding

a. Overall ratio**:** 40% of them fall outside 1 standard deviation, 0% fall out 2 standard deviation.

b. Anterior ratio: 24% of them fall outside 1 standard deviation, 8% fall out 2 standard deviation.

(4) For female subjects

a. Overall ratio**:** 29.17% of them fall outside 1 standard deviation, 4.17% fall out 2 standard deviation.

b. Anterior ratio: 41.67% of them fall outside 1 standard deviation, 4.17% fall out 2 standard deviation.

(5) For male subjects

a. Overall ratio**:** 34.38% of them fall outside 1 standard deviation, 0% fall out 2 standard deviation.

b. Anterior ratio: 25% of them fall outside 1 standard deviation, 6.25% fall out 2 standard deviation.

Table A2. Overall and anterior ratio by subject

Subject	Gender	Group	Overall Ratio	Anterior Ratio
M1	M	1	0.90385	0.74487
M2	M	1	0.91163	0.78237
M3	M	1	0.91701	0.7925
M9	M	1	0.8822	0.73973
M13	M	1	0.92859	0.78653
M16	M	1	0.89618	0.75809
M24	M	1	0.91998	0.78121
M28	M	1	0.93427	0.76042
M33	M	1	0.90422	0.77556
M35	M	1	0.94465	0.79753
M38	M	1	0.88792	0.76113
M41	M	1	0.92775	0.78972
M51	M	1	0.91033	0.77265
M68	M	1	0.91443	0.74887
M73	M	1	0.90196	0.7587
M76	M	1	0.92694	0.81043
M82	M	1	0.88952	0.75734
F19	F	1	0.89603	0.75547
F20	F	1	0.89583	0.76191
F32	F	1	0.89275	0.76244
F39	F	1	0.90208	0.77089
F40	F	1	0.91644	0.7837
F43	F	1	0.92178	0.80857
F46	F	1	0.90429	0.75628
F49	F	1	0.93192	0.81669
F52	F	1	0.90952	0.79368
F59	F	1	0.91183	0.77667
F70	F	1	0.93953	0.80639
F72	F	1	0.90817	0.78681
F76	F	1	0.91382	0.78078
F78	F	1	0.92597	0.7885
M6	M	2	0.87999	0.74587
M10	M	2	0.91226	0.76348
M19	M	2	0.90797	0.76875
M21	M	2	0.91517	0.77876
M37	M	2	0.95816	0.86322
M40	M	2	0.9511	0.82289
M47	M	2	0.91352	0.77216
M48	M	2	0.96018	0.82143

Table A2 cont.

Subject	Gender	Group	Overall Ratio	Anterior Ratio
M60	M	2	0.93163	0.79298
M64	M	2	0.87465	0.71422
M65	M	2	0.92774	0.79628
M77	M	2	0.886	0.75978
M80	M	2	0.89979	0.75138
F3	F	2	0.8747	0.75599
F18	F	2	0.92161	0.78381
F41	F	2	0.89431	0.75839
F44	F	2	0.94346	0.80145
F45	F	2	0.89352	0.77889
F47	F	2	0.94781	0.79937
F48	F	2	0.9089	0.7764
F50	F	2	0.93188	0.80688
F66	F	2	0.90109	0.73844
F68	F	2	0.89408	0.76657

Table A3. Group 1 (>2mm crowding/spacing) tooth measurements

Tooth	M1	M2	M3	M9	M13	M16
8	9.06	7.84	8.49	8.26	7.72	9.26
7	7.2	6.63	6.34	6.41	6.44	6.97
6	7.43	8.12	7.81	7.58	7.51	8.16
5	7.62	6.81	7.22	7.1	6.38	6.81
4	6.93	6.81	7.01	6.26	6.15	7.29
3	10.95	9.84	10.71	9.87	9.8	10.28
9	8.79	8.03	8.5	8.55	7.73	8.72
10	7.92	6.62	6.1	6.37	6.11	7.1
11	7.61	8.26	7.67	7.36	7.47	8.08
12	7.96	6.77	6.97	7	6.29	6.92
13	6.95	6.81	6.91	6.46	6.1	7.25
14	10.74	10.17	10.42	9.87	10.04	10.28
25	5.33	5.19	5.53	4.69	4.84	5.37
26	6.03	5.8	5.97	5.12	5.54	6.16
27	6.61	6.78	6.58	6.45	6.54	6.73
28	7.4	6.69	6.81	6.72	6.56	6.62
29	7.34	7.02	6.75	6.64	6.27	7.35
30	12.04	10.48	11.57	10.15	10.62	11.42
24	5.11	5.11	5.54	4.69	4.87	5.31
23	6.12	5.88	5.74	5.27	5.53	6.21
22	6.84	6.83	6.34	6.51	6.66	6.91
21	7.36	6.85	6.98	6.52	6.82	6.58
20	7.53	7.09	6.86	6.63	6.73	7.63
19	12.06	10.94	11.64	10.61	10.85	11.2
8- 2	8.98	7.91	8.53	8.18	7.82	9.29
7- 2	7.14	6.62	6.34	6.44	6.5	7.04
6- 2	7.76	8.22	7.76	7.62	7.58	8.14
5- 2	7.62	6.78	7.26	7.12	6.5	6.88
4- 2	6.98	6.69	7.09	6.3	6.21	7.26
3- 2	10.83	10.22	10.52	9.7	9.93	10.29
9- 2	8.99	7.96	8.56	8.59	7.7	8.72
10- 2	7.85	6.64	6.05	6.32	6.14	7.24
11- 2	7.69	8.22	7.73	7.38	7.38	8.05
12- 2	7.83	6.69	6.85	6.97	6.17	6.83
13- 2	6.9	6.73	6.83	6.34	5.95	7.1
14- 2	10.7	10.07	10.78	9.7	9.85	10.31
25- 2	5.32	5.18	5.47	4.73	4.87	5.27
26- 2	5.87	5.68	5.94	5.14	5.53	6.09
27- 2	6.58	6.98	6.53	6.6	6.22	6.96
28- 2	7.44	6.68	6.86	6.48	6.54	6.59
29- 2	7.33	7.01	6.95	6.7	6.21	7.33

Table A3 cont

Tooth	M1	M2	M3	M9	M13	M16
30- 2	11.93	10.3	11.65	10.18	10.54	11.22
24- 2	5.13	5.09	5.5	4.7	4.93	5.3
23- 2	6.11	5.94	5.76	5.4	5.48	6.24
22- 2	6.77	6.79	6.33	6.58	6.71	6.81
21- 2	7.46	6.82	6.96	6.59	6.62	6.36
20- 2	7.62	7.08	6.91	6.53	6.61	7.48
19- 2	12.02	10.86	11.64	10.71	10.85	10.96

Table A3 cont

Tooth	M24	M28	M33	M35	M38	M41	M51
8	8.35	8.66	8.81	9.19	8.48	8.92	8.83
7	6.11	6.72	6.26	6.85	6.17	6.39	7.49
6	7.45	7.98	7.92	7.8	7.36	7.7	8.51
5	6.61	7.03	6.64	7.22	6.7	6.35	7.45
4	6.17	6.5	6.37	7.15	6.3	6.16	6.99
3	10.59	10.2	10.21	10.57	10.07	10.07	10.74
9	8.09	8.61	8.69	9.22	8.4	8.79	8.57
10	6.02	6.9	6.27	7.03	6.48	6.21	7.11
11	7.32	7.75	7.94	8.05	7.4	7.82	8.37
12	6.57	7.3	6.99	6.97	6.68	6.35	7.11
13	5.83	6.61	6.44	7.34	6.47	6.47	7.23
14	10.43	10.21	10.35	10.5	9.78	9.92	10.42
25	4.92	5.46	5.2	5.27	4.84	5.71	5.99
26	5.67	5.98	5.78	6.52	5.48	6.05	6.11
27	6.46	6.2	6.47	7.31	6.33	6.56	6.99
28	6.81	7.5	6.7	7.65	6.64	6.43	6.9
29	6.77	7.69	6.76	7.83	6.51	6.67	7.51
30	10.75	11.47	10.36	11.56	10.06	10.88	11.56
24	4.68	5.5	5.22	5.32	5.05	5.64	5.85
23	5.64	5.86	5.85	6.6	5.44	6.03	5.79
22	6.45	6.57	6.94	7.37	6.5	6.55	7.18
21	6.71	7.43	6.74	7.6	6.59	6.85	7.37
20	6.79	7.34	7.31	7.65	6.37	6.76	7.28
19	10.95	11.41	10.51	11.75	10.17	10.9	11.79
8- 2	8.34	8.67	8.82	9.13	8.52	8.94	8.84
7- 2	6.06	6.9	6.33	6.98	6.12	6.39	7.33
6- 2	7.41	8.03	7.77	7.79	7.32	7.7	8.33
5- 2	6.66	7.03	6.65	7.23	6.7	6.46	7.45
4- 2	6.12	6.54	6.41	7.18	6.32	6.26	7.16
3- 2	10.7	10.27	10.33	10.45	9.88	10.04	10.71
9- 2	8.06	8.81	8.68	9.22	8.48	8.74	8.6
10- 2	6.09	7.11	6.21	7.15	6.35	6.23	7.08
11- 2	7.36	7.9	7.95	8	7.38	7.76	8.41
12- 2	6.58	7.25	6.81	7.04	6.69	6.27	7.27
13- 2	5.88	6.53	6.47	7.35	6.4	6.4	7.37
14- 2	10.53	10.36	10.31	10.42	9.69	9.95	10.58
25- 2	4.91	5.48	5.39	5.18	4.92	5.51	5.84
26- 2	5.56	6.07	5.68	6.45	5.53	5.85	6.05
27- 2	6.47	6.39	6.59	7.29	6.32	6.47	7.06
28- 2	6.54	7.52	6.74	7.71	6.67	6.48	6.83
29- 2	6.81	7.87	6.78	7.86	6.57	6.59	7.61

Table A3 cont

Tooth	M24	M28	M33	M35	M38	M41	M51
30- 2	10.56	11.33	10.42	11.64	10.03	10.75	11.59
24- 2	4.78	5.5	5.3	5.51	5.12	5.7	5.75
23- 2	5.82	5.82	5.86	6.57	5.28	5.95	5.7
22- 2	6.34	6.68	6.8	7.5	6.52	6.31	7
21- 2	6.7	7.47	6.82	7.51	6.58	6.85	7.26
20- 2	6.76	7.29	7.16	7.58	6.24	6.78	7.38
19- 2	11.13	11.56	10.47	11.76	10.19	10.85	11.81

Table A3 cont

Tooth	M68	M73	M76	M82	F19	F20	F32
8	7.85	8.38	7.52	8.7	7.75	9.2	8.27
7	6.25	6.37	5.9	6.44	6.24	7.2	6.16
6	7.44	7.36	7.31	7.94	7.38	7.38	7.63
5	6.55	6.48	6.32	7.08	6.37	7.07	6.86
4	6.17	5.81	6.41	6.67	6.67	6.73	6.67
3	9.85	9.44	10.15	10.15	9.09	9.5	10.77
9	7.89	8.33	7.73	8.87	7.62	8.81	8.11
10	6.38	6.68	5.74	6.57	6.24	7.09	6.52
11	7.57	7.23	7.63	7.7	7.55	7.42	7.69
12	6.17	6.64	6.46	6.99	6.27	7.06	7.04
13	5.99	5.8	6.63	6.94	6.32	6.94	6.53
14	9.97	9.22	10.08	10.09	9.07	9.77	10.73
25	4.98	5.29	5.65	5.49	4.61	5.42	4.91
26	5.35	5.41	5.24	5.7	5.39	5.99	5.66
27	5.87	6.35	6.47	6.42	6.2	6.47	6.58
28	6.63	6.23	6.56	7.06	6.47	6.41	6.57
29	6.45	5.91	7	7.05	6.66	6.98	6.93
30	10.55	10.2	10.05	10.22	9.36	10.26	10.81
24	5.06	4.69	5.06	5.16	4.54	5.47	4.97
23	5.24	5.53	5.13	5.91	5.03	6.04	5.48
22	5.95	6.37	6.49	6.28	6.51	6.57	6.35
21	6.69	6.4	6.76	6.96	6.51	6.98	6.57
20	6.64	6.34	6.95	7.05	6.75	7.08	7.04
19	10.91	9.93	10.15	10.37	9.61	10.61	11.03
8- 2	7.8	8.3	7.57	8.69	7.72	9.25	8.18
7- 2	6.22	6.32	5.79	6.38	6.18	7.15	6.06
6- 2	7.22	7.35	7.36	7.93	7.32	7.37	7.57
5- 2	6.52	6.4	6.29	7.27	6.32	7.03	6.85
4- 2	6.1	5.85	6.32	6.66	6.66	6.65	6.64
3- 2	9.77	9.19	10.06	10.13	9.13	9.58	10.77
9- 2	7.95	8.3	7.6	9.01	7.6	8.92	8.34
10- 2	6.4	6.82	5.88	6.63	6.33	7.09	6.57
11- 2	7.36	7.08	7.74	7.78	7.54	7.58	7.72
12- 2	6.27	6.45	6.5	6.94	6.2	6.98	6.98
13- 2	5.91	5.65	6.58	6.9	6.41	6.95	6.45
14- 2	9.82	9.27	10.18	10.08	9.15	9.82	10.72
25- 2	4.89	5.2	5.62	5.42	4.68	5.3	4.79
26- 2	5.32	5.42	5.22	5.73	5.31	5.99	5.6
27- 2	5.74	6.42	6.46	6.54	6.18	6.55	6.58
28- 2	6.71	6.33	6.47	7.09	6.38	6.4	6.52
29- 2	6.6	6.07	7.17	7.08	6.67	6.96	6.98

Table A3 cont

Tooth	M68	M73	M76	M82	F19	F20	F32
30- 2	10.54	10.17	10.04	10.28	9.26	10.38	10.91
24- 2	5.02	4.72	4.99	5.2	4.56	5.47	4.93
23- 2	5.33	5.53	5.1	5.96	5.08	6.03	5.38
22- 2	5.9	6.23	6.46	6.35	6.48	6.67	6.49
21- 2	6.57	6.46	6.73	7.01	6.58	7.02	6.61
20- 2	6.47	6.4	6.91	7.05	6.67	7.11	7.17
19- 2	11	9.99	10.23	10.33	9.64	10.74	11.04

Table A3 cont

Tooth	F39	F40	F43	F46	F49	F52	F59
8	8.61	7.77	7.51	7.96	8.78	8.71	8.09
7	6.58	6.46	5.24	6.81	7.59	6.43	5.23
6	6.72	7.3	7.23	7.45	8.01	7.81	7.62
5	6.88	6.57	6.02	6.37	7.04	7.09	6.42
4	6.39	6.32	6.11	6.04	6.77	6.85	6.31
3	10.26	9.83	10.47	9.54	10.18	10.15	10.2
9	8.35	7.8	7.58	8.18	8.7	8.67	8.02
10	6.96	6.21	5.31	6.7	7.33	6.63	5.02
11	6.86	7.22	7.53	7.39	8.22	7.85	7.73
12	7.21	6.6	6.29	6.71	7.43	6.97	6.24
13	6.21	6.47	6.05	6.19	6.94	6.73	6.32
14	10.21	9.76	10.15	9.39	10.07	10.06	10.1
25	5.43	5.13	4.87	5.01	5.78	5.47	4.57
26	5.52	5.43	5.34	5.7	6.88	6.1	5.13
27	5.98	6.21	6.03	6.14	7.4	6.56	6.24
28	6.96	6.92	6.56	6.76	7.66	6.84	6.88
29	6.44	6.44	6.77	6.62	7.22	7.25	6.78
30	10.64	10.48	9.62	9.9	10.34	10.66	9.86
24	5.24	5.27	5.04	5.18	5.8	5.71	4.73
23	5.83	5.56	5.34	5.67	6.65	6.05	5.42
22	5.85	6.15	5.97	6	7.24	6.63	6.21
21	7.06	6.82	6.65	6.65	7.45	6.87	6.74
20	6.82	6.34	6.59	6.49	7.86	6.8	7.04
19	10.51	10.48	9.87	10.12	10.29	10.52	10.07
8- 2	8.62	7.8	7.45	8.05	8.89	8.65	8.08
7- 2	6.6	6.57	5.24	6.83	7.52	6.41	5.15
6- 2	6.78	7.44	7.31	7.48	8.07	7.7	7.61
5- 2	6.87	6.61	6.01	6.48	7.09	7.12	6.43
4- 2	6.31	6.37	6.13	6.08	6.85	6.95	6.36
3- 2	10.25	9.89	10.56	9.52	10.19	10.18	10.11
9- 2	8.44	7.82	7.56	8.22	8.82	8.69	7.97
10- 2	6.92	6.38	5.17	6.77	7.37	6.57	5.14
11- 2	6.77	7.22	7.58	7.4	8.24	7.92	7.67
12- 2	7.19	6.57	6.13	6.79	7.47	7.02	6.27
13- 2	6.44	6.45	6.08	6.22	6.84	6.85	6.5
14- 2	10.17	9.8	10.1	9.26	10.07	9.99	10.18
25- 2	5.48	5.12	4.8	5.07	5.78	5.54	4.62
26- 2	5.74	5.39	5.36	5.65	6.96	6.01	5.15
27- 2	5.98	6.29	6.17	6.15	7.43	6.66	6.26
28- 2	6.79	6.89	6.55	6.82	7.62	6.82	6.91
29- 2	6.5	6.43	6.73	6.76	7.27	7.22	6.71

Table A3 cont

Tooth	F39	F40	F43	F46	F49	F52	F59
30- 2	10.65	10.54	9.71	9.9	10.41	10.69	9.88
24- 2	5.23	5.26	4.99	5.16	5.81	5.72	4.76
23- 2	5.77	5.46	5.43	5.73	6.67	6.02	5.36
22- 2	5.95	6.12	5.92	6.03	7.26	6.58	6.27
21- 2	7.04	6.84	6.56	6.64	7.43	6.9	6.74
20- 2	6.66	6.32	6.72	6.5	7.8	6.83	7.01
19- 2	10.65	10.53	9.86	10.16	10.23	10.54	10.02

Table A3 cont

Tooth	F70	F72	F76	F78
8	8.63	10.46	8.38	8.62
7	5.9	6.97	6.49	5.97
6	8.07	8.08	7.19	7.07
5	6.85	7.48	6.6	6.37
4	6.7	7.23	6.54	6.14
3	10.43	10.22	10.18	9.32
9	8.92	10.19	7.98	8.39
10	6.13	6.3	6.14	5.79
11	7.81	7.85	7	7.08
12	6.79	7.93	6.63	6.24
13	6.67	7.22	6.61	6.02
14	10.36	10.08	10.39	9.36
25	5.45	6.15	5.07	5.22
26	6.23	6.55	5.44	5.52
27	7.04	7.23	6.43	6.32
28	7.06	7.69	7.01	6.57
29	7.2	7.18	6.78	6.52
30	10.85	10.73	10.77	9.86
24	5.35	5.96	4.77	4.96
23	5.86	6.39	5.75	5.57
22	6.82	6.96	6.31	6.04
21	7.24	7.48	6.73	6.74
20	7.48	7.49	6.74	6.62
19	11.02	10.88	10.67	9.84
8- 2	8.66	10.35	8.43	8.63
7- 2	5.92	6.93	6.41	5.81
6- 2	8.01	8.06	7.26	6.96
5- 2	6.84	7.34	6.72	6.25
4- 2	6.67	7.34	6.44	6.11
3- 2	10.33	10.24	10.12	9.28
9- 2	8.95	10.14	7.97	8.45
10- 2	6.08	6.33	6.26	5.67
11- 2	7.72	7.83	7.07	6.95
12- 2	6.74	7.94	6.62	6.39
13- 2	6.69	7.1	6.62	6.12
14- 2	10.35	9.99	10.27	9.38
25- 2	5.43	6.12	5.1	5.18
26- 2	6.09	6.52	5.37	5.51
27- 2	7.02	7.2	6.35	6.3
28- 2	7	7.76	6.97	6.53
29- 2	7.19	7.27	6.65	6.62

Table A3 cont

Tooth	F70	F72	F76	F78
30- 2	10.86	10.63	10.65	9.7
24- 2	5.31	6	4.91	5.03
23- 2	5.85	6.32	5.73	5.56
22- 2	6.77	6.88	6.37	6.12
21- 2	7.25	7.41	6.67	6.68
20- 2	7.51	7.51	6.73	6.69
19- 2	11.08	10.96	10.81	9.91

Table A4. Group 2 (2-4mm crowding/spacing) tooth measurements

Tooth	M6	M10	M19	M21	M37	M40	M47
8	9.03	7.38	8.93	9.28	7.99	8.82	8.82
7	7.04	6.27	6.79	7.08	5.61	6.89	7.1
6	7.54	6.82	7.76	8.24	6.6	8.31	8.59
5	7.1	6.65	7.68	6.96	6.6	7.18	6.97
4	7.05	6.61	6.36	7.05	6.21	6.99	7.01
3	10.75	9.74	10.81	10.86	9.63	10.38	10.37
9	9.22	8.34	8.84	9.1	7.88	8.91	8.67
10	7.03	6.1	6.36	7.11	5.58	6.66	6.96
11	7.48	6.82	8.03	8.37	6.41	8.49	8.38
12	7.02	6.86	7.51	7.18	6.41	7.07	6.93
13	6.96	6.9	6.14	6.48	5.99	6.92	7.46
14	10.79	10.02	10.19	10.79	9.46	10.41	10.37
25	5.49	4.71	5.23	5.48	5.18	6	5.54
26	5.82	5.25	5.81	6.55	5.51	6.45	6.3
27	6.5	5.96	7.02	7.27	6.57	7.56	6.85
28	6.84	6.74	7.12	7.15	6.15	7.61	7.13
29	7.14	6.94	7	6.98	6.39	7.56	7.32
30	11	10.86	10.77	11.79	10.1	11.25	11.5
24	5.36	4.55	5.05	5.47	5.03	5.89	5.47
23	5.52	5.24	5.83	6.39	5.84	5.94	6.09
22	6.52	6.08	6.93	7.23	6.41	7.67	7.11
21	6.96	6.8	7.64	7.2	6.51	7.59	6.92
20	7.25	6.81	7.12	6.95	6.78	7.41	7.47
19	10.97	10.91	10.9	11.7	10.23	11.35	11.38
8- 2	8.97	7.37	8.85	9.21	7.99	8.75	8.82
7- 2	6.94	6.21	6.75	6.98	5.55	6.82	7
6- 2	7.54	6.74	7.97	8.24	6.66	8.32	8.59
5- 2	7.16	6.76	7.69	6.87	6.5	7.21	6.92
4- 2	6.97	6.65	6.28	6.99	6.14	6.89	7.03
3- 2	10.71	9.83	10.82	10.83	9.55	10.35	10.37
9- 2	9.28	8.33	8.86	9.13	7.82	8.88	8.6
10- 2	6.98	6.08	6.47	7.07	5.55	6.61	7
11- 2	7.43	6.83	7.88	8.32	6.34	8.47	8.51
12- 2	7.12	6.91	7.44	7.21	6.44	7.01	6.87
13- 2	6.87	6.73	6.1	6.51	5.93	6.94	7.6
14- 2	10.84	9.93	10.08	10.78	9.44	10.39	10.47
25- 2	5.49	4.74	5.24	5.38	5.2	5.9	5.5
26- 2	5.9	5.16	5.78	6.49	5.41	6.41	6.3
27- 2	6.44	5.89	7.06	7.17	6.49	7.63	6.97
28- 2	6.78	6.74	7.05	7.09	6.2	7.52	7.1

Table A4 cont.

Tooth	M6	M10	M19	M21	M37	M40	M47
29- 2	7.02	6.96	6.98	6.97	6.36	7.56	7.32
30- 2	11.04	10.71	10.78	11.81	10.07	11.14	11.59
24- 2	5.39	4.63	5.08	5.41	5.11	5.79	5.54
23- 2	5.58	5.29	5.91	6.31	5.86	6.04	6.09
22- 2	6.46	6.09	6.93	7.27	6.43	7.66	7.17
21- 2	6.91	6.74	7.68	7.14	6.52	7.58	6.92
20- 2	7.23	6.76	7.12	6.99	6.67	7.4	7.39
19- 2	10.95	10.8	11.02	11.77	10.22	11.29	11.54

Table A4 cont.

Tooth	M48	M50	M53	M60	M64	M65	M77
8	8.76	8.33	8.72	9.06	8.61	9.1	7.79
7	6.74	6.46	6.81	7.3	6.79	6.88	6.54
6	8.4	8.55	7.93	8.53	8.07	7.79	7.33
5	7.06	6.95	7.5	7.64	6.53	6.48	6.67
4	6.22	6.72	7.1	7.75	6.43	6.82	6.34
3	10.11	10.35	10.15	11.19	10.62	10.43	9
9	8.66	9	8.83	9.24	8.16	9.24	7.84
10	6.8	6.37	6.82	7.17	6.58	6.68	6.41
11	8.26	8.47	8.11	8.52	8.12	8.01	7.07
12	7.29	6.94	7	7.78	6.56	6.45	6.45
13	6.35	6.4	6.83	6.82	6.5	6.63	6.45
14	10.05	10.42	10.21	10.71	10.6	10.52	9.31
25	5.78	5.43	5.62	6.09	5.08	5.79	4.85
26	6.28	6.09	6.21	6.46	4.98	6.33	5.35
27	7.66	7.18	6.91	7.31	6.24	6.9	6.02
28	7.6	7.17	7.03	7.92	6.71	6.85	6.61
29	7.4	7.5	7.42	7.26	6.43	7.12	6.64
30	10.81	10.92	11.72	12.07	11.15	11.09	9.07
24	5.55	5.35	5.79	5.52	5.06	5.51	4.97
23	6.41	6.11	6.07	6.64	5.31	6.32	5.35
22	7.48	7.16	6.55	7.44	6.27	7.08	6.09
21	7.42	7.11	7.47	7.69	6.74	6.98	6.66
20	7.31	7.67	7.32	8.48	6.36	7.26	6.41
19	11.29	10.58	12.31	11.96	11.31	11.02	9.13
8- 2	8.73	8.4	8.66	9.07	8.62	8.98	7.88
7- 2	6.73	6.41	6.73	7.22	6.65	7	6.52
6- 2	8.42	8.48	8.01	8.49	8.13	7.73	7.33
5- 2	7.09	6.99	7.47	7.76	6.52	6.48	6.68
4- 2	6.25	6.69	7.12	7.68	6.38	6.88	6.2
3- 2	10.09	10.38	10.16	11.19	10.54	10.49	8.9
9- 2	8.64	8.91	8.8	9.23	8.1	9.2	7.87
10- 2	6.77	6.36	6.82	7.22	6.6	6.5	6.32
11- 2	8.29	8.46	8.26	8.36	8.16	7.97	7.23
12- 2	7.27	6.86	7.04	7.77	6.67	6.47	6.51
13- 2	6.36	6.41	6.79	6.8	6.59	6.65	6.43
14- 2	10.24	10.32	10.15	10.82	10.46	10.62	9.31
25- 2	5.74	5.46	5.66	6.07	5.1	5.7	4.88
26- 2	6.26	6.09	6.15	6.41	5.06	6.17	5.34
27- 2	7.64	7.15	6.82	7.26	6.29	6.89	6.08
28- 2	7.63	7.17	7.05	7.82	6.74	6.84	6.69

Table A4 cont.

Tooth	M48	M50	M53	M60	M64	M65	M77
29- 2	7.44	7.43	7.34	7.27	6.44	7.07	6.7
30- 2	10.88	10.9	11.83	12.11	11.13	11.16	9.12
24- 2	5.49	5.32	5.8	5.62	5.09	5.59	4.96
23- 2	6.38	6.09	6.17	6.67	5.28	6.43	5.43
22- 2	7.53	7.09	6.61	7.34	6.37	7	6.12
21- 2	7.44	7.03	7.45	7.64	6.71	6.91	6.61
20- 2	7.36	7.83	7.36	8.47	6.39	7.24	6.27
19- 2	11.25	10.58	12.2	11.9	11.31	11.02	9.15

Table A4 cont.

Tooth	M65	M77	M80	F18	F41	F44	F45
8	9.1	7.79	8.88	8.43	8.66	8.59	9.44
7	6.88	6.54	6.93	6.67	6.6	6.63	6.55
6	7.79	7.33	8.24	6.96	7.26	7.75	7.33
5	6.48	6.67	7.35	6.44	6.66	7.26	6.73
4	6.82	6.34	7.1	6.26	6.7	6.61	6.43
3	10.43	9	10.2	9.59	9.4	10.99	10.58
9	9.24	7.84	9.27	8.55	8.69	8.86	9.8
10	6.68	6.41	6.64	4.99	6.73	6.77	7.21
11	8.01	7.07	8.17	5.58	6.97	7.65	7.43
12	6.45	6.45	7.49	6.71	6.65	7.43	7.09
13	6.63	6.45	7.2	6.42	6.67	6.6	6.75
14	10.52	9.31	10.64	9.63	9.7	11.17	10.31
25	5.79	4.85	5.34	5.02	5.19	5.62	5.87
26	6.33	5.35	5.81	5.62	5.78	6.25	6.21
27	6.9	6.02	6.91	5.86	6.16	6.62	6.4
28	6.85	6.61	7.37	6.76	6.46	7.51	6.7
29	7.12	6.64	7.09	6.87	6.87	7.11	7.23
30	11.09	9.07	11.21	10.18	10.02	11.75	9.89
24	5.51	4.97	5.23	5.07	5.04	5.4	5.98
23	6.32	5.35	5.83	5.8	5.67	6.44	6.12
22	7.08	6.09	7.04	6	6.13	6.58	6.63
21	6.98	6.66	7.52	6.65	6.34	7.82	6.97
20	7.26	6.41	7.58	6.7	6.81	7.76	7.08
19	11.02	9.13	11.19	10.29	10.47	11.79	10.23
8- 2	8.98	7.88	8.88	8.45	8.6	8.61	9.43
7- 2	7	6.52	6.92	6.59	6.54	6.65	6.59
6- 2	7.73	7.33	8.26	6.87	7.19	7.64	7.38
5- 2	6.48	6.68	7.32	6.43	6.66	7.18	6.71
4- 2	6.88	6.2	7.09	6.15	6.59	6.53	6.51
3- 2	10.49	8.9	10.28	9.67	9.31	11.11	10.5
9- 2	9.2	7.87	9.25	8.55	8.63	8.87	9.7
10- 2	6.5	6.32	6.69	6.66	6.82	6.61	7.2
11- 2	7.97	7.23	8.2	6.81	7.04	7.64	7.46
12- 2	6.47	6.51	7.49	6.66	6.69	7.42	6.99
13- 2	6.65	6.43	7.17	6.46	6.68	6.63	6.64
14- 2	10.62	9.31	10.53	9.62	9.56	11.22	10.27
25- 2	5.7	4.88	5.44	4.99	5.22	5.66	5.84
26- 2	6.17	5.34	5.79	5.64	5.79	6.29	6.26
27- 2	6.89	6.08	6.98	5.77	6.17	6.6	6.46
28- 2	6.84	6.69	7.36	6.65	6.46	7.62	6.74

Table A4 cont

Tooth	M65	M77	M80	F18	F41	F44	F45
29- 2	7.07	6.7	7.28	6.73	6.73	7.3	7.22
30- 2	11.16	9.12	11.39	10.22	10.02	11.7	10.06
24- 2	5.59	4.96	5.31	5.03	4.97	5.41	5.92
23- 2	6.43	5.43	5.79	5.8	5.75	6.46	6.11
22- 2	7	6.12	6.91	6.11	6.18	6.62	6.6
21- 2	6.91	6.61	7.48	6.51	6.36	7.75	6.95
20- 2	7.24	6.27	7.51	6.77	6.78	7.71	6.99
19- 2	11.02	9.15	11.17	10.38	10.5	11.77	10.23

Table A4 cont.

Tooth	F47	F48	F50	F66	F68
8	9.21	9.43	9.08	8.12	8.19
7	6.25	7.26	6.28	6.72	6.66
6	7.05	7.53	7.66	7.18	7.58
5	6.5	7.28	7.03	6.23	6.94
4	6.4	7.17	6.91	5.9	6.4
3	9.61	11.36	9.84	9.64	9.44
9	8.72	9.35	9.21	8.14	8.19
10	6.24	7.04	6.53	6.55	6.63
11	7.05	7.46	7.66	7.03	7.42
12	6.25	7.5	6.84	6.44	6.75
13	6.43	7.32	6.81	6	6.42
14	10.11	10.93	9.69	10.02	9.41
25	5.25	5.72	5.63	5.18	5.12
26	6.27	6.07	6.14	5.43	5.63
27	6.21	6.87	6.94	5.93	6.57
28	6.45	7.72	7.01	7.16	6.87
29	6.78	7.97	7.06	6.57	6.91
30	11.54	11.18	10.21	10.12	9.47
24	5.62	5.78	5.49	4.65	5.18
23	6.13	6.09	6.32	5.4	5.5
22	6.17	6.69	6.82	5.82	6.35
21	6.62	7.43	7.34	6.6	6.69
20	6.54	7.57	7.11	6.43	6.79
19	11.51	11.27	10.94	10.05	9.46
8- 2	9.17	9.35	9.12	8.14	8.22
7- 2	6.23	7.19	6.15	6.63	6.71
6- 2	7.08	7.46	7.63	7.18	7.66
5- 2	6.36	7.37	6.93	6.31	6.94
4- 2	6.4	7.08	7.03	5.91	6.39
3- 2	9.65	11.2	9.97	9.6	9.46
9- 2	8.76	9.31	9.21	8.24	8.12
10- 2	6.27	6.97	6.59	6.47	6.59
11- 2	6.94	7.4	7.62	7	7.35
12- 2	6.27	7.36	6.93	6.34	6.75
13- 2	6.39	7.26	6.71	5.86	6.43
14- 2	10.02	10.99	9.75	9.96	9.4
25- 2	5.24	5.8	5.52	5.14	5.07
26- 2	6.27	6.08	6.13	5.38	5.54
27- 2	6.18	6.78	7.01	5.94	6.49
28- 2	6.43	7.72	7.18	7.06	6.75
29- 2	6.84	7.91	7.04	6.58	6.85

Table A4 cont.

Tooth	F47	F48	F50	F66	F68
30- 2	11.42	11.28	10.12	10.14	9.55
24- 2	5.59	5.63	5.52	4.69	5.14
23- 2	6.05	6.12	6.48	5.24	5.56
22- 2	6.14	6.71	6.83	5.74	6.32
21- 2	6.61	7.42	7.4	6.6	6.73
20- 2	6.63	7.47	7.18	6.37	6.89
19- 2	11.51	11.2	11.01	10.02	9.55

Table A5. Poss analysis of ITSD

OVERALL RATIO

Sum mandibular 12 _______ mm   Mean 91.4 ± 2.10%   % Range 87.5 – 96.0%
Sum maxillary 12 _______ mm = x 100 Overall Ratio

Maxillary 12	**Mandibular 12**	**Maxillary**	**Mandibular**	**Maxillary**	**Mandibular**
85	77.69	94	85.92	103	94.14
86	78.60	95	86.83	104	95.06
87	79.52	96	87.74	105	95.97
88	80.43	97	88.66	106	96.88
89	81.35	98	89.57	107	97.80
90	82.26	99	90.49	108	98.71
91	83.17	100	91.40	109	99.63
92	84.09	101	92.31	110	100.54
93	85.00	102	93.23		

Patient Analysis

If the overall ratio exceeds 91.4 the discrepancy is in excessive mandibular tooth size. In the above chart locate the patient’s maxillary 12 measurement, and opposite it is the correct mandibular measurement. The difference between the actual and correct mandibular measurements is the amount of excessive mandibular tooth size.

Actual Mandibular 12 - Correct Mandibular 12 = Excess Mandibular 12
If the overall ratio is less than 91.3:
Actual Maxillary 12 - Correct Maxillary 12 = Excess Maxillary 12

ANTERIOR RATIO

Sum mandibular 6 _______ mm   Mean 77.8 ± 2.50%   % Range 71.4 – 86.3%
Sum maxillary 6 _______ mm = x 100 Anterior Ratio

Maxillary 6	**Mandibular 6**	**Maxillary**	**Mandibular**	**Maxillary**	**Mandibular**
40	31.12	45.5	35.40	50.5	39.29
40.5	31.51	46	35.79	51	39.68
41	31.90	46.5	36.18	51.5	40.07
41.5	32.29	47	36.57	52	40.46
42	32.68	47.5	36.96	52.5	40.85
42.5	33.07	48	37.34	53	41.23
43	33.45	48.5	37.73	53.5	41.62
43.5	33.84	49	38.12	54	42.01
44	34.23	49.5	38.51	54.5	42.40
44.5	34.62	50	38.90	55	42.79
45	35.01				

Patient Analysis

If anterior ratio exceeds 77.8:
Actual Mandibular 6 - Correct Mandibular 6 = Excess Mandibular 6
If anterior ratio is less than 77.8:
Actual Maxillary 6 - Correct Maxillary 6 = Excess Maxillary 6

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