CASE WESTERN RESERVE UNIVERSITY

SCHOOL OF DENTAL MEDICINE

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Date: January 13, 2006

EVALUATION OF DIGITAL DENTAL CASTS USING THE ABO OBJECTIVE GRADING SYSTEM

by

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Submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry

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EVALUATION OF DIGITAL DENTAL CASTS USING THE ABO OBJECTIVE GRADING SYSTEM

Abstract

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The American Board of Orthodontics Objective Grading System (ABO OGS) for plaster casts has limitations, but is considered the gold standard and is used for measuring finished cases as part of Phase III of board certification. The use of dental casts in an orthodontic office is a standard part of a complete patient record. However, storage space for the casts is a problem. Some orthodontists have turned to digital casts as a way to easily store, retrieve, and share diagnostic and final casts with patients and other dentists.

Thirty six identical pairs of plaster and digital final casts were scored using an ABO OGS software program version of the published ABO OGS designed to be used with digital casts (OrthoCAD™) and the traditional ABO gauge designed for use with plaster casts. Reliability of the

two scoring methods was assessed by scoring the casts multiple times and looking at the absolute differences between the scores. Spearman's rank correlation coefficient was used to assess correlation of the different scoring sessions. Comparison of the two scoring methods was assessed using the same descriptive statistics (absolute mean difference, range, and standard deviation) as well as the Spearman's rank correlation coefficient and Wilcoxon rank sum test. A p-value of 0.05 was used to determine statistical significance.

Intraoperator reliability was high for the plaster casts scored with the ABO gauge and digital casts scored with the ABO OGS software program ($r = 0.998$). However, a statistically significant difference ($p < 0.001$) was found between the total ABO score produced from the two scoring methods used on the same casts, with digital scores exceeding plaster scores by an average of 9.0 ± 5.5 points. The difference was produced by statistically significant differences three components; alignment, occlusal contact, and overjet.

The components overjet and occlusal contact showed statistical differences between the scoring methods and was attributable to imprecise articulation of the digital

casts. The ABO OGS software program did not correctly score the casts using the ABO OGS guidelines as published by the American Board of Orthodontics.

DEDICATION

This thesis is dedicated to:

God for the blessings and talents that he has allotted me.

My parents David and Carol. Thanks for being the most supportive and caring people I know. You both are the best parents a child could ask for. Thanks for the many sacrifices you both have done to give me this wonderful education and opportunity.

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LITERATURE REVIEW

Orthodontic History

As early as 460 B.C., Hippocrates referred to the dentition with the phrase "crooked teeth." As people became more aware of their appearance, the need for beautiful teeth followed. Edward H. Angle made it his life's work to straighten teeth. He was one of the first pioneers of orthodontics and established the Angle School of Orthodontia in 1905 to teach others his methods of straightening teeth. Then, his passion for the perfect occlusion inspired him to organize the Society of Orthodontics. Angle's mark has been left on the profession and his system for classification of malocclusions is still used today.

In 1929, the American Society of Orthodontia established the ABO which is the oldest specialty board in dentistry.(Dewel 1962) Later, the Society changed its name to the American Association of Orthodontics (AAO). The Orthodontic Board was developed by Dr. Albert Ketcham who believed that the specialty of orthodontics should

have a certifying body.(Vaden and Kokich 2000) The Board is autonomous, but the eight directors of the Board are nominated by the AAO. The certification from the Board does not confer any legal qualification, privilege, or license to practice orthodontics. In the 1950s, the Board was recognized by the American Dental Association as the official certifying board. As the Board attained prestige more orthodontists applied for board certification.

> "The mission of The American Board of Orthodontics is to establish and maintain the highest standards of clinical excellence in orthodontics. In its mission statement, the Board clearly defines four objectives: 1) to evaluate the knowledge and clinical competency of graduates of accredited orthodontic programs; 2) to re-evaluate clinical competency throughout a Diplomate's career through recertification; 3) to contribute to the development of quality graduate, postgraduate, and continuing education programs in orthodontics; and 4) to contribute to certification expertise throughout the world."(Vaden and Kokich 2000)

Board Certification

The Board has developed a three phase process for certification. Phase I is a thorough evaluation of the applicant's credentials. Only dentists who have completed an advanced education program in orthodontics approved by the Commission on Dental Accreditation of the

American Dental Association are eligible to apply for certification. Upon approval of the prospective candidate's credentials, the individual is classified as a "Board Applicant." A Board Applicant has five years to successfully complete the Phase II written examination. The written examination has evolved into a well-respected testing instrument that is now used by many graduate orthodontic programs as a method for evaluating the academic qualifications of their students and the educational effectiveness of their graduate curricula. Phase III need not be completed to practice orthodontics, but is a measure of accomplishment and a way to critically evaluate case outcomes.(American Board of Orthodontics 2004) The Board's adoption of the clinical Phase III examination is:

> "...to elevate the standard of the practice of orthodontia; to familiarize the public with its aims and ideals; to protect the public against irresponsible and unqualified practitioners..." (Eismann 1974)

In the past, Phase III consisted of the presentation of fifteen case reports, with records made before treatment, immediately after treatment, and at least two years after removal of orthodontic appliances. Today, the candidate is required to present ten case reports

that represent specific categories of malocclusion. The Board has made these changes in order to encourage completion of the Phase III examination.

Need for Quantifying Orthodontic Case Results

The American Board of Orthodontics needed a standardized method for grading a finished case. It began investigating objective methods. Over the years, several indices were used to evaluate outcome of orthodontic treatment.(Eismann 1974; Gottlieb 1975) Early indices compared pre-treatment and post-treatment records to determine changes that occurred due to the orthodontic treatment. However, these indices were not precise enough to give a grade for the final outcome. A more precise method was needed to quantify minor discrepancies in a finished case. Although the Occlusal Index by Summers (1971) was developed to determine treatment quality, it was not widely accepted due to its difficultly of application and because it was time consuming. The ABO sought an index to access a final occlusion that would be simple and fast for orthodontists to use before submission of their cases for Phase III.

In 1987, the PAR Index (Peer Assessment Rating) was developed to assess occlusion at any stage of

development.(Richmond et al. 1992) Over two hundred dental casts, representing various pre-treatment and post-treatment stages of occlusion, were used to establish this index. The PAR Index has good reliability and validity. However, this system is not precise enough to discriminate between the minor inadequacies of tooth position that are found in ABO case reports.(Gottlieb 1975) Therefore, an ABO committee was formed in 1994 to field test more precise methods of objectively evaluating post-treatment dental casts and panoramic radiographs.

Development of Outcome Assessment

The assessment of an orthodontic outcome is complicated and can be formulated in many different ways. Final alignment of teeth, difficulty of treatment, facial esthetics, and stability are a few of the considerations in outcome assessment. In 1975, Gottlieb presented his criteria for orthodontic correction which included:

1. Class I molar relation
2. Class I cuspid relation
3. Cusp inter-digitation
4. Overbite
5. Over jet
6. Midline

7. Rotation
8. Crowding or spacing
9. Arch form
10. Torque
11. Parallelism of root

Treatment results are subject to circumstances that are sometimes beyond the orthodontist's control. There is no official standard of treatment results to which orthodontists must adhere. Orthodontists must rely on self-evaluation of their own cases to maintain their own level of quality which varies from orthodontist to orthodontist. Since most orthodontic treatment is elective, the option to discontinue treatment can be the patient's choice even if the treating orthodontist is not satisfied with the final outcome. Espeland and Stenvik (1991) studied 130 young adults and asked them to quantify their own occlusion. Anterior malalignment was the most common to be judged as unaesthetic. Birkeland et al. (2000) assessed the relationship between dental appearance, self esteem, and occlusion. He found that improvement in self-esteem in children was not correlated with treatment changes.

Quantifying the severity of the dental malocclusion became important when indices were being developed to calculate the degree of reduction of malocclusion. Quantitative indices were developed in the following chronological order listed in Table 1.

The ABO has developed a discrepancy index to measure case complexity. The presenting clinical features of a patient are quantified and summarized in the discrepancy index.(Cangialosi et al. 2004) The greater number of the conditions present at the start of treatment, the greater the challenge to the orthodontist.

An occlusal index categorizes an occlusion by assigning a numeric or alphanumeric value to an occlusion. An index is a graduated scale which should be reliable and valid. For an index to be useful it must also be quick and easy to perform, equally sensitive to all malocclusions, and be amenable to statistical analysis and modification.

With the development of the American Board of Orthodontic Objective Grading System (ABO OGS), a numerical grade can be given to a final occlusion. A case that loses more than a total of thirty points on the eight components will fail.

TABLE 1.--Development of Indices

Year	Index
1899 Angle	Classification of molar relationship
1932 Stallard	General dental status; some malocclusion traits. No definition of traits given.
1945 Sclare	Record the presence of certain malocclusion traits: a) Molar relationship b) Arch constriction c) Protrusion of incisors d) Labial prominence of canine e) Lingually displaced incisors f) Rotated incisors g) Cross bite h) Open bite or closed bite
1957 Poulton and Aaronson	Occlusal Feature Index (OFI)
1959 Van Kirk and Pennell	Malalignment Index
1960 Draker	Handicapping Labio-lingual Deviation
1964 Bjork et al.	Objective assessment of malocclusion based on defined-three areas of assessment: a) Dental anomalies: tooth anomalies, abnormal eruption, alignment b) Occlusal anomalies: sagittal, vertical and transverse deviation of the dental arches c) Spacing or crowding
1966 Jamison and McMillan	No name
1967 Grainger	Treatment Priority Index (TPI)
1967 Howitt et al.	Eastman Esthetic Index (EEI)
1968 Salzmann	Handicapping Malocclusion Assessment Record (HMAR)
1971 Summer	Occlusal Index (OI)
1974 Linder-Aronson	Swedish National Board for Health and Welfare Index
1984 Behrents	Behrents Index
1986 Cons et al.	Dental Aesthetic Index (DAI)
1987 Richmond et al.	PAR Index
1989 Brook and Shaw	Index of Orthodontic Treatment Priority
1991 Shaw et al.	Index of Orthodontic Treatment Need (IOTN)
1995 AAO	AAO Objective Grading System
1998 Richmond	ICON

Era of Computerization

Recently the video graphics of computers and the emerging interest of offices to have a completely digital system have been the driving forces for products like digital x-rays and digital photos.

Digital casts have begun to replace conventional plaster casts.(Garino and Garino 2002; Marcel 2001; Sachdeva and White 2000) Digitally photographed casts was the first step toward making orthodontic casts electronic. Unfortunately, manipulation of the casts was not available with this format. Another drawback was that the casts had to be first poured in plaster and then photographed. Researchers then attempted to develop 3-D casts through laser technology combined with holographic images.(Rossouw et al. 1991; Martensson and Ryden 1992; Gabor 1948) Topography and holography were some of the first methods used to convert study casts into 3-D images.(Bell et al. 2003; Takasaki 1970; Kanazawa et al. 1984) Holography involved microscopy by reconstructed wavefronts.(Gabor 1948; Ansley 1970) An advantage to holography was that it allowed direct measurement of the 3-D image.(Wedendal and Bjelkhagen 1974; Ryden et al. 1982) However the costs of these capture devices were

prohibitive. Drawbacks of the holography casts included poor quality and limited detail.(Harradine and Stephens 1990) Another downside to the holograms was that the image is stored in a static form and cannot be manipulated.(Bell et al. 2003)

Different types of lasers have also been used to scan dental casts and store the images on computers for measuring purposes.(Motohashi and Kuroda 1999; Lu et al. 2000; Hirogaki et al. 2001) The scanning technology has been available since the 1990's, but the software was not developed until just recently. With the invention of the computer-aided design (CAD) scanned-in images are now commercially viable.(Joffe 2004) Today impressions are taken in either alginate, polyvinyl silicone or polyether material. The impressions are sent to a manufacturer to be poured in plaster.(Marcel 2001; Redmond 2001) Then the plaster cast is scanned into a digital 3-D cast.

Digital Casts

With the introduction of "virtual study casts," patient's records be completely electronic.(Joffe 2004) The conversion of dental casts from plaster to a three-dimensional digital format, with viewing on a two-dimensional computer screen, is now possible. A digital

cast is something that most orthodontists are familiar with due to pioneer companies like Invisalign™, E-casts™, OrthoCad™, and OrthoClear™. Dentists already use computers for record keeping, practice management, patient education, communication with colleagues, restoration fabrications, and many other tasks.

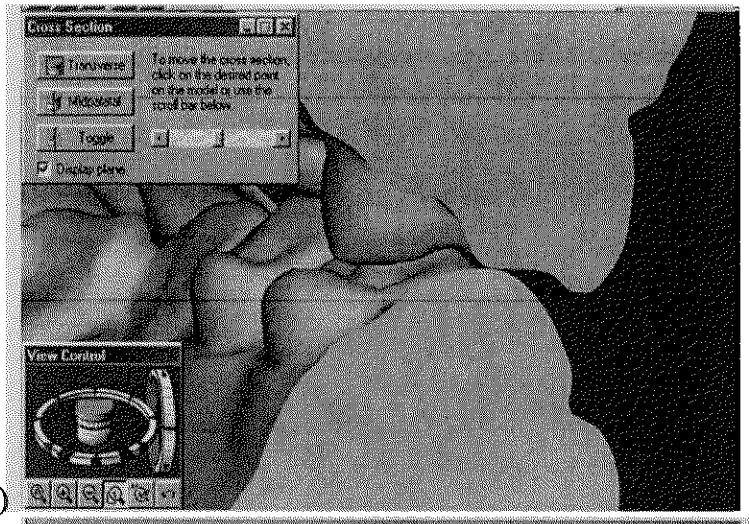
In the workshop report by Hans, (1993) it was agreed that the space required to store casts was a universal problem for all orthodontists. The digitization of the dental cast allows for easy storage, fast access, and conservation of the dental casts. This saves physical space and conserves the records in an intact form, and possibly for a longer time, since old records would not need to be trashed due to space constraints.

Plaster study casts are a standard component of orthodontic records and they are fundamental for diagnosis, treatment planning, case presentations, evaluation of treatment progress, and final results. The burden of storage and preservation of plaster casts has taken its toll on orthodontists.(Joffe 2004) The Consumer Protection Act 1987 requires that all patient records be retained for not less than 11 years.(Bell et al. 2003) Many orthodontist have rented extra storage

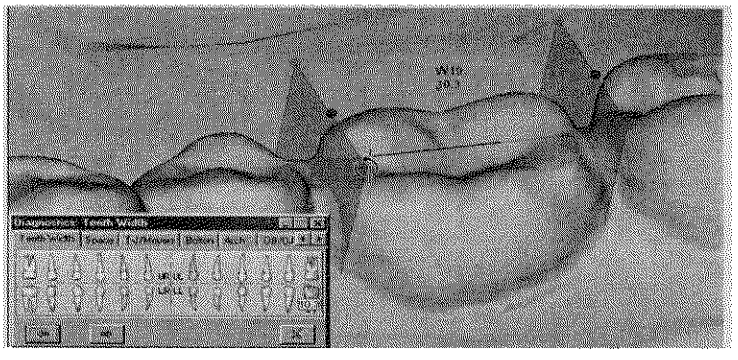
spaces or have an attic full of their life's work. The convenience and economy of digital casts has been a driving force for clinicians to switch to pre-treatment and post-treatment digital casts.(Quimby et al. 2004; Bell 2003) The ability to archive such large amounts of data on compact discs and computer hard drives has helped tremendously in the storage of patient data.

Another advantage of digital casts is the ability to do an indirect bonding set-up on the computer.(Garino and Garino 2003, 2004; Redmond et al. 2004) The limitations of the traditional casts are being eliminated by the digital casts and the ever increasing demand for interdisciplinary care is evolving. Digital casts have the advantage of allowing transverse and saggital cuts to be made to measure lingual inclinations and occlusal schemes without destroying the cast.

A)



B)



C)

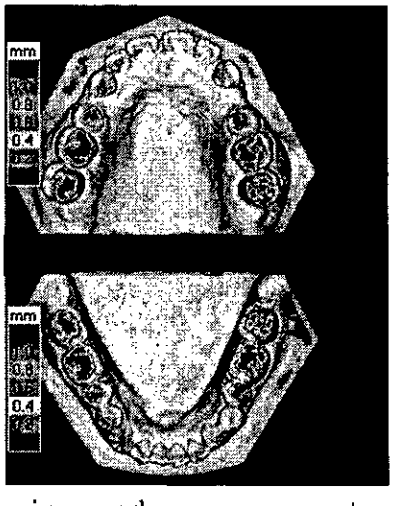


Figure 1. Analysis and measurements performed in a digital dental cast. A) Cross-sectional view, B) measurement on a digital dental cast, and C) analyses of contact points. (Courtesy of OrthoCad™/Cadent. Carlstadt, NJ. USA). 2004)

The ability to digitally share a patient's casts and the software available to diagnosis Bolton discrepancy, Moyers, Tanaka, and arch length discrepancy analyses can be useful in developing treatment plans.(Garino and Garino 2004) Once a practice has streamlined communication between other dentists, an ideal interdisciplinary practice can be established.(Redmond et al. 2000) The ability to share 3-D cast images with other practitioners on your team increases the level of patient care.(Redmond 2001)

Manufacturers provide free software the orthodontist can use to make routine measurements, such as tooth size, overjet, overbite, and Bolton analysis, and a program that walks the orthodontist through an ABO OGS software program. Disadvantages include lack of tactile input for the orthodontist and time needed to learn how to use the system. As with any new method, accuracy and reliability must be assessed by comparison with the existing gold standard.

The Reliability and Validity of Digital Measurements

Much debate has been done on the validity of digital casts. Recently, studies have been done to assess the intra-judge reliability of the ABO OGS on plaster casts.

The Board members revealed that their intra-judge reliability was clinically acceptable at R = 0.85.(Lieber et al. 2003) Studies have been done on other indexes which include Buchanan's reliability study of the PAR index and found intra-judge reliability to be slightly higher at R = 0.98.(Buchanan et al. 1993) Since the ABO OGS is broken up into seven different components for the cast measurement, each component has its own reliability score independent of the other.

The clinical use of the ABO OGS was tested by Lieber et al. (2003) at the University of the Pacific. With testing thirty six post treatment study casts using the ABO OGS, intra-judge and inter-judge reliability was calculated. Lieber et al. used descriptive statistics (namely mean, median, mode) and nonparametric statistics (Spearman rank coefficient, Wilcoxon, Kruskal-Wallis, and Mann-Whitney tests) for calculating the intrajudge and interjudege reliability of the ABO OGS on plaster casts. Nonparametric tests were used because the ABO OGS is an index which is ordinal. Inter-judge correlation averaged R = 0.85. They also found that with the ABO OGS most deductions were found in the buccal segments and most were related to the second molars. Lieber et al. found

that the strongest intra-judge relationship existed with the occlusal relationship criterion (R = 0.83) and the weakest was observed in the interproximal contacts criterion (R = 0.52). Although interproximal contacts had a weak correlation it was the only component to not have a statistically significant difference when the Wilcoxon Rank sum test was applied. This can be explained by the small amount of data interproximal scores produce which would not render any clinically significant results.

Other studies have compared measurements made on plaster casts with measurements done on digital casts. These measurements would be evaluated with parametric statistical tests since they are continuous.(Schirmer and Wiltshire 1997) Bell et al. (2003) found his differences were within the range of operator error and that the average difference between any of his measurements was 0.27mm which was considered not clinically significant. Ursus (1997) found that manual measurements using a calibrated gauge produced the most accurate, reliable, and reproducible results. When using the ABO OGS which is sensitive to a scale of < 0.1 mm, a minute difference even though clinically not significant, will play a

factor in the ABO score. If an index like the ABO OGS is accurate enough to measure small degrees in final tooth positions, then a replacement for plaster casts must be equally as precise.

Zilberman et al. (2003) also found that the digital casts' accuracy is clinically acceptable when comparing measurements, but the digital calipers on plaster casts was superior. He showed that the digital casts had high reproducibility. Quimby et al. (2004) showed through intra-class correlation coefficient that the reproducibility (reliability) of digital casts was R>0.90 which was similar to plaster casts when using measurements. Tomassetti et al. (2001) showed a high Intra-examiner reliability for plaster and digital casts using measurements with mean R values of 0.930 and 0.843, but lower inter method R value at 0.574(low correlation) for the anterior region. At present, plaster casts are considered the gold standard for orthodontic records. As computers become more integrated into the orthodontic practice, the idea of digital casts will also evolve. Zilberman et al. (2003) believes that the digital cast reality is now coming into the realm of being noted as

"clinically acceptable" and will become the standard for orthodontic clinical use.(Quimby et al. 2004)

The accuracy, reproducibility, efficacy, and effectiveness of computer-based cast measurements compared to plaster cast measurements were examined in a study done in 2004 by Quimby et al. It was found that reproducibility was high for both computer-based and plaster casts.(Mayers et al. 2005) Efficacy and effectiveness of digital casts was also similar to plaster casts. Measuring plaster casts by digital hand calipers has been the traditional way to measure tooth size discrepancies, overjet, overbite, and crowding and spacing. It has been shown that a statistically significant difference between tooth size and overbite exists when comparing digital casts to plaster casts. The results showed that the digital casts were smaller comparatively with a range from 0.16 mm to 0.49 mm, but can be clinically not relevant.(Santoro et al. 2003)

Costalos et al.(2005) evaluated the accuracy of the ABO OGS software program. The study included impressions from twenty four finished orthodontic patients. The plaster and digital casts were scored using the ABO OGS gauge and the ABO OGS software program. Interexaminer

reliability was pour with R = 0.46 for plaster casts and R = 0.65 for digital casts. Parametric statistical tests were used to determine statistical significance even though the ABO OGS is an index that uses ordinal numbers not continuous numbers. All seven components were added together and the final ABO scores were compared. Intra-class correlation showed R = 0.69. No separate components were compared for their individual correlation. Adding all seven components together runs the risk of individual component differences canceling each other out and having correlated values but not accurate values. An ANOVA test was run which gave the mean average for each component of all twenty four casts without regard to their order. Alignment and buccolingual inclination scores showed a statistically significant difference. Taking the average score of twenty four different casts diminishes the ability to validate a difference in individually scored plaster and digital casts. If the overjet scores for the digital casts were switched around, then the expected result would be a statistically significant difference from the plaster cast scores. The ANOVA test used here would actually give the same result allowing the digital score

to appear accurate and similar to the plaster score. The mean calculated for each component on the plaster cast was compared with the digital cast means, but again the order the casts that are compared can be jumbled up and still give the same results. To correct for this the absolute difference of each cast needs to be taken individually and then the means can be accurately be compared and used to assess the accuracy of digital casts and the ABO OGS software program.

The greatest limitation to the ABO OGS is be landmark identification.(Tomassetti et al. 2001) This is noticed when examining inter-judge results. Regarding inter-judge reliability, The data of Lieber et al.(2003) shows that some judges were, on the average, much more lenient than others. Measurements done on the same cast twice showed that the same individual would locate the landmarks and grade the cast the same. When applying these findings to a studying involving landmark location, it would seem appropriate to have the same individual consistently mark the landmarks for both the digital and plaster casts.

Development of the ABO Objective Grading System

During 1997 and 1998 field tests, both subjective and objective methods of scoring the dental casts and panoramic radiographs were used by the directors. Based on a comparison of these two methods, a passing score was established. In general, a case report that loses more than thirty points will fail. A case report that loses less than twenty points will generally pass. However, this figure only represents a part of the overall score for each case report. The quality of the records, appropriateness of the treatment plan, and objectives for the positioning of the maxilla, mandible, maxillary dentition, mandibular dentition, and facial profile are also carefully scrutinized.

In 1999, measuring gauges and grading guidelines for using the ABO OGS were also sent to candidates so they could grade their own treatment results before presenting them to the Board for Phase III. The Board has strived to make the Phase III examination a fair and accurate outcome assessment.(Casko et al. 1998) The Board created a Calibration Committee to oversee the implementation and modification of their published Objective Grading System. This scoring system has been developed systematically

through a series of four field tests over a period of five years.(Vaden and Kokich 2000) The Board realizes that the method of assessing candidates may change in the future, and it will continue to review these systems and modify them in order to keep-up with the evolutionary changes in the delivery and assessment of orthodontic treatment in the future.

The introduction of an ABO Objective Grading System (ABO OGS) for assessing the quality of the candidate's treatment results has been a huge step in the standardization of measuring and quantifying final outcomes of orthodontic cases. The American Board of Orthodontics published its grading system for dental casts and panoramic radiographs in 1998 (Vaden and Kokich 2000). This system has the following components:

1. alignment
2. marginal ridges
3. buccolingual inclination
4. occlusal relationships
5. occlusal contacts
6. over jet
7. interproximal contacts
8. radiographic analysis

The numerical values of 0, 1, and 2 are used to rate the item being examined (tooth or cusp) and the total of these gives the total for each category. The total of all seven cast components and the one radiographic component produces the final ABO score. The measurements for those components are performed by using the ABO measuring gauge.

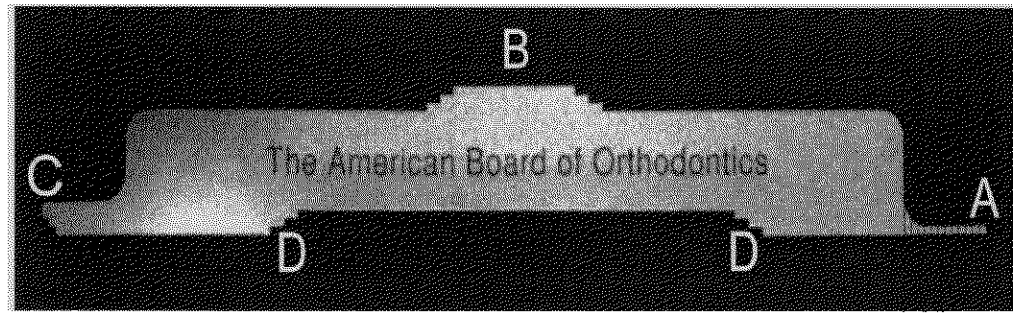


Figure 2. ABO OGS Measuring Gauge. A) This portion of the gauge is 1mm in width and is used to measure discrepancies in alignment, overjet, occlusal contact, interproximal contact, and occlusal relationships. B) This portion of the gauge has steps measuring 1 mm in height and is used to determine discrepancies in mandibular posterior bucco-lingual inclination. C) This portion of the gauge has steps measuring 1mm in height and is used to determine discrepancies in marginal ridges. D) This portion of the gauge has steps measuring 1mm in height and is used to determine discrepancies in maxillary posterior bucco-lingual inclination.

The Board also provides Phase III applicants with a standardized grading sheet used for the case examination.

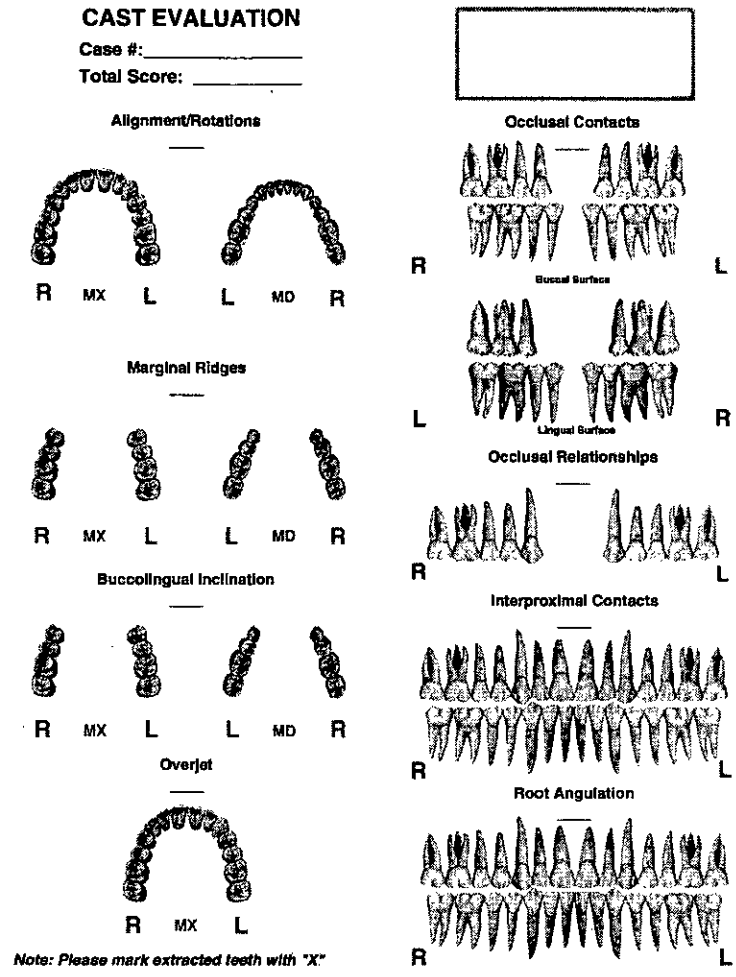


Figure 3. ABO OGS grading sheet.

ABO OGS Guidelines

In the maxillary anterior region, proper alignment is characterized by coordination of alignment of the lingual incisal surfaces of the maxillary incisors and canines. In the mandibular anterior region, the labial incisal surfaces of the mandibular incisors and canines.

In the maxillary arch, the central grooves (mesio-distal) should all be in alignment. In the mandibular posterior quadrants, the mesiobuccal and distobuccal cusps of the molars and premolars should be in the same mesiodistal alignment. If all teeth are in alignment, or within 0.50mm of proper alignment, no points are subtracted from the candidate's score. If the mesial or distal alignment at any contact point is 0.50 mm to 1 mm deviated from proper alignment, 1 point shall be subtracted for the tooth that is out of alignment. If the discrepancy is greater than 1mm, then 2 points shall be subtracted for that tooth. No more than 2 points shall be subtracted for any tooth.

In both maxillary and mandibular arches, marginal ridges of adjacent posterior teeth shall be at the same level, or within 0.50 mm of the same level. If adjacent marginal ridges deviate from 0.50 to 1 mm, then 1 point shall be subtracted for that interproximal contact. If the marginal ridge discrepancy is greater than 1 mm, then 2 points shall be subtracted for that interproximal contact. No more than 2 points will be subtracted for any contact point. The marginal ridge will be considered as

the most occlusal point that is within 1mm of the contact at the occlusal surface of adjacent teeth.

The bucco-lingual inclination of the maxillary and mandibular posterior teeth shall be assessed by using a flat surface that is extended between the occlusal surfaces of the right and left posterior teeth. When positioned in this manner, the straight edge should contact the buccal cusps of contralateral mandibular molars. The lingual cusps should be within 1mm of the surface of the straight edge. In the maxillary arch, the straight edge should contact the lingual cusps of the maxillary molars and premolars. The buccal cusps should be within 1mm of the surface of the straight edge. If the mandibular lingual cusps or maxillary buccal cusps are more than 1mm, but less than 2mm from the straight edge surface, 1 point shall be subtracted for that tooth. If the discrepancy is greater than 2mm, then 2 points are subtracted for that tooth. No more than 2 points shall be subtracted for any tooth.

The next section of the evaluation determines the adequacy of occlusal contact of the premolars and molars. The buccal cusps of the mandibular premolars and molars and the lingual cusps of the maxillary premolars and

molars should be contacting the occlusal surfaces of the opposing teeth. If the cusps are in contact with the opposing arch, no points are deducted. If a cusp is out of contact with the opposing arch, and the distance is 1mm or less, then 1 point is subtracted for that cusp. If the cusp is out of contact and the distance is greater than 1 mm, then 2 points are subtracted for that cusp. No more than 2 points are subtracted for each cusp.

This section of the evaluation determines whether the occlusion has been finished in an Angle Class I relationship. Ideally, the maxillary canine cusp tip should align within 1 mm of the embrasure of the mandibular canine and adjacent premolar. The buccal cusps of the maxillary premolars should align within 1mm of the embrasures of the mandibular premolars and first molar. The mesiobuccal cusps of the maxillary molars should align within 1mm of the buccal grooves of the mandibular molars. If the maxillary buccal cusps deviate between 1 and 2 mm from the previously mentioned positions, then 1 point shall be subtracted for that maxillary tooth. If the buccal cusps of the maxillary premolars or molars deviate by more than 2 mm from ideal position, then 2 points shall be subtracted for each maxillary tooth that

deviates. No more than 2 points shall be subtracted for each maxillary tooth.

The overjet is evaluated by articulating the casts and viewing the labio-lingual relationship of the maxillary arch relative to the mandibular arch. In order to determine the proper relationship of the casts, the examiner must rely on the trimming of the backs of the bases of the casts. If the proper overjet has been established, then the buccal cusps of the mandibular molars and premolars should contact in the center of the occlusal surfaces, bucco-lingually, of the maxillary premolars and molars. In the anterior region, the mandibular canines and incisors will contact the lingual surfaces of the maxillary canines and incisors. If this relationship exists, no points are subtracted. If the mandibular buccal cusps deviate 1mm or less from the central groove of the opposing tooth, 1 point is subtracted for that tooth. If the position of the mandibular buccal cusps deviates more than 1mm from the central groove of the opposing tooth, then two points are subtracted for that tooth. No more than 2 points are subtracted for any tooth. In the anterior region, if the mandibular canines or incisors are not contacting lingual

surfaces of the maxillary canines and incisors, and the distance is 1mm or less, then 1 point is subtracted for each maxillary tooth. If the discrepancy is greater than 1mm, then 2 points are subtracted for each maxillary tooth.

There should be no interproximal distances between teeth. If 0.50 mm or less interproximal space exists, then no points are subtracted. If greater than 0.50 to 1mm of interproximal space exists between two adjacent teeth, then 1 point is subtracted for that interproximal contact. If more than 1mm of space is present between two teeth, then 2 points are subtracted for that interproximal contact. No more than 2 points are subtracted for any contact that deviates from ideal.

The ABO cast score is a composite score of the seven components mentioned above. An evaluation of the panoramic radiograph makes-up the eighth and final score of the total ABO score.

Evaluation of an ABO Objective Grading System Software Program on Digital Casts Using Nonparametric Tests and Descriptive Analysis

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Abstract

Introduction: The American Board of Orthodontists' Objective Grading System (ABO-OGS) is currently the gold standard for evaluating plaster casts of completed orthodontic cases. **Methods**: Thirty six identical pairs of plaster and digital final casts were scored using two methods; a software program version of the ABO-OGS designed to be used with digital casts (OrthoCAD's^{TM}, Cadent Inc, Fairview, NJ) and the ABO gauge designed for use with plaster casts. Intraexaminer reliability was tested. Comparison of the two scoring methods was assessed using descriptive analysis (range, absolute mean difference, and standard deviation), the Spearman's rank correlation coefficient, and the Wilcoxon rank sum test. **Results**: Intraexaminer reliability was high for both the plaster and digital casts ($r = 0.998$). A statistically significant difference ($p < 0.001$) was found between the total ABO scores from the plaster and digital casts. The ABO-OGS scores produced from the software program on digital casts exceeded the ABO-OGS scores produced from the ABO gauge on plaster casts by an average of 9.0 ± 5.4 points. This difference was due to statistically significant differences in three ABO-OGS components; alignment, occlusal contact, and overjet. **Conclusion**: The ABO gauge and plaster casts remain the gold standard for evaluation of orthodontic treatment outcome.

INTRODUCTION

Since the inception of the specialty, orthodontists have been interested in outcomes assessment. From 1900 to 1935, outcomes assessment usually took the form of expert evaluation of the finished study casts. By 1940, cephalometric tracing of before and after radiographs was added to the evaluation. Recently, interest in quantifying outcomes using objective measurements resulted in the development of the Peer Assessment Rating (PAR) Index.[1] Although the PAR has been used extensively to compare treatment outcomes between practitioners and practice groups, one criticism of the index has been that the PAR Index does not detect minor variations in tooth position that are important factors in ABO case reports.[2] To address this deficiency, the American Board of Orthodontics (ABO) published the Objective Grading System (OGS) which uses dental casts and panoramic radiographs to evaluate and grade the orthodontic outcome.[3,4] The ABO-OGS is currently used by ABO examiners to assess the quality of treatment of case reports presented during the phase III ABO diplomat clinical examination. The ABO-OGS contains seven scoring components for casts (alignment, marginal ridges, buccolingual inclination, occlusal relationships, occlusal contacts, overjet, and interproximal contacts) and one component for the panoramic x-ray. The sum of all seven cast categories produces the total ABO score for a cast.

At the same time that outcomes assessment was gaining popularity, the computer industry was revolutionizing the way orthodontists practice. One recent change is the increased use of digital study casts in place of traditional plaster casts.

Digital casts are attractive to the practitioner because of the problems inherent in the storage, retrieval, and archiving of plaster replicas of the dentition. A workshop report by Hans, [5] reported that the space required to store casts was a universal problem for orthodontists. The digitization of the dental cast allows for easy storage, fast access, and conservation of the dental casts. This saves physical space and preserves the record in a three dimensional form. The digitization of the dental casts not only allows for traditional measuring and analyses, but also provides viewing angles that would not be possible without destruction of the dental cast.[6] Companies like Invisalign™ (Align Technology, Santa Clara, CA), E-Models™ (GeoDigm Corporation, Chanhassen, MN) , OrthoCAD™ (Cadent Inc, Fairview, NJ), and OrthoClear™ (OrthoClear, Inc., San Francisco, CA) pioneering the use of digital cast technology and have forced orthodontists to use digital casts to use their products.

As digital casts become the norm, practitioners will be interested in comparing the accuracy (validity) and reproducibility (reliability) of computer-based measurements made on digital casts to measurements made on plaster casts. A study done in 2004 by Quimby[7] reported correlations greater than 0.90 when comparing digital and plaster cast measurements. A study done in 2005 by Mayers[8] found high reliability of plaster ($r=0.98$) and digital ($r=0.96$) casts when assessing the PAR index scores. Mayers also found no significant differences between overall PAR scores of plaster and digital casts. Other studies though have reported differences in tooth size and overjet when digital cast measurements were compared with plaster casts measurements. Santoro showed, in 2003, that the digital measurements were smaller

than measurements made on plaster casts by a range of 0.16mm to 0.49mm.[9] Bell in 2003[10] showed the same results with an average measurement difference between the digital and plaster casts of 0.27mm. Lower reliability ($r<0.77$) was shown for the ABO-OGS on plaster casts and no studies have reported on the intraexaminer reliability of digital implementations of OrthoCAD's ABO-OGS software program.[11]

Costalos et al. (2005)[12] evaluated the accuracy of OrthoCAD's ABO-OGS software program. The study included impressions from twenty four finished orthodontic patients. The plaster and digital casts were scored using the ABO-OGS gauge and OrthoCAD's ABO-OGS software program. Interexaminer reliability was poor with $r=0.46$ for plaster casts and $r=0.65$ for digital casts. Parametric statistical tests were used to determine statistical significance. Intraclass correlation for the plaster and digital total ABO scores showed $r=0.69$. No separate components were compared for their individual correlation. Alignment and buccolingual inclination scores showed a statistically significant difference. The absolute difference of each component of each cast needs to be calculated and then the mean differences can be accurately compared and used to assess the accuracy OrthoCAD's ABO-OGS software program on digital casts. The ABO-OGS is highly sensitive to final tooth positions and so a replacement for plaster casts would have to be an exact replication or differences will be reflected in the ABO score.

Therefore, the purpose of the present study was to evaluate the total ABO-OGS score and each of the components when applying OrthoCAD's™ (Cadent Inc, Fairview, NJ) ABO-OGS software program that scores digital casts. A comparison

of the scores produced with the ABO gauge on plaster casts with those produced with OrthoCAD's ABO-OGS software program was done by using descriptive and nonparametric analysis since the ABO-OGS uses ordinal values.

MATERIALS AND METHODS

Sample Selection

The Institutional Review Board approved the experimental protocol. The sample consisted of thirty six randomly selected plaster casts from finished cases from the graduate orthodontic clinic at Case Western Reserve University School of Dental Medicine. Inclusion criteria for the casts selected were: a signed consent form and good quality casts (without bubbles or broken teeth) that were properly trimmed (backs flush in a way that when casts are placed on a flat surface the casts show maximum intercuspation occlusion). All casts were sent to OrthoCAD manufacturer (Cadent Inc, Fairview, NJ) to be converted into a three dimensional digital cast format. ABO scores were computed using OrthoCAD's (version 2.66) ABO-OGS software program that scores digital casts. [13] Traditional ABO-OGS scoring was done on plaster casts using the ABO gauge.

All data was collected by a single operator (J.C.H.). Intraexaminer reliability was computed by rescoring ten randomly selected casts at three different time points separated by two week intervals. Calibration of the operator in the use of the ABO gauge was done using the ABO calibration kit, voice–over CD-ROM provided by the ABO and the information for the ABO phase III grading tool available in the OrthoCAD software package.[13, 14] To insure intraexaminer reliability, the three

calibration casts were graded at three different times two weeks apart and reliability was 0.90 prior to measuring any casts in the study.

Data analysis

Data from the thirty six digital and plaster casts were entered into an Excel ™ (Microsoft Corporation - Redmond, WA) spreadsheet and then transferred into the Statistical Package for the Social Sciences, version 12.0. (SPSS Inc. - Chicago, IL). The scores for each of the seven components of the thirty six casts were individually compared along with the total ABO-OGS scores. The range, absolute mean, and standard deviation were calculated for the differences of each of the seven components. Calculating the absolute difference of each model allows the examiner to see the total variation that is actually present. The Spearman's rank correlation coefficient (nonparametric test) was also computed to assess intraexaminer reliability. Since ordinal indices have been analyzed using parametric tests instead of nonparametric tests in past literature publications, an equivalent parametric test (intraclass correlation coefficient) was run in conjunction with the nonparametric analysis.[7, 8, 12]

Three separate types of statistics were run to compare the digital casts with plaster casts. First, a descriptive analysis was reported for the absolute differences between the plaster and digital casts for each separate cast in each of the seven components and the total ABO-OGS score. Descriptive statistics of the differences included range, absolute mean, and the standard deviation. Second, the Spearman rank correlation coefficient was calculated for each component and the total ABO

score to assess the degree of association. Third, the Wilcoxon rank sum test was used to detect differences in the seven ABO scoring components. Due to past publications computing ordinal values in parametric tests, equivalent parametric tests, intraclass correlation coefficients and paired *t*-Tests, were also computed.

Using the raw data from Costalos et al. (2005), the same descriptive analyses were done and compared with the results from this study. Since the previous study did not utilize tests explained in this project to compare to absolute differences of each cast, a better understanding of their findings and the differences between the two scoring methods can be seen using the descriptive analysis used in this study. At the outset of this project multiple changes in OrthoCAD's ABO-OGS software program grading guidelines had to be changed that did not follow the published ABO-OGS guidelines, but had been used when grading digital casts in the 2005 article. [12]

RESULTS

Table I and II consist of the raw data and upon observation of the data it is noticed that the total ABO scores for digital casts are on greater. This would be extremely important if a clinician were hoping for a passing score when submitting a digital cast for grading during Phase III diplomat certification.

Table III lists the descriptive and statistical results for intraexaminer reliability. High reliability was found for both the individual components and total ABO scores. The descriptive analyses also showed no differences. The equivalent parametric test agreed with the nonparametric test results.

Table VI outlines the descriptive analysis of the compared scores and shows the largest clinically significant difference to be in the overjet component. An average difference of 3.94 pts was found between plaster and digital casts in the overjet component. The largest individual cast difference found between the digital and plaster total ABO scores was 21 pts. Thirty five of the thirty six digital scores were higher than the plaster scores.

The statistical test results are shown in table V. Amongst the seven components that make up the total score, three (alignment, occlusal contacts, overjet) showed a statistically significant difference. The total ABO score also showed a statistically significant difference. Low correlations were found in the occlusal contact and overjet categories. The equivalent parametric tests, intraclass correlation coefficient and paired *t*-test, were equivalent to these findings.

The three components found to be clinically significant in this study were also found to have clinically significant differences in the previously published study by Costalos in 2005 when the correct descriptive analysis was applied which compared the individual components per cast.[12] The descriptive test results are outlined in Table VI.

DISCUSSION

The total ABO-OGS scores from the plaster and digital casts showed a medium correlation, but the two scores showed a statistically significant difference between them. The absolute mean difference of each casts' scores confirmed this finding showing an average of a 9 pt difference between OrthoCAD's ABO-OGS

software program computed score and the manually computed score on plaster models. A 9 pt increase in an ABO score with the use of digital models could cause a passing case to fail during Phase III diplomat certification.

Alignment, overjet, and occlusal contacts all showed a statistically significant difference when the digitally scored casts were compared with the plaster casts. These three components added together caused the total ABO score to also show a statistically significant difference.

OrthoCAD's ABO-OGS software program lacks the ability to adjust for the anterior curvature of a dental arch when measuring alignment. The software program places dots for the mesial and distal contact points of an individual tooth and makes the measurements of alignment using straight lines without consideration that the anterior teeth are on an arc and not in a straight plane. Also in the alignment section, the second molars could be rotated and still unscored when using OrthoCAD's ABO-OGS software program. This is because program only measures the mesial contact point of the second molar and not the plane of the buccal cusps as noted to do in the ABO grading guidelines. (Fig 1) The ABO-OGS criteria for grading alignment states that points are deducted per tooth rotation, but OrthoCAD's ABO-OGS software program grades per tooth contact which leads to double scoring a singularly rotated tooth (Fig 2). The software program that grades per contact point also only allows a maximum of 44 pts and the plaster casts can lose up to 56 pts in this component. The software program also lacks the ability to show which teeth should be graded if it is an extraction case because it does not mark which teeth are not present on the grading

template. If clinician grading the case is unaware which premolars were extracted then the cast would be graded incorrectly. In OrthoCAD's ABO-OGS software program, first bicuspids are not scored for alignment.

The largest discrepancies between the two ABO-OGS scores can be seen in interarch components. Overjet and occlusal contact digital scores show the largest difference when compared to the plaster casts scores. The ABO-OGS guidelines for grading occlusal contacts states that each cusp should be scored which is different from OrthoCAD's ABO-OGS software program which incorrectly grades each tooth. This leads to a potential of missing 16 scoring points. (Fig 3) The digital articulation (mounting) of the casts in the OrthoCAD™ program allows digital cast material (teeth) to be overlapping. This suggests improper articulation of the two digital arches because two objects can not take up the same space in the physical world. If two anterior teeth are overlapping each other in the digital program then OrthoCAD's ABO-OGS software program scores that tooth as having a positive overjet. (Fig 4) A point is given for overlapping digital material instead of being viewed as negative overjet which is not physically possible. The articulation of the digital casts is not accurate enough to be graded with the ABO-OGS (Fig 5 A, B).

A statistically significant difference between the manual and digital casts' scores was found in the components overjet and occlusal contact for three different reasons. The first one is incorrect articulation of the digital casts. A programming error allowing the digital casts to be able to be super imposed on top of each other demonstrates that the digital casts are not properly articulated causing deviations

when scoring the teeth with the ABO-OGS. The next one is incorrectly scoring the casts. OrthoCAD's ABO-OGS software program does not follow the same grading guidelines that are used when grading plaster casts. The last one is the difficulty in landmark identification of the digital cast. A limitation of using a two dimensional screen to accurately measure a three dimensional object is identification of landmarks after cutting the digital model to allow access for measuring. Landmark identification becomes a problem once the digital cast is saggitally cut which is necessary to allow access for assigning measuring dots to the central groove and cusp tip in calculating posterior overjet. (Fig 6) Tomassetti[15] also found that distinguishing the proper landmarks was difficult with digital casts. The digital marking dots must be completely on top of each other exactly to not score a point in the occlusal contact and overjet components. Zilberman[6] found landmark identification a constant problem due to looking at a three dimensional object in two dimensions. Costalos et al[12] also found that landmark identification was a problem when applying OrthoCAD's ABO-OGS software program to digital models.

The results obtained after analyzing Costalos' data shows the same three components found in this study to be significantly different when comparing the plaster and digital scores on an individual case by case basis. This comparison can only be done if the correct statistics are applied. The use of the absolute difference was chosen to find the true variation between OrthoCAD's ABO-OGS software program scores and manually scored plaster casts. Buccolingual inclination also showed a statistically significant difference in Costalos' study, but software

programming updates were implemented before measurements were made in this study. If only the mean difference is evaluated then actual differences in individual casts can be missed. When the data from Costalos et al. was reviewed, average differences of 3.46 and 3.83 pts were found between the plaster and digital scores in occlusal contact and overjet components. The standard deviation was 3.12 and 2.96 pts which shows that there was a large amount of random error in the data and a statistical difference would not be likely due to the large variation in the scores. This does however show that the two methods are not correlated and OrthoCAD's ABO-OGS software program does not produce the same score in the components overjet and occlusal contact as manually scoring the casts.

The data shows statistically significant differences between the two different scoring methods. The clinical significance of receiving a higher score on any component is a concern for orthodontists submitting casts to be evaluated for the case evaluation part of Phase III diplomat certification. The discrepancies between OrthoCAD's ABO-OGS software program and the published ABO-OGS guidelines are enough to cause the scores of occlusal contact and alignment to have a statistically significant difference. OrthoCAD's ABO-OGS software program can produce a maximum score of 220 while the guidelines published by the ABO can produce a maximum score of 248. To test the validity of the ABO-OGS on digital casts will require a digital grading program to first be identical in the scoring guidelines as the published guidelines for plaster casts.

The advantages of having digital casts make it an attractive product for orthodontists. The use of the OrthoCAD ABO-OGS software program must be used with caution though as it does not produce the same results as scoring the final casts in plaster. In past studies, slight discrepancies in the actual milometric measurements between digital and plaster models have been noted which can cause large scoring differences when using an index as sensitive as the ABO-OGS.[9, 10]

New versions of the digital software are constantly being released. Digital casts are advantageous for clinical practice and further improvements in scoring and software will be anticipated in the future.

If an orthodontist has switched to digital casts then the question is, "Can he or she become board certified without having plaster casts?" Right now the answer is no.

Conclusions

The ABO developed the Objective Grading System to evaluate the final occlusions of plaster casts and root angulations for cases submitted by applicants for board certification during Phase III diplomat certification. The reliability of OrthoCAD's ABO-OGS software on digital casts is high. When the digital and plaster scores were compared, the following findings were obtained.

1. There was a statistically significant difference found between the total ABO scores.
2. The categories alignment, occlusal contact, and overjet showed statistically significant differences.

3. Low correlation was found for the occlusal contact and overjet categories.
4. OrthoCAD's ABO-OGS software program does not score the teeth correctly and is inconsistent with the guidelines published by the ABO for grading casts.
5. The digital casts are not articulated precise enough and contain overlapping of digital material which causes inaccurate grading.
6. The total ABO score produced by OrthoCAD's ABO-OGS software program was 9 pts higher on average.
7. There was high reliability in the scores produced by digital and plaster casts when using the ABO-OGS when done by the one examiner.

These results indicate that although there are many advantages to the digital casts, they are not accurate enough in all ABO grading components. There is not an accurate ABO-OGS software program available for grading digital models. Final casts must be in plaster if the case is being submitted for grading during Phase III diplomat certification.

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List of Figures

Fig 1. The digital program uses the mesial contact point of the 2nd molars instead of the buccal cusp plane and allows the molar to not be scored even when rotated out of alignment (Courtesy of OrthoCad/Cadent–Carlstadt–NJ, USA).

Fig 2. Single tooth rotations are double scored and award points to adjacent teeth that are not rotated (Courtesy of OrthoCad/Cadent–Carlstadt–NJ, USA).

Fig 3. OrthoCAD's ABO-OGS software program does not score both molar cusps in the occlusal contact component (Courtesy of OrthoCad/Cadent–Carlstadt–NJ, USA).

Fig 4. Overlapping of digital cast material demonstrates the imprecise articulation of the digital casts and scores 1 point to each tooth overlapping indicating that a positive overjet is present (Courtesy of OrthoCad/Cadent–Carlstadt–NJ, USA).

Fig 5. A) Plaster cast: An anterior view showing positive overjet on a plaster cast. B) Digital cast: An anterior view of the same patient showing negative (overlapping digital material) overjet on a digital cast (Courtesy of OrthoCad/Cadent–Carlstadt–NJ, USA).

Fig 6. Exact location (< .01mm) of the central groove becomes extremely difficult after a transverse cut of the digital casts is done. 1 pt is scored even when the line looks completely straight (Courtesy of OrthoCad/Cadent–Carlstadt–NJ, USA).

Table I. Data collected from analyses of 36 plaster casts

Cast Number	A	MR	BLI	OC	OR	OJ	IPC	Total Score
1	4	2	7	8	8	7	0	36
2	8	5	12	10	1	9	0	45
3	1	8	4	6	4	4	0	27
4	3	3	10	4	4	5	0	29
5	3	4	12	7	4	7	0	37
6	2	5	12	8	2	5	0	34
7	1	7	6	8	2	0	0	24
8	8	12	14	8	2	7	0	51
9	6	2	10	4	2	2	0	26
10	2	8	9	7	2	7	0	35
11	6	5	10	10	4	10	1	46
12	7	2	5	7	10	8	0	39
13	11	4	13	5	2	6	0	41
14	1	1	6	5	1	6	0	20
15	10	3	10	6	2	3	0	34
16	4	2	8	0	1	2	0	17
17	2	2	3	2	0	6	0	15
18	4	7	8	6	2	5	0	32
19	1	5	10	4	6	6	0	32
20	0	4	6	4	1	5	0	20
21	4	4	11	8	1	2	2	32
22	6	2	14	18	1	7	0	48
23	3	9	8	10	1	6	0	37
24	5	1	9	3	4	6	0	28
25	3	2	7	10	2	9	2	35
26	1	2	10	6	1	4	0	24
27	2	1	7	0	1	2	0	13
28	3	4	14	5	0	4	0	30
29	1	3	9	16	3	4	0	36
30	1	5	7	6	0	4	3	26
31	3	6	9	5	3	3	0	29
32	3	3	14	2	0	2	0	24
33	4	2	14	11	1	4	0	36
34	0	7	8	5	0	9	2	31
35	4	4	6	3	0	4	0	21
36	4	3	13	7	4	3	0	34

Table II. Data collected from analyses of 36 digital casts

Cast Number	A	MR	BLI	OC	OR	OJ	IPC	Total Score
1	4	2	6	9	8	8	0	37
2	8	5	12	12	1	13	0	51
3	2	7	4	6	4	5	0	28
4	3	2	11	5	4	13	0	38
5	2	4	11	7	4	10	0	38
6	3	5	12	13	4	9	0	46
7	1	7	6	9	2	5	0	30
8	9	10	14	6	2	10	0	51
9	7	2	10	7	2	7	0	35
10	2	8	10	9	2	12	0	43
11	8	4	9	9	4	13	0	47
12	7	2	5	12	10	13	0	49
13	11	4	13	5	2	6	0	41
14	1	1	6	6	1	9	0	24
15	11	1	10	5	2	8	0	37
16	4	2	8	0	1	12	0	27
17	2	2	3	3	0	6	0	16
18	5	7	8	14	2	14	0	50
19	3	5	10	6	6	8	0	38
20	0	4	6	4	1	6	0	21
21	4	3	11	8	1	6	2	35
22	6	3	14	19	0	9	0	51
23	3	9	9	10	1	8	0	40
24	5	1	9	4	4	6	0	29
25	6	2	7	7	2	13	2	39
26	1	2	10	5	1	6	0	25
27	3	1	8	12	1	7	0	32
28	3	4	14	5	0	8	0	34
29	1	4	9	14	3	13	0	44
30	1	5	7	6	0	12	3	34
31	5	6	9	4	3	7	0	34
32	5	3	14	2	0	6	0	30
33	4	2	14	12	1	9	0	42
34	1	7	7	9	0	13	2	39
35	5	4	8	7	1	12	0	37
36	5	3	13	5	4	4	0	34

Table III. Descriptive and Statistical Analysis of the Intraexaminer's Absolute ABO Score Differences between Times 1, 2, and 3 on Plaster and Digital Casts. (n=36)

		Range	Mean	SD	Spearman's rank correlation coefficient r	Intraclass correlation coefficient r
ABO score	Plaster casts	0-2	<1.00	<1.00	0.998	0.996
	Digital Casts	0-2	<1.00	<1.00	0.998	0.995

Clinical Significant >2 pts (*) Statistical Significance at P<0.05 (**)

Table IV. Descriptive Analysis of the Absolute Score Differences between Digital and Plaster Casts. (n=36)

	Range	Mean	SD	Median
Alignment	0-3*	0.61	0.80	0.00
Marginal Ridges	0-2	0.28	0.57	0.00
Buccolingual inclination	0-2	0.28	0.51	0.00
Occlusal Contacts	0-12*	1.89	2.48*	1.00
Occlusal relationship	0-2	0.11	0.40	0.00
Overjet	0-10*	3.94*	2.65*	4.00*
Interproximal contact	0-1	0.03	0.17	0.00
Total ABO score	**0-21***	**9.00***	**5.54***	**9***

Clinically Significant >2pts (*)

Table V. Statistical Anaylsis of Digital and Plaster Casts Using Nonparametric and Parametric Tests. (n=36)

	Nonparametric tests		**Parametric tests**	
	Spearman rank correlation coefficient r	Wilcoxon rank sum test P	Intraclass correlation coefficent r	Paired *t*-test P
Alignment	0.927	0.001*	0.953	<0.001*
Marginal Ridges	0.956	0.107	0.969	0.110
Buccolingual inclination	0.977	0.564	0.981	0.571
Occlusal Contacts	0.666	0.032*	0.713	0.021*
Occlusal relationship	0.971	0.414	0.983	0.422
Overjet	0.525	0.001*	0.513	<0.001*
Interproximal contact	0.907	0.317	0.974	0.324
Total ABO score	**0.860**	**<0.001***	**0.842**	**<0.001***

Statistical Significance at P<0.05 (*)

Table VI. Descriptive Analysis of the Absolute Score Differences between Digital and Plaster Casts from Costalos et al. [14] (n=24)

	Range	Mean	SD	Median
Alignment	0-7*	2.75*	1.92	2.00
Marginal Ridges	0-6*	1.67	1.46	1.00
Buccolingual inclination	0-6*	2.21*	1.47	2.00
Occlusal Contacts	0-11*	3.46*	3.12*	2.50*
Occlusal relationship	0-5*	1.17	1.31	1.00
Overjet	0-9*	3.83*	2.96*	4.00*
Interproximal contact	0-3*	0.54	1.02	0.00
Total ABO score	**0-18***	**5.92***	**4.93***	**4.00***

Clinically Significant >2pts (*)

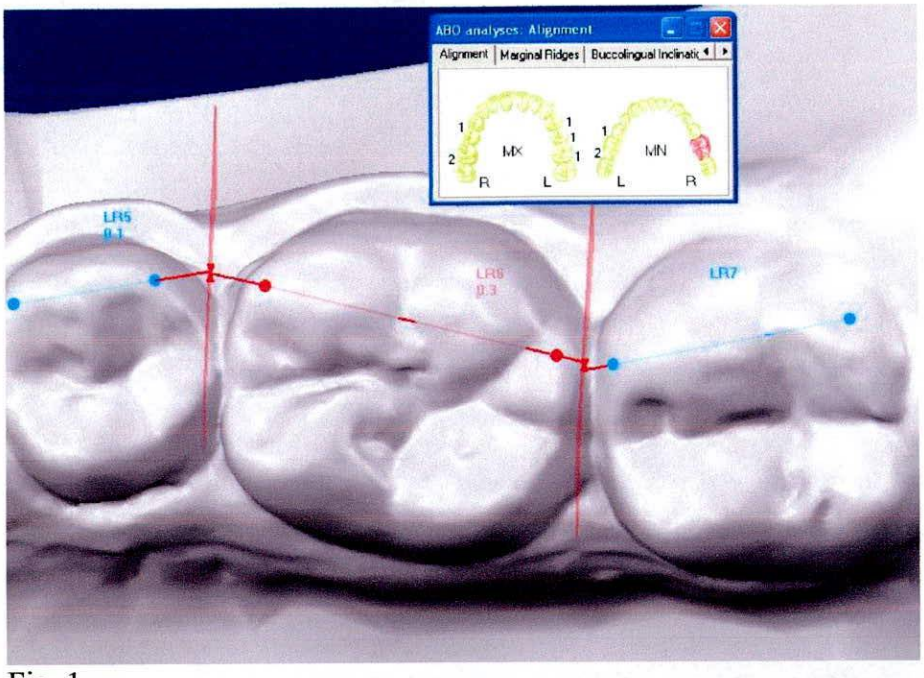

ABO analyses: Alignment
Alignment
Marginal Ridges
Buccolingual Inclinatic
MX
MN
R
L
L
R
LR5
0.1
LR6
0.3
LR7

Fig. 1

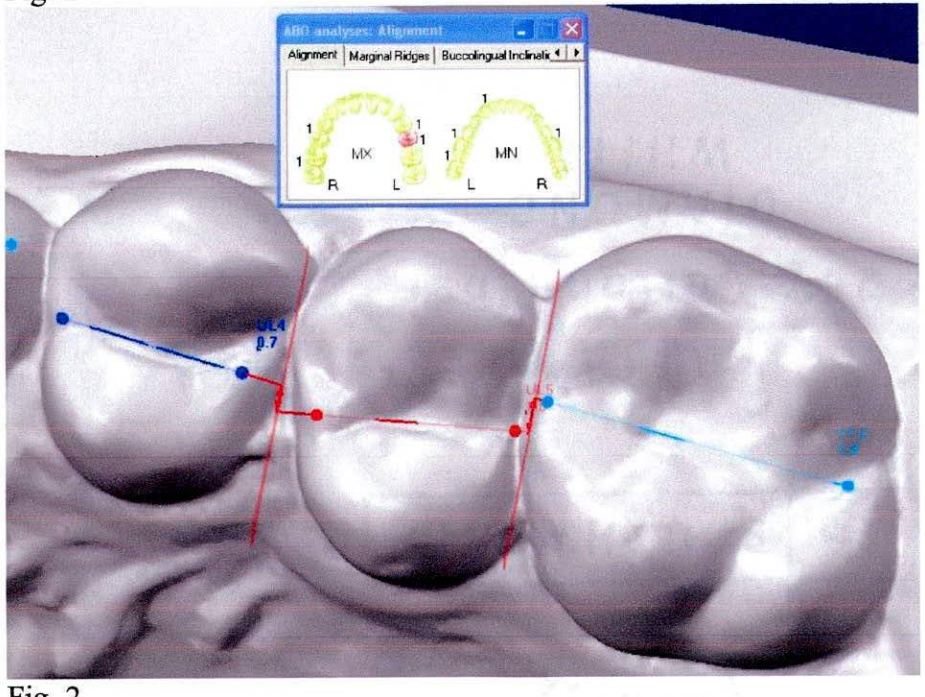

ABO analyses: Alignment
Alignment
Marginal Ridges
Buccolingual Inclinatic
MX
MN
R
L
L
R
UL4
0.7

Fig. 2

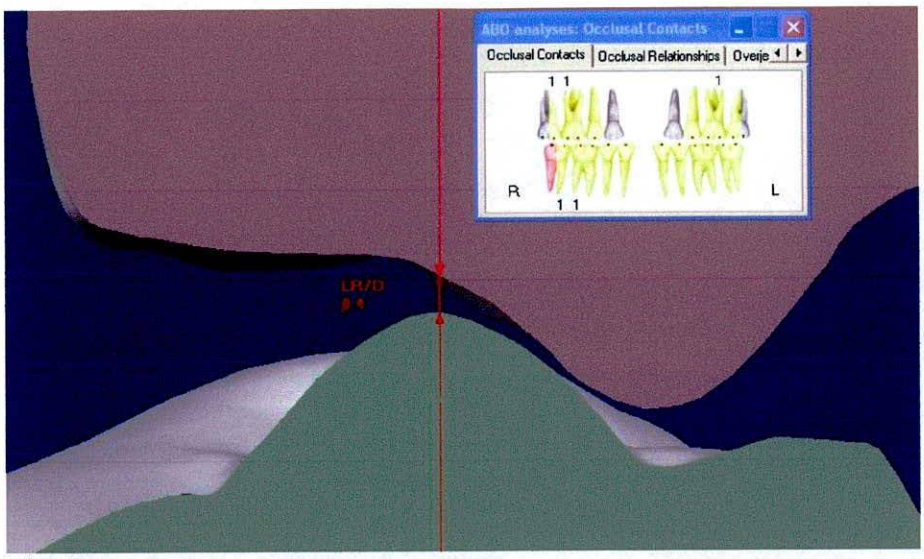

ABO analyses: Occlusal Contacts
Occlusal Contacts
Occlusal Relationships
Overje
R
L
LR/D
β 4

Fig. 3

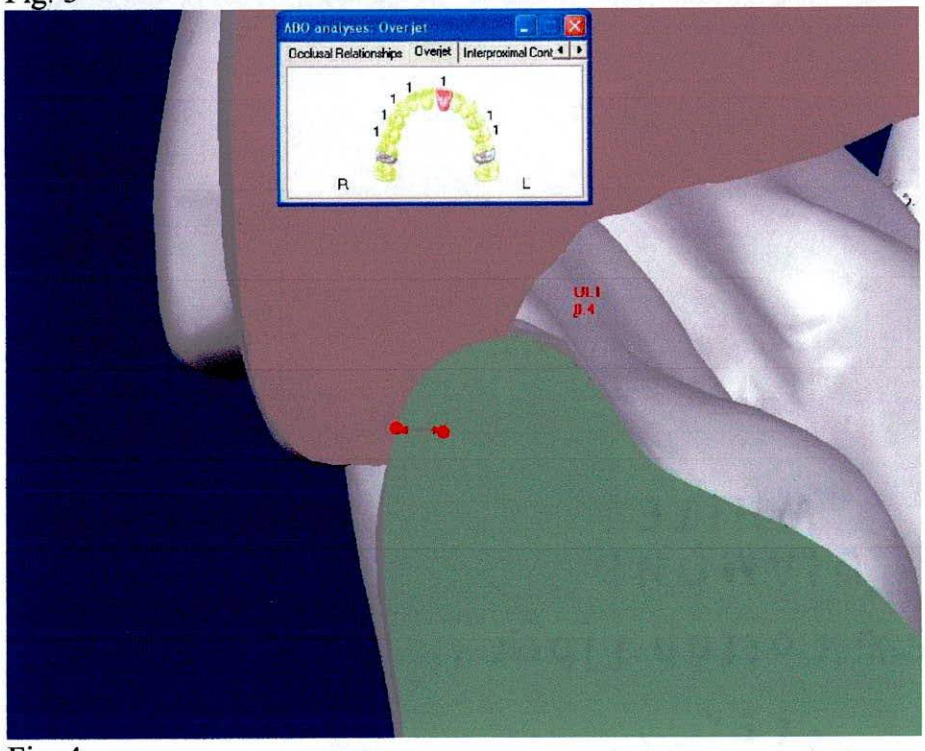

ABO analyses: Overjet
Occlusal Relationships
Overjet
Interproximal Cont
R
L
UL1
β 4

Fig. 4



Fig. 5 A

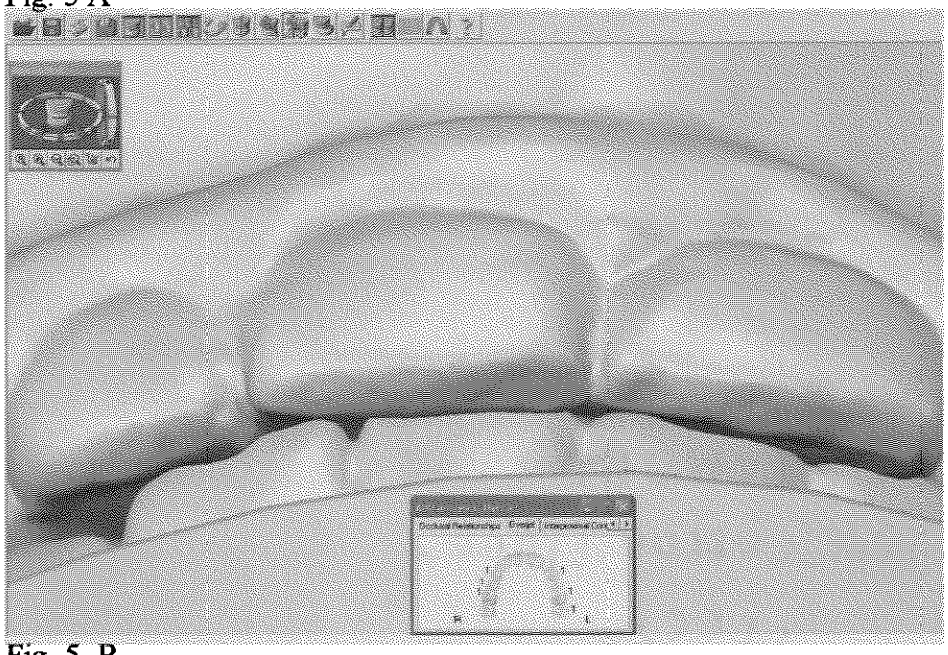


Fig. 5 B

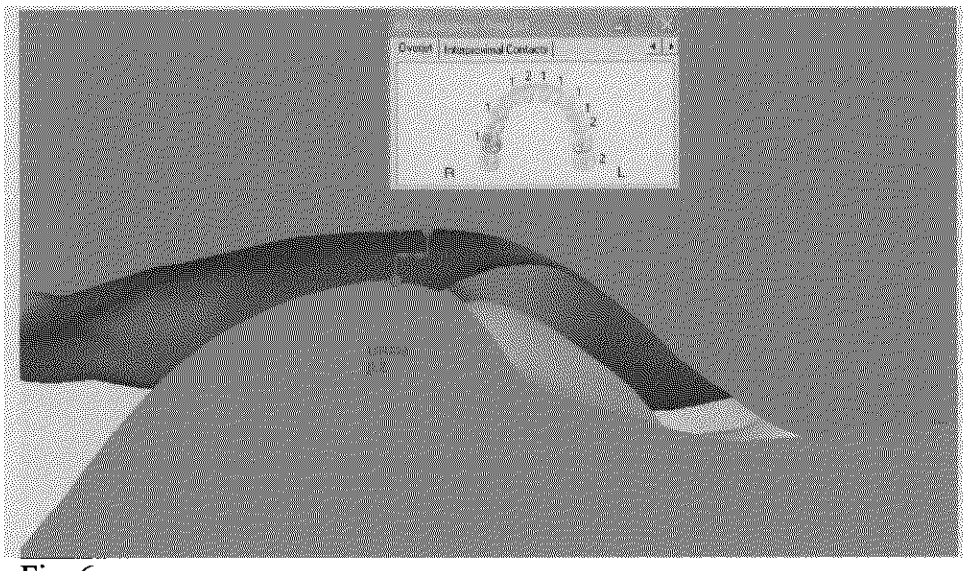


Fig. 6

APPENDIX 1

IRB Approval

Case Western Reserve University
Institutional Review Board
NOTICE OF APPROVAL

Responsible Investigator: **J. Martin Palomo**
Department: **Dental Clinic Ortho**
IRB Protocol #: **20041203**
Title: ***Evaluation of digital and Plaster Models Using the ABO-Scoring Index***
Co-Investigator: **Jed Hilderbrand**

Approval Date: **January 18, 2005**
Continuing Review Deadline: **January 3, 2006**
Expiration Date: **January 17, 2006**

The Institutional Review Board (IRB) has APPROVED the above new protocol through the full review process.

It has been determined that this study involves minimal risk, and that no vulnerable populations will be involved.

As an investigator of human subjects, your responsibilities include the following (see full description of responsibilities at our website):

1. Report all adverse events and unanticipated problems involving human subjects to the IRB Office, located in the Office of Research Compliance (ORC), within three (3) business days of your knowledge of the occurrence.
2. Provide the IRB with a complete Continuing Review form (available at the CWRU IRB Web Pages, or from the ORC) by the continuing review deadline noted above, and when the study is terminated.
3. Discontinue all work pertaining to this protocol if a continuing review approval is not finalized by the expiration date noted above.
4. Submit all proposed changes to the protocol to the IRB, and receive approval from the IRB, before implementation of the change.
5. Keep all research data and original consent documents in your possession for at least three (3) years after the study is terminated.

Questions? Please visit our website: http://ora.ra.cwru.edu/orc_humansubjects_CWRU_IRB.asp
OR
contact our administrative office...
Isabel Sanchez, IRB Administrator
216.368.6993
Maureen Dore-Arshenovitz, IRB Assistant
216.368.6925
Fax: 216.368.3737
CASE Institutional Review Board
Office of Research Compliance
Sears Building 657
Cleveland, OH 44106-7230

APPENDIX 2

The ABO Objective Grading System instruction

MODEL GRADING SYSTEM

INTRODUCTION

The American Board of Orthodontics is constantly striving to make the phase III clinical examination a fair, accurate, and meaningful experience for candidates. In an effort to enhance the reliability of the examiners and provide the candidates with a tool to assess the adequacy of their finished orthodontic results, the Board has established an Objective Grading System to evaluate the final dental casts and panoramic radiographs. This scoring system has been developed systematically through a series of four field tests over a period of five years. The Board has instituted the model and radiographic portions of the Objective Grading System, which will be officially used to grade these portions of the candidates' clinical case reports since 1999. In an effort to assist candidates with the selection of their cases, the Board is making this Objective Grading System available to all candidates. The Board encourages candidates to score their own case reports with this scoring system to determine if they meet Board standards.

BACKGROUND

In 1994, The American Board of Orthodontics began investigating methods of making the phase III examination more objective. Since a major emphasis has always been placed on the final occlusion, the first efforts were directed at developing an objective method of evaluating the dental casts and intraoral radiographs.

In the past, several indices have been used to evaluate the outcome of orthodontic treatment.[1,2,3,4] Generally,

these indices compare pretreatment and posttreatment records to determine the quality of the final result. However, these indices are not precise, and the validity and reliability of these indices has not been established. The Occlusal Index[5] has also been used to determine treatment quality. However, this method is tedious, and the system is more appropriate for scoring pretreatment rather than posttreatment records.

In 1987, the PAR Index[6] (Peer Assessment Rating) was developed to assess an occlusion at any stage of development. Over 200 dental casts representing various pretreatment and posttreatment stages of occlusion were used to establish this index. The PAR Index has good reliability and validity, however this measuring system is not precise enough to discriminate between the minor inadequacies of tooth position that are found in ABO case reports. Therefore, an ABO committee was formed in 1994, to begin field testing precise methods of objectively evaluating posttreatment dental casts and panoramic radiographs.

At the 1995 ABO phase III examination, 100 cases were evaluated. A series of 15 criteria were measured on each of the final dental casts and panoramic radiographs. The data showed that 85% of the inadequacies in the final results occurred in seven of the 15 criteria (alignment, marginal ridges, buccolingual inclination, overjet, occlusal relationships, occlusal contacts, root angulation).

Therefore, at the 1996 phase III examination, a second field-test was initiated to verify the results of the previous test and to determine if multiple examiners could score the records reliably and consistently. In this field test, a subcommittee of four Directors evaluated 300 sets of post-treatment dental casts and panoramic radiographs. Again, the majority of the inadequacies in the final results occurred in the same seven categories, but the committee had difficulty establishing adequate inter-examiner reliability. The subcommittee recommended that a measuring instrument be developed to make the measuring process more reliable.

In 1997, a third field test was performed using the modified scoring system with the addition of an instrument to measure the various criteria more accurately. All of the Directors participated in this field test, and a total of 832 dental casts and panoramic radiographs were measured. The same seven criteria were evaluated. A calibration session preceded the examination to establish more accurate use of the measuring instrument and improve the reliability of the Directors. The results again showed that the overwhelming majority of the inadequacies in the finished results occurred in the aforementioned categories. However, the Directors decided to add interproximal contacts to the scoring system to raise the total number of criteria to eight. In addition, modifications were made in the measuring instrument to improve measuring accuracy among Directors.

In 1998, the fourth and final field test was initiated. Again all Directors participated in the evaluation process. The new and improved measuring instrument was used. An extensive training and calibration session was performed prior to the actual examination. The major objectives of this final field test were to refine the measuring and calibration process, and to gather enough data on general performance to establish the validity or cut-off for passing this portion of the phase III examination. This field test was extremely successful. Not only did it reaffirm the benefits of using an objective system for grading the dental casts and panoramic radiographs, but also it helped to establish standards for successful completion of this portion of the phase III examination.

Based upon the collective and cumulative results of these extensive field tests, the Board decided to officially initiate the use of this Objective Grading System for candidates who were examined at the February 1999, ABO phase III examination in St. Louis. In order to assist the candidate in selecting cases that will successfully pass the examination process, the Board is providing the candidate with the same system used by the Directors. The Board encourages candidates to score their own dental casts and panoramic radiographs during their preparation for the phase III examination in order to select cases

that will successfully pass the ABO Objective Grading System.

CRITERIA AND RATIONALE

The ABO Objective Grading System for scoring dental casts and panoramic radiographs contains eight criteria. These are: alignment, marginal ridges, buccolingual inclination, occlusal relationships, occlusal contacts, overjet, interproximal contacts, and root angulation. The rationale for using these criteria is stated in the following section.

Alignment is usually a fundamental objective of any orthodontic treatment plan. Therefore, it seems reasonable that any assessment of quality of orthodontic result must contain an assessment of tooth alignment. In the anterior region, the incisal edges and lingual surfaces of the maxillary anterior teeth and the incisal edges and labial-incisal surfaces of the mandibular anterior teeth were chosen as the guide to assess anterior alignment. These are not only the functioning areas of these teeth, but they also influence esthetics if they are not arranged in proper relationship. In the maxillary posterior region, the mesiodistal central groove of the premolars and molars is used to assess adequacy of alignment. In the mandibular arch, the buccal cusps of the premolars and molars are used to assess proper alignment. These areas were chosen since they represent easily identifiable points on the teeth, and represent the functioning areas of the posterior teeth. The results of the four field tests show that the most commonly malaligned teeth were the maxillary and mandibular lateral incisors and second molars, which accounted for nearly 80% of the mistakes.

Marginal ridges are used to assess proper vertical positioning of the posterior teeth. In patients with no restorations, minimal attrition, and no periodontal bone loss, the marginal ridges of adjacent teeth should be at the same level. If the marginal ridges are at the same relative height, the cementoenamel junctions will be at the same level. In a periodontally healthy individual, this will result in flat bone level between adjacent

teeth. In addition, if marginal ridges are at the same height, it will be easier to establish proper occlusal contacts, since some marginal ridges provide contact areas for opposing cusps. Based upon the four field tests, the most common mistakes in marginal ridge alignment occurred between the maxillary first and second molars. The second most common problem area was between the mandibular first and second molars.

Buccolingual inclination is used to assess the buccolingual angulation of the posterior teeth. In order to establish proper occlusion in maximum intercuspation and avoid balancing interferences, there should not be a significant difference between the heights of the buccal and lingual cusps of the maxillary and mandibular molars and premolars. The Directors use a special step gauge to assess this relationship. Some latitude is allowed, however in past field tests significant problems were observed in the buccolingual inclination of the maxillary and mandibular second molars.

CRITERIA AND RATIONALE

Occlusal relationship is used to assess the relative anteroposterior position of the maxillary and mandibular posterior teeth. In order to achieve accuracy and reliability in measuring this relationship, results of previous field tests have shown that the most verifiable method of scoring this criterion is to use Angle's relationship. Therefore, the buccal cusps of the maxillary molars, premolars, and canines must align within 1 mm of the interproximal embrasures of the mandibular posterior teeth. The mesiobuccal cusp of the maxillary first molar must align within 1 mm of the buccal groove of the mandibular first molar.

Occlusal contacts are measured to assess the adequacy of the posterior occlusion. Again, a major objective of orthodontic treatment is to establish maximum intercuspation of opposing teeth. Therefore, the functioning cusps are used to assess the adequacy of this criterion; i.e., the buccal cusps of the mandibular molars and premolars, and the lingual cusps of the maxillary molars and premolars. If cusp form is small or

diminutive, that cusp is not scored. In past field tests, the most common problem area has been inadequate contact between maxillary and mandibular second molars.

Overjet is used to assess the relative transverse relationship of the posterior teeth, and the anteroposterior relationship of the anterior teeth. In the posterior region, the mandibular buccal cusps and maxillary lingual cusps are used to determine proper position within the fossae of the opposing arch. In the anterior region, the mandibular incisal edges should be in contact with the lingual surfaces of the maxillary anterior teeth. In past field tests, the common mistakes in overjet have occurred between the maxillary and mandibular incisors and second molars.

Interproximal contacts are used to determine if all spaces within the dental arch have been closed. Persistent spaces between teeth after orthodontic therapy are not only unesthetic, but can lead to food impaction. In past field tests, spacing is generally not a major problem with ABO cases.

Root angulation is used to assess how well the roots of the teeth have been positioned relative to one another. Although the panoramic radiograph is not the perfect record for evaluating root angulation, it is probably the best means possible for making this assessment. If roots are properly angulated, then sufficient bone will be present between adjacent roots, which could be important if the patient were susceptible to periodontal bone loss at some point in time. If roots are dilacerated, then they are not graded. In past field tests, the common mistakes in root angulation occurred in the maxillary lateral incisors, canines, second premolars, and mandibular first premolars.

GUIDE FOR GRADING CLINICAL CASE REPORTS MODEL ANALYSIS

ALIGNMENT

In the maxillary and mandibular anterior regions, proper alignment is characterized by coordination of alignment of the incisal edges and lingual incisal surfaces of the

maxillary incisors and canines (Fig. 1), and the incisal edges and labial incisal surfaces of the mandibular incisors and canines (Fig. 2).

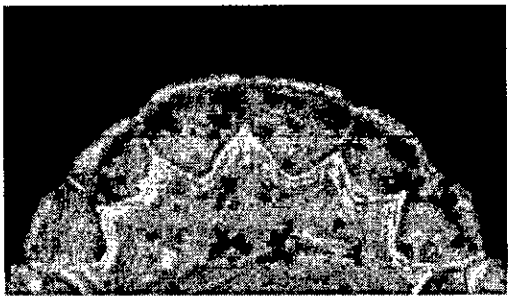


Figure 1

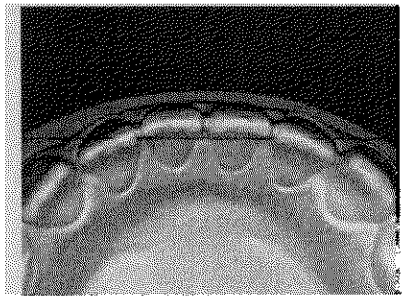


Figure 2

In the mandibular posterior quadrants, the mesiobuccal and distobuccal cusps of the molars and premolars should be in the same mesiodistal alignment. In the maxillary arch, the central grooves (mesio-distal) should all be in the same plane or alignment (Fig. 3). If all teeth are in alignment, or within 0.50 mm of proper alignment, no points are subtracted from the candidate's score.



Figure 3

If the mesial or distal alignment at any of the contact points is 0.50 mm to 1 mm deviated from proper alignment (Fig. 4a,b), 1 point shall be subtracted for the tooth that is out of alignment. If adjacent teeth are out of alignment, then 1 point should be subtracted for each tooth.



Figure 4a

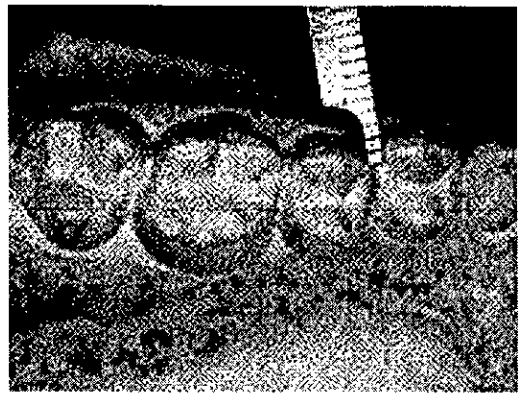


Figure 4b

If the discrepancy in alignment of a tooth at the contact point is greater than 1 mm, then 2 points shall be subtracted for that tooth (Fig. 5a,b). No more than 2 points shall be subtracted for any tooth.



Figure 5a



Figure 5b

MARGINAL RIDGES

In both maxillary and mandibular arches, marginal ridges of adjacent posterior teeth shall be at the same level, or within 0.50 mm of the same level (Fig. 6).

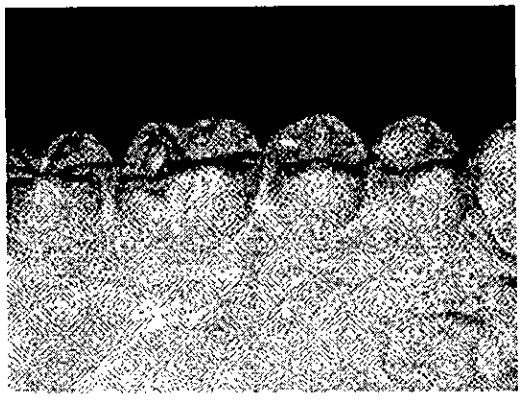


Figure 6

If adjacent marginal ridges deviate from 0.50 to 1 mm (Fig. 7), then 1 point shall be subtracted for that interproximal contact. If the marginal ridge discrepancy is greater than 1 mm (Fig. 8), then 2 points shall be subtracted for that interproximal contact. No more than 2 points will be subtracted for any contact point. The marginal ridge will be considered as the most occlusal point that is within 1 mm of the contact at the occlusal surface of adjacent teeth.



Figure 7



Figure 8

BUCCOLINGUAL INCLINATION

The buccolingual inclination of the maxillary and mandibular posterior teeth shall be assessed by using a flat surface that is extended between the occlusal surfaces of the right and left posterior teeth. When positioned in this manner, the straight edge should contact the buccal cusps of contralateral mandibular molars. The lingual cusps should be within 1 mm of the surface of the straight edge (Fig. 9). In the maxillary arch, the straight edge should contact the lingual cusps of the maxillary molars and premolars. The buccal cusps should be within 1 mm of the surface of the straight edge (Fig. 10).

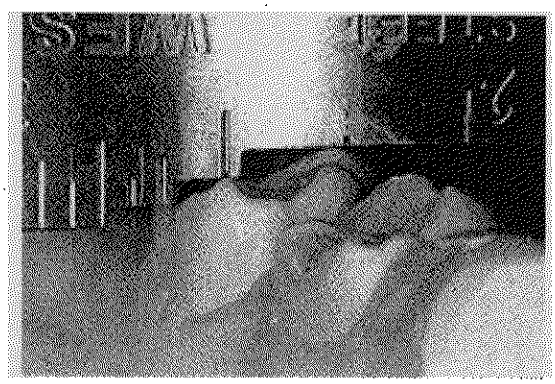


Figure 9



Figure 10

If the mandibular lingual cusps or maxillary buccal cusps are more than 1 mm, but less than 2 mm from the straight edge surface (Fig. 11a,b), 1 point shall be subtracted for that tooth.



Figure 11a



Figure 11b

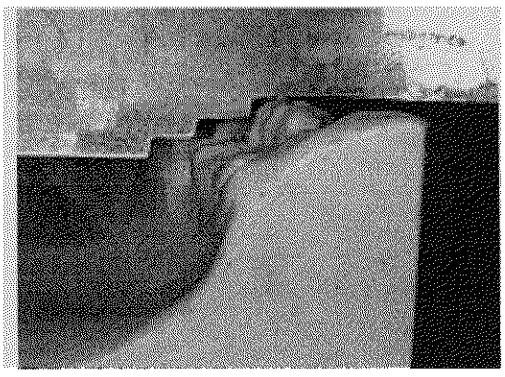


Figure 12A



Figure 12B

If the discrepancy is greater than 2 mm (Fig. 12a,b), then 2 points are subtracted for that tooth. No more than 2 points shall be subtracted for any tooth.

OCCLUSAL CONTACTS

This section of the evaluation determines the adequacy of occlusal contact of the premolars and molars. The buccal cusps of the mandibular premolars and molars (Fig. 13) and the lingual cusps of the maxillary premolars and molars (Fig. 14) should be contacting the occlusal surfaces of the opposing teeth. Each mandibular premolar has one functional cusp. Each mandibular molar has two functional buccal cusps. The maxillary premolars have one functional lingual cusp. However, the maxillary molars may have only a mesiolingual functional cusp.

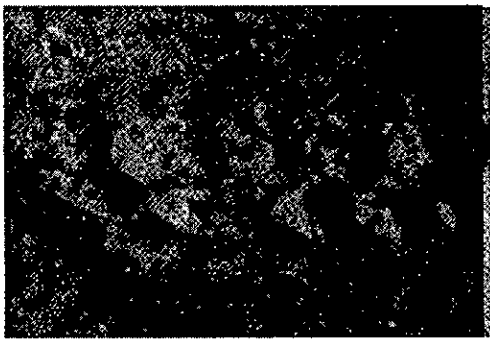


Figure 13

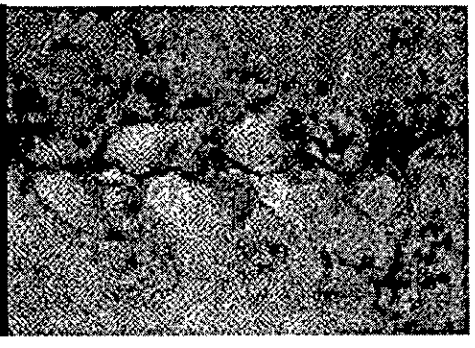


Figure 14

If the distolingual cusp is short or diminutive (Fig. 15), it should not be considered in the evaluation. If this cusp is prominent, but does not contact with the opposing arch, then points may be deducted. If the cusps are in contact with the opposing arch, no points are deducted.



Figure 15

If a cusp is out of contact with the opposing arch, and the distance is 1 mm or less (Fig. 16), then 1 point is subtracted for that cusp. If the cusp is out of contact and the distance is greater than 1 mm (Fig. 17), then 2 points are subtracted for that cusp. No more than 2 points are subtracted for each cusp.



Figure 16



Figure 17

OCCLUSAL RELATIONSHIP

This section of the evaluation determines whether the occlusion has been finished in an Angle Class I relationship. Ideally, the maxillary canine cusp tip should align with (or within 1 mm of) the embrasure or

contact between the mandibular canine and adjacent premolar (Fig. 18). The buccal cusps of the maxillary premolars should align with (or be within 1 mm of) the embrasures or contacts between the mandibular premolars and first molar (Fig. 18). The mesiobuccal cusps of the maxillary molars should align with (or be within 1 mm of) the buccal grooves of the mandibular molars (Fig. 18).



Figure 18

If the maxillary buccal cusps deviate between 1 and 2 mm from the aforementioned positions (Fig. 19), then 1 point shall be subtracted for that maxillary tooth. If the buccal cusps of the maxillary premolars or molars deviate by more than 2 mm from ideal position (Fig. 20), then 2 points shall be subtracted for each maxillary tooth that deviates. No more than 2 points shall be subtracted for each maxillary tooth. In some situations, the posterior occlusion may be finished in either an Angle Class II or Class III relationship, depending upon the type of tooth extraction in the maxillary or mandibular arches.



Figure 19

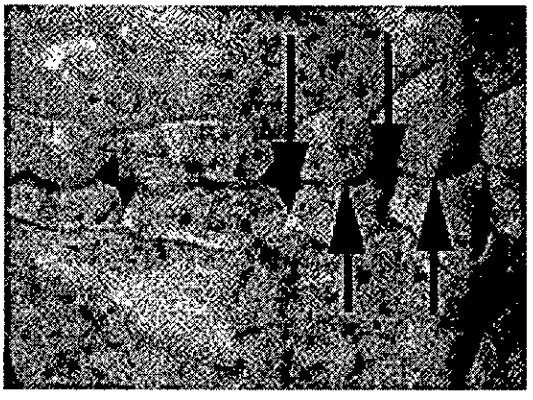


Figure 20

In a Class II situation (Fig. 21), the buccal cusp of the maxillary first molar should align with the embrasure or interproximal contact between the mandibular second premolar and first molar. The buccal cusp of the maxillary second molar should align with the embrasure or interproximal contact between the mandibular first and second molars. If the final occlusion is finished in a Class III relationship (when mandibular premolars are extracted), the buccal cusp of the maxillary second premolar should align with the buccal groove of the mandibular first molar (Fig. 22). The remaining occlusion distal to the maxillary second premolar and mandibular first molar are adjusted accordingly.

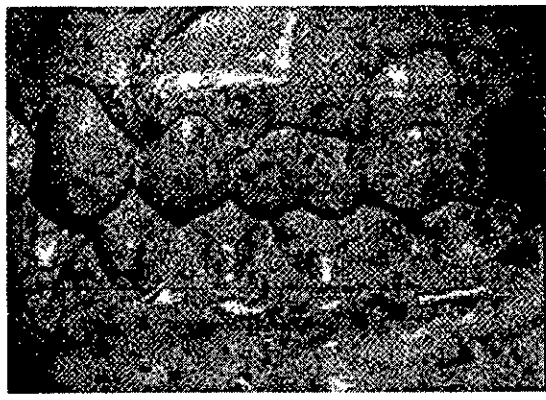


Figure 21

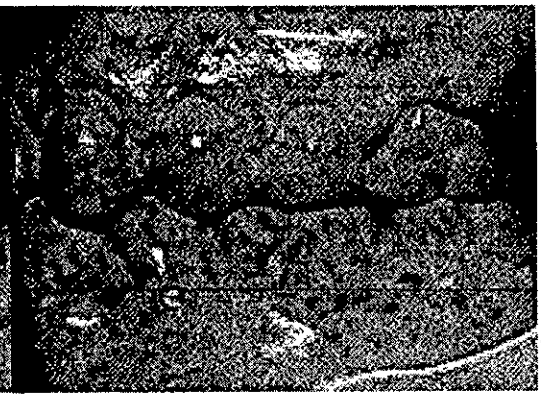


Figure 22

OVERJET

The overjet is evaluated by articulating the models and viewing the labiolingual relationship of the maxillary arch relative to the mandibular arch. In order to determine the proper relationship of the casts, the examiner must rely on the trimming of the backs of the bases of the models. The models are set flat on their backs, in order to determine this assessment (Fig. 23).

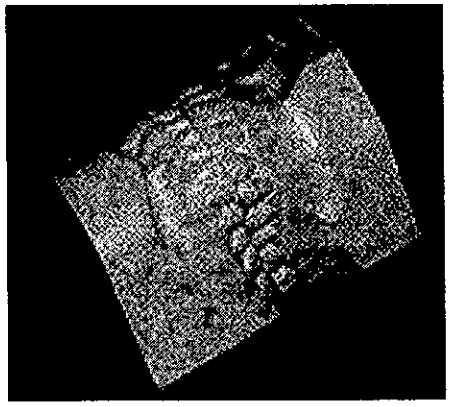


Figure 23

If the models are mounted on an articulator, then the articulated mounting shall determine the proper maxillary and mandibular model relationship. If the proper overjet

has been established, then the buccal cusps of the mandibular molars and premolars will contact in the center of the occlusal surfaces, buccolingually, of the maxillary premolars and molars (Fig. 24). In the anterior region, the mandibular canines and incisors will contact the lingual surfaces of the maxillary canines and incisors (Fig. 25). If this relationship exists, no points are subtracted.

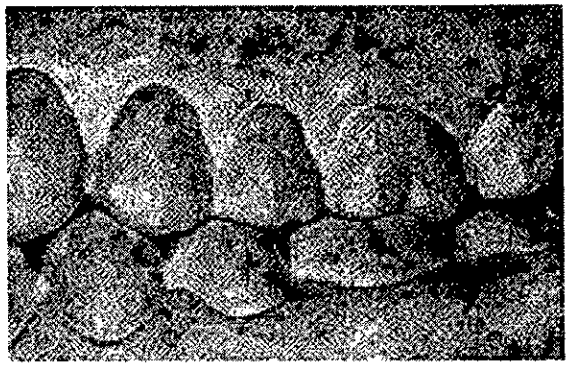


Figure 24

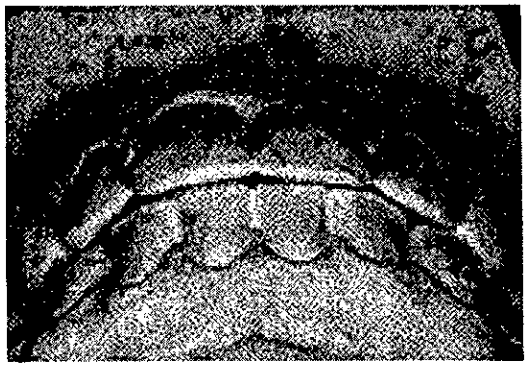


Figure 25

If the mandibular buccal cusps deviate 1 mm or less from the center of the opposing tooth (Fig. 26), 1 point is subtracted for that tooth, If the position of the mandibular buccal cusps deviates more than 1 mm from the center of the opposing tooth (Fig. 27), two points are

subtracted for that tooth. No more than 2 points are subtracted for any tooth.

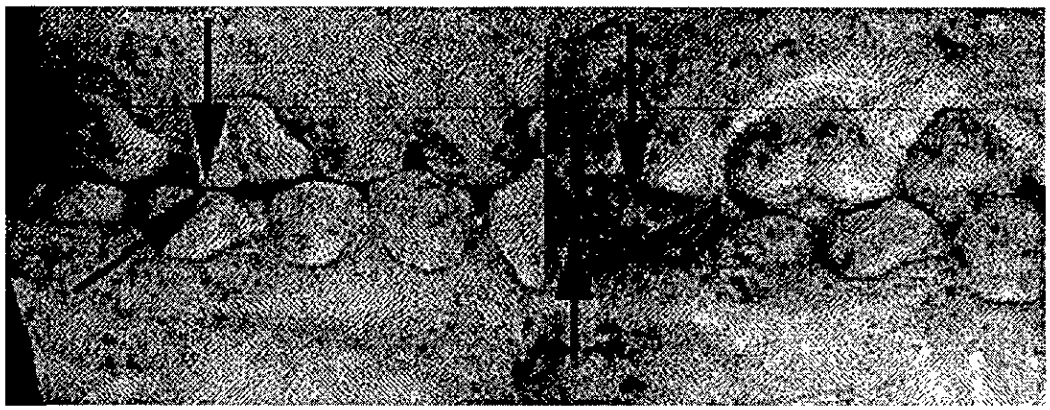


Figure 26

Figure 27

In the anterior region, if the mandibular canines or incisors are not contacting lingual surfaces of the maxillary canines and incisors, and the distance is 1 mm or less (Fig. 28), then 1 point is subtracted for each maxillary tooth. If the discrepancy is greater than 1 mm (Fig. 29), then 2 points are subtracted for each maxillary tooth.

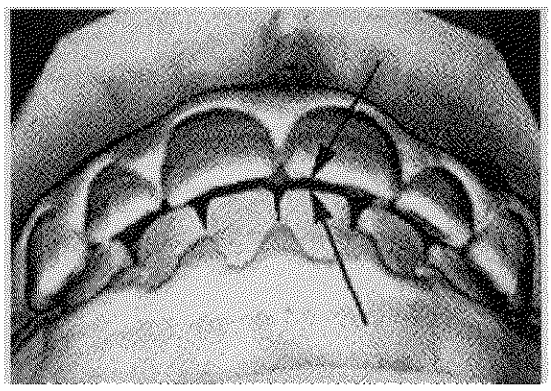


Figure 28



Figure 29

INTERPROXIMAL CONTACTS

This assessment is made by viewing the maxillary and mandibular dental casts from an occlusal perspective. The mesial and distal surfaces of the teeth should be in contact with one another (Fig. 30). If 0.50 mm or less interproximal space exist, then no points are subtracted.

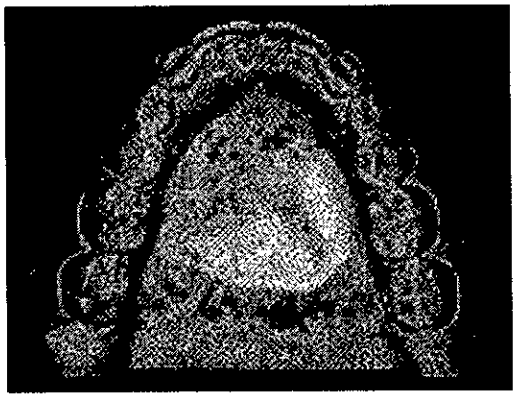


Figure 30

If greater than 0.50 to 1 mm of interproximal space exists between two adjacent teeth (Fig. 31), then 1 point is subtracted for that interproximal contact. If more

than 1 mm of space is present between two teeth (Fig. 32), then 2 points are subtracted for that interproximal contact. No more than 2 points are subtracted for any contact that deviates from ideal.



Figure 31

Figure 32

RADIOGRAPHIC ANALYSIS

ROOT ANGULATION

The relative angulation of the roots of the maxillary and mandibular teeth is assessed on the panoramic radiograph. Although this is not ideal, it gives a reasonably good assessment of root position. Generally, the roots of the maxillary and mandibular teeth should be parallel to one another and oriented perpendicular to the occlusal plane (Fig. 33). If this situation exists, or if a deviation of the apex is 1 mm or less, then no points are subtracted.



Figure 33

If a root is angled to the mesial or distal on the panoramic radiograph, and if the discrepancy is mild, with the apex of the affected tooth greater than 1 mm, but not touching the adjacent tooth root (Fig. 34), then 1 point is subtracted for that tooth. If the root is angled to the mesial or distal and is contacting the adjacent tooth root (Fig. 35), then 2 points are subtracted for that tooth.

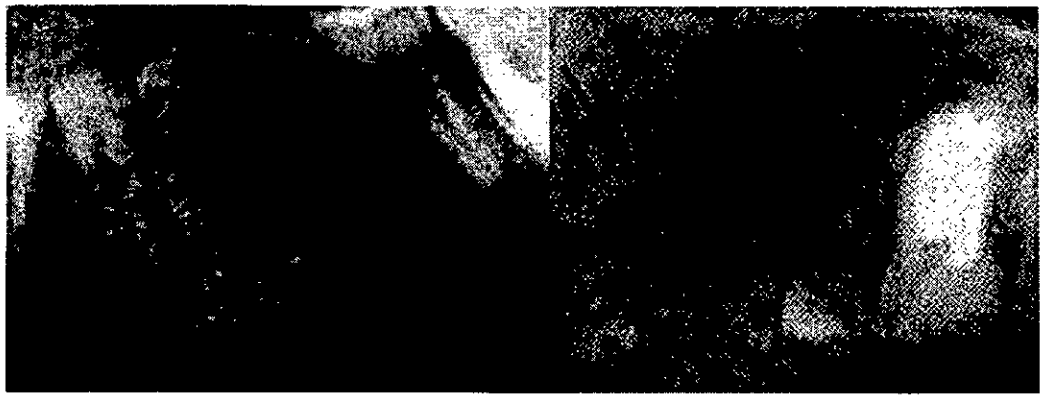


Figure 34

Figure 35

PASSING SCORE

During the 1997 and 1998 field tests, both subjective and objective methods of scoring the dental casts and panoramic radiographs were used by the Directors. Based upon a comparison of these two methods, a passing score was established. In general, a case report that loses more than 30 points will fail. A case report that loses less than 20 points will generally pass that portion of the phase III examination. However, this Figure only represents a part of the overall score for each case report. The quality of the records, appropriateness of the treatment plan, and objectives for positioning of the maxilla, mandible, maxillary dentition, mandibular dentition, and facial profile are also carefully scrutinized. The Board is presently field testing objective methods for grading these other aspects of the phase III examination.

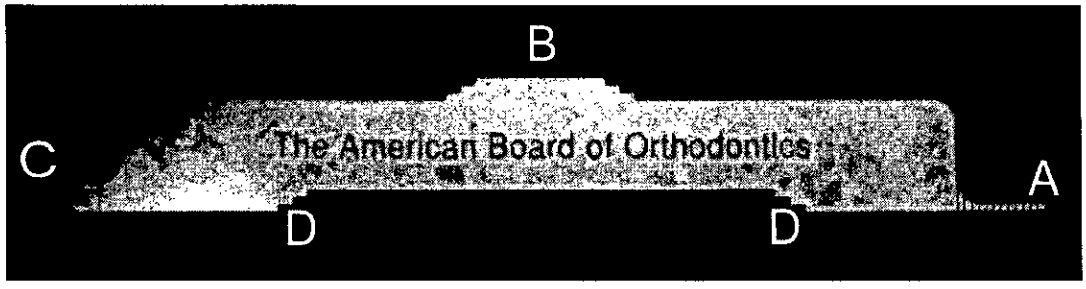
SUMMARY

The Directors of The American Board of Orthodontics have spent countless hours developing this system for assessing the occlusal and radiographic results of orthodontic treatment. The usefulness of this system depends not only on its objectivity, but more importantly on the validity and reliability of the measurements. After repeated comparison of both objective and subjective systems, the Directors are confident that the "cut-off" score to pass this portion of the phase III examination is valid. Reliability will be insured through the use of a precise measuring instrument, in addition to training and calibration of the Directors before each examination. In order to be fair to all candidates, a confidence interval is established to account for interrater variability.

Although the underlying purpose of establishing this grading system is to insure reliable, objective evaluation of orthodontic records, the Board sees a much greater benefit to publishing this grading system. In the future, candidates may grade their own results before the phase III examination. Candidates will know if their results will pass the CCROE portion of the phase III

examination. Furthermore, Diplomates may use this scoring system at anytime in their clinical career to determine if they are producing "Board quality" results. The Board hopes that this method of self-evaluation will help to elevate the quality of orthodontic care in the future.

THE AMERICAN BOARD OF ORTHODONTICS MEASURING GAUGE



A This portion of the gauge is 1 mm in width and is used to measure discrepancies in alignment, overjet, occlusal contact, interproximal contact, and occlusal relationships.

B This portion of the gauge has steps measuring 1 mm in height and is used to determine discrepancies in mandibular posterior buccolingual inclination.

C This portion of the gauge has steps measuring 1 mm in height and is used to determine discrepancies in marginal ridges.

D This portion of the gauge has steps measuring 1 mm in height and is used to determine discrepancies in maxillary posterior buccolingual inclination.

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THE AMERICAN BOARD OF ORTHODONTICS
Grading System for Dental Casts

ALIGNMENT

0.5 - 1 mm	= -1	for each tooth
> 1 mm	= -2	for each tooth

MARGINAL RIDGES*

0.5 - 1 mm	= -1	for each posterior tooth interproximal contact
> 1 mm	= -2	for each posterior tooth interproximal contact

* Do not include the canine premolar contact.
Do not include the distal of lower 1st premolar.

BUCCOLINGUAL INCLINATION**

0 - 1 mm	=	satisfactory
1 - 2 mm	= -1	for each posterior tooth
> 2 mm	= -2	for each posterior tooth

** Do not score the mandibular 1st premolars.

Upper 2nd molars can deviate up to 2 mm with no points deducted in transverse discrepancy cases. Then:

2 - 3 mm = -1

> 3 mm = -2

OVERJET

0 - 1 mm = -1 for each maxillary tooth

> 1 mm = -2 for each maxillary tooth

OCCLUSAL CONTACTS***

Contact = 0

0 - 1 mm = -1 for each posterior tooth cusp

> 1 mm = -2 for each posterior tooth cusp

*** Do not score the distolingual cusps of the maxillary 1st and 2nd molars if they are small.

Do not score the lingual cusp of maxillary 1st premolars.

OCCLUSAL RELATIONSHIPS

0 - 1 mm = satisfactory

1 - 2 mm = -1 for each maxillary tooth from the canines to the 2nd molars inclusive

> 2 mm = -2 for each posterior tooth from the canines to the 2nd molars inclusive

INTERPROXIMAL CONTACTS

0.5 - 1 mm = -1 for each interproximal contact

> 1 mm = -2 for each interproximal contact

ROOT ANGULATION

Parallel	= 0	
Not Parallel	= -1	for each tooth
Root contacting adjacent root	= -2	for each posterior tooth

NOTE:

Gauge width = 0.5 mm

Gauge height = 1 mm

NOTE: Third molars are scored if they have erupted. If they are partially erupted or scheduled for extraction, they are not scored.

APPENDIX 7

Raw Data (Excel)

Plaster Models

Cast Number	Alignment plaster	Marginal Ridges plaster	Buccolingual Inclination plaster	Occlusal Contacts plaster	Occlusal Relationship plaster	Overjet plaster	Interproximal Contacts plaster	ABO Score plaster
101	4	2	7	8	8	7	0	36
102	8	5	12	10	1	9	0	45
103	1	8	4	6	4	4	0	27
104	3	3	10	4	4	5	0	29
105	3	4	12	7	4	7	0	37
106	2	5	12	8	2	5	0	34
107	1	7	6	8	2	0	0	24
108	8	12	14	8	2	7	0	51
109	6	2	10	4	2	2	0	26
110	2	8	9	7	2	7	0	35
111	6	5	10	10	4	10	1	46
112	7	2	5	7	10	8	0	39
126	11	4	13	5	2	6	0	41
127	1	1	6	5	1	6	0	20
128	10	3	10	6	2	3	0	34
129	4	2	8	0	1	2	0	17
130	2	2	3	2	0	6	0	15
131	4	7	8	6	2	5	0	32
132	1	5	10	4	6	6	0	32
133	0	4	6	4	1	5	0	20
134	4	4	11	8	1	2	2	32
135	6	2	14	18	1	7	0	48
136	3	9	8	10	1	6	0	37
201	5	1	9	3	4	6	0	28
202	3	2	7	10	2	9	2	35
203	1	2	10	6	1	4	0	24
204	2	1	7	0	1	2	0	13
205	3	4	14	5	0	4	0	30
206	1	3	9	16	3	4	0	36
207	1	5	7	6	0	4	3	26
208	3	6	9	5	3	3	0	29
209	3	3	14	2	0	2	0	24
210	4	2	14	11	1	4	0	36
211	0	7	8	5	0	9	2	31
212	4	4	6	3	0	4	0	21
213	4	3	13	7	4	3	0	34

Digital Models

Cast Number	Alignment orthocad	Marginal Ridges orthocad	Buccolingual Inclination orthocad	Occlusal Contacts orthocad	Occlusal Relationship orthocad	Overjet orthocad	Interproximal Contacts orthocad	ABO Score orthocad
101	4	2	6	9	8	8	0	37
102	8	5	12	12	1	13	0	51
103	2	7	4	6	4	5	0	28
104	3	2	11	5	4	13	0	38
105	2	4	11	7	4	10	0	38
106	3	5	12	13	4	9	0	46
107	1	7	6	9	2	5	0	30
108	9	10	14	6	2	10	0	51
109	7	2	10	7	2	7	0	35
110	2	8	10	9	2	12	0	43
111	8	4	9	9	4	13	0	47
112	7	2	5	12	10	13	0	49
126	11	4	13	5	2	6	0	41
127	1	1	6	6	1	9	0	24
128	11	1	10	5	2	8	0	37
129	4	2	8	0	1	12	0	27
130	2	2	3	3	0	6	0	16
131	5	7	8	14	2	14	0	50
132	3	5	10	6	6	8	0	38
133	0	4	6	4	1	6	0	21
134	4	3	11	8	1	6	2	35
135	6	3	14	19	0	9	0	51
136	3	9	9	10	1	8	0	40
201	5	1	9	4	4	6	0	29
202	6	2	7	7	2	13	2	39
203	1	2	10	5	1	6	0	25
204	3	1	8	12	1	7	0	32
205	3	4	14	5	0	8	0	34
206	1	4	9	14	3	13	0	44
207	1	5	7	6	0	12	3	34
208	5	6	9	4	3	7	0	34
209	5	3	14	2	0	6	0	30
210	4	2	14	12	1	9	0	42
211	1	7	7	9	0	13	2	39
212	5	4	8	7	1	12	0	37
213	5	3	13	5	4	4	0	34

Alignment

Cast Number	Plaster	Digital	Deviance
101	4	4	0
102	8	8	0
103	1	2	1
104	3	3	0
105	3	2	1
106	2	3	1
107	1	1	0
108	8	9	1
109	6	7	1
110	2	2	0
111	6	8	2
112	7	7	0
126	11	11	0
127	1	1	0
128	10	11	1
129	4	4	0
130	2	2	0
131	4	5	1
132	1	3	2
133	0	0	0
134	4	4	0
135	6	6	0
136	3	3	0
201	5	5	0
202	3	6	3
203	1	1	0
204	2	3	1
205	3	3	0
206	1	1	0
207	1	1	0
208	3	5	2
209	3	5	2
210	4	4	0
211	0	1	1
212	4	5	1
213	4	5	1
Totals	131	151	22
Average	3.638889	4.1944444	0.61
SD	2.684908	2.8164765	0.80
Median	3	4	0.00

Marginal Ridges

Cast Number	Plaster	Digital	Deviance
101	2	2	0
102	5	5	0
103	8	7	1
104	3	2	1
105	4	4	0
106	5	5	0
107	7	7	0
108	12	10	2
109	2	2	0
110	8	8	0
111	5	4	1
112	2	2	0
126	4	4	0
127	1	1	0
128	3	1	2
129	2	2	0
130	2	2	0
131	7	7	0
132	5	5	0
133	4	4	0
134	4	3	1
135	2	3	1
136	9	9	0
201	1	1	0
202	2	2	0
203	2	2	0
204	1	1	0
205	4	4	0
206	3	4	1
207	5	5	0
208	6	6	0
209	3	3	0
210	2	2	0
211	7	7	0
212	4	4	0
213	3	3	0
Totals	149	143	10
Average	4.138889	3.9722222	0.28
SD	2.531547	2.3722938	0.57
Median	4	4	0.00

Buccal Inclination

Cast Number	Plaster	Digital	Deviance
101	7	6	1
102	12	12	0
103	4	4	0
104	10	11	1
105	12	11	1
106	12	12	0
107	6	6	0
108	14	14	0
109	10	10	0
110	9	10	1
111	10	9	1
112	5	5	0
126	13	13	0
127	6	6	0
128	10	10	0
129	8	8	0
130	3	3	0
131	8	8	0
132	10	10	0
133	6	6	0
134	11	11	0
135	14	14	0
136	8	9	1
201	9	9	0
202	7	7	0
203	10	10	0
204	7	8	1
205	14	14	0
206	9	9	0
207	7	7	0
208	9	9	0
209	14	14	0
210	14	14	0
211	8	7	1
212	6	8	2
213	13	13	0
Totals	335	337	10
Average	9.305556	9.3611111	0.28
SD	3.040859	3.0062105	0.51
Median	9	9	0.00

Occlusal Contacts

Cast Number	Plaster	Digital	Deviance
101	8	9	1
102	10	12	2
103	6	6	0
104	4	5	1
105	7	7	0
106	8	13	5
107	8	9	1
108	8	6	2
109	4	7	3
110	7	9	2
111	10	9	1
112	7	12	5
126	5	5	0
127	5	6	1
128	6	5	1
129	0	0	0
130	2	3	1
131	6	14	8
132	4	6	2
133	4	4	0
134	8	8	0
135	18	19	1
136	10	10	0
201	3	4	1
202	10	7	3
203	6	5	1
204	0	12	12
205	5	5	0
206	16	14	2
207	6	6	0
208	5	4	1
209	2	2	0
210	11	12	1
211	5	9	4
212	3	7	4
213	7	5	2
Totals	234	276	68
Average	6.5	7.6666667	1.89
SD	3.745473	3.9206413	2.48
Median	6	7	1.00
T-test	0.021288		

Occlusal Relationship

Cast Number	Plaster	Digital	Deviance
101	8	8	0
102	1	1	0
103	4	4	0
104	4	4	0
105	4	4	0
106	2	4	2
107	2	2	0
108	2	2	0
109	2	2	0
110	2	2	0
111	4	4	0
112	10	10	0
126	2	2	0
127	1	1	0
128	2	2	0
129	1	1	0
130	0	0	0
131	2	2	0
132	6	6	0
133	1	1	0
134	1	1	0
135	1	0	1
136	1	1	0
201	4	4	0
202	2	2	0
203	1	1	0
204	1	1	0
205	0	0	0
206	3	3	0
207	0	0	0
208	3	3	0
209	0	0	0
210	1	1	0
211	0	0	0
212	0	1	1
213	4	4	0
Totals	82	84	4
Average	2.277778	2.3333333	0.11
SD	2.224681	2.2424476	0.40
Median	2	2	0.00

Overjet

Cast Number	Plaster	Digital	Deviance
101	7	8	1
102	9	12	3
103	4	5	1
104	5	13	8
105	7	10	3
106	5	9	4
107	0	5	5
108	7	10	3
109	2	7	5
110	7	12	5
111	10	13	3
112	8	13	5
126	6	6	0
127	6	9	3
128	3	8	5
129	2	12	10
130	6	6	0
131	5	14	9
132	6	8	2
133	5	6	1
134	2	6	4
135	7	9	2
136	6	8	2
201	6	6	0
202	9	13	4
203	4	6	2
204	2	7	5
205	4	8	4
206	4	13	9
207	4	12	8
208	3	7	4
209	2	6	4
210	4	9	5
211	9	13	4
212	4	12	8
213	3	4	1
Totals	183	325	142
Average	5.083333	9.0277778	3.94
SD	2.370955	2.9518625	2.65
Median	5	8.5	4.00

Interproximal Contacts

Cast Number	Plaster	Digital	Deviance
101	0	0	0
102	0	0	0
103	0	0	0
104	0	0	0
105	0	0	0
106	0	0	0
107	0	0	0
108	0	0	0
109	0	0	0
110	0	0	0
111	1	0	1
112	0	0	0
126	0	0	0
127	0	0	0
128	0	0	0
129	0	0	0
130	0	0	0
131	0	0	0
132	0	0	0
133	0	0	0
134	2	2	0
135	0	0	0
136	0	0	0
201	0	0	0
202	2	2	0
203	0	0	0
204	0	0	0
205	0	0	0
206	0	0	0
207	3	3	0
208	0	0	0
209	0	0	0
210	0	0	0
211	2	2	0
212	0	0	0
213	0	0	0
Totals	10	9	1
Average	0.277778	0.25	0.03
SD	0.741085	0.7319251	0.17
Median	0	0	0.00

ABO Score

Cast Number	Plaster	Digital	Deviance
101	36	37	1
102	45	50	5
103	27	28	1
104	29	38	9
105	37	38	1
106	34	46	12
107	24	30	6
108	52	51	1
109	24	35	11
110	28	43	15
111	36	47	11
112	31	49	18
126	41	41	0
127	13	24	11
128	31	37	6
129	15	27	12
130	9	16	7
131	32	50	18
132	26	38	12
133	15	21	6
134	32	35	3
135	46	51	5
136	31	40	9
201	22	29	7
202	26	39	13
203	20	25	5
204	11	32	21
205	26	34	8
206	32	44	12
207	22	34	12
208	25	34	9
209	22	30	8
210	32	42	10
211	22	39	17
212	18	37	19
213	31	34	3
Totals	1003	1325	324
Average	27.86111	36.805556	9.00
SD	9.678113	8.6547079	5.54
Median	27.5	37	9.00

Anatomic Measurements: Plaster Casts

	time 1	time 1	time 1	time 1	time 1	time 1	time 1	time 1
Cast Number	**Alignment**	**Marginal Ridges**	**Buccolingual Inclination**	**Occlusal Contacts**	**Occlusal Relationship**	**Overjet**	**Interproximal Contacts**	**ABO Score**
102	8	5	12	10	1	9	0	45
103	1	8	4	6	4	4	0	27
105	3	4	12	7	4	7	0	37
108	8	12	14	8	2	7	0	51
110	2	8	9	7	2	7	0	35
111	6	5	10	10	4	10	1	46
112	7	2	5	7	10	8	0	39
136	3	9	8	10	1	6	0	37
205	3	4	14	5	0	4	0	30
212	4	4	6	3	0	4	0	21
Totals	45	61	94	73	28	66	1	368

Anatomical Measurments: Plaster Casts

	time 2	time 2	time 2	time 2	time 2	time 2	time 2	time 2
Cast Number	**Alignment**	**Marginal Ridges**	**Buccolingual Inclination**	**Occlusal Contacts**	**Occlusal Relationship**	**Overjet**	**Interproximal Contacts**	**ABO Score**
102	8	5	12	9	1	9	0	44
103	2	8	4	6	4	4	0	28
105	3	4	12	7	4	7	0	37
108	8	12	14	8	2	7	0	51
110	2	8	9	7	2	6	0	34
111	6	4	10	10	4	11	1	46
112	7	2	5	7	10	8	0	39
136	3	9	8	10	1	6	0	37
205	3	4	14	5	0	4	0	30
212	4	4	6	3	0	4	0	21
Totals	46	60	94	72	28	66	1	367

Anatomical Measurments: Plaster Casts								
	time 3	time 3	time 3	time 3	time 3	time 3	time 3	time 3
Cast Number	**Alignment**	**Marginal Ridges**	**Buccolingual Inclination**	**Occlusal Contacts**	**Occlusal Relationship**	**Overjet**	**Interproximal Contacts**	**ABO Score**
102	8	5	12	10	1	8	0	44
103	1	8	4	6	4	4	0	27
105	3	4	11	7	4	7	0	36
108	8	11	14	7	2	7	0	49
110	2	8	9	7	2	6	0	34
111	6	5	10	10	4	10	1	46
112	7	2	5	8	10	8	0	40
136	3	9	8	10	1	6	0	37
205	3	4	14	5	0	4	0	30
212	4	4	6	3	0	4	0	21
Totals	45	60	93	73	28	64	1	364

Anatomical Measurments: Digital

	time 1	time 1	time 1	time 1	time 1	time 1	time 1	time 1
Cast Number	**Alignment**	**Marginal Ridges**	**Buccolingual Inclination**	**Occlusal Contacts**	**Occlusal Relationship**	**Overjet**	**Interproximal Contacts**	**ABO Score**
102	8	5	12	12	1	13	0	51
103	2	7	4	6	4	5	0	28
105	2	4	11	7	4	10	0	38
108	9	10	14	6	2	10	0	51
110	2	8	10	9	2	12	0	43
111	8	4	9	9	4	13	0	47
112	7	2	5	12	10	13	0	49
136	3	9	9	10	1	8	0	40
205	3	4	14	5	0	8	0	34
212	5	4	8	7	1	12	0	37
Totals	49	57	96	83	29	104	0	418

Anatomical Measurments: Digital

	time 2	time 2	time 2	time 2	time 2	time 2	time 2	time 2
Cast Number	**Alignment**	**Marginal Ridges**	**Buccolingual Inclination**	**Occlusal Contacts**	**Occlusal Relationship**	**Overjet**	**Interproximal Contacts**	**ABO Score**
102	8	5	12	11	1	13	0	50
103	2	7	4	6	4	5	0	28
105	2	4	11	7	4	9	0	37
108	9	10	14	5	2	10	0	50
110	2	8	10	9	2	12	0	43
111	8	5	9	9	4	13	0	48
112	7	2	5	12	10	13	0	49
136	3	9	9	10	1	8	0	40
205	3	4	14	5	0	8	0	34
212	4	4	8	7	1	11	0	35
Totals	48	58	96	81	29	102	0	414

Anatomical Measurments: Digital								
	time 3	time 3	time 3	time 3	time 3	time 3	time 3	time 3
Cast Number	**Alignment**	**Marginal Ridges**	**Buccolingual Inclination**	**Occlusal Contacts**	**Occlusal Relationship**	**Overjet**	**Interproximal Contacts**	**ABO Score**
102	8	5	12	12	1	13	0	51
103	2	8	4	6	4	5	0	29
105	2	4	11	7	4	9	0	37
108	8	10	14	6	2	10	0	50
110	2	8	10	9	2	12	0	43
111	8	4	9	9	4	13	0	47
112	7	2	5	11	10	13	0	48
136	3	9	9	10	1	8	0	40
205	3	4	14	5	0	7	0	33
212	5	4	7	7	1	12	0	36
Totals	48	58	95	82	29	102	0	414

APPENDIX 8

Spearman's Rank Coefficient

Nonparametric Correlations

Correlations

			Alignment 1 plaster	Alignment 2 plaster
Spearman's rho	Alignment 1 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Alignment 2 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Alignment 2 plaster	Alignment 3 plaster
Spearman's rho	Alignment 2 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Alignment 3 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Alignment 3 plaster	Alignment 1 plaster
Spearman's rho	Alignment 3 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Alignment 1 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Marginal Ridges 1 plaster	Marginal Ridges 2 plaster
Spearman's rho	Marginal Ridges 1 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Marginal Ridges 2 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Marginal Ridges 2 plaster	Marginal Ridges 3 plaster
Spearman's rho	Marginal Ridges 2 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Marginal Ridges 3 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Marginal Ridges 3 plaster	Marginal Ridges 1 plaster
Spearman's rho	Marginal Ridges 3 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Marginal Ridges 1 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Buccolingual Inclination 1 plaster	Buccolingual Inclination 2 plaster
Spearman's rho	Buccolingual Inclination 1 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Buccolingual Inclination 2 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Buccolingual Inclination 2 plaster	Buccolingual Inclination 3 plaster
Spearman's rho	Buccolingual Inclination 2 plaster	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Buccolingual Inclination 3 plaster	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Buccolingual Inclination 3 plaster	Buccolingual Inclination 1 plaster
Spearman's rho	Buccolingual Inclination 3 plaster	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Buccolingual Inclination 1 plaster	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Contacts 1 plaster	Occlusal Contacts 2 plaster
Spearman's rho	Occlusal Contacts 1 plaster	Correlation Coefficient	1.000	.991(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Occlusal Contacts 2 plaster	Correlation Coefficient	.991(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Contacts 2 plaster	Occlusal Contacts 3 plaster
Spearman's rho	Occlusal Contacts 2 plaster	Correlation Coefficient	1.000	.940(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Occlusal Contacts 3 plaster	Correlation Coefficient	.940(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Contacts 3 plaster	Occlusal Contacts 1 plaster
Spearman's rho	Occlusal Contacts 3 plaster	Correlation Coefficient	1.000	.949(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Occlusal Contacts 1 plaster	Correlation Coefficient	.949(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Relationship 1 plaster	Occlusal Relationship 2 plaster
Spearman's rho	Occlusal Relationship 1 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Occlusal Relationship 2 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Relationship 2 plaster	Occlusal Relationship 3 plaster
Spearman's rho	Occlusal Relationship 2 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Occlusal Relationship 3 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Relationship 3 plaster	Occlusal Relationship 1 plaster
Spearman's rho	Occlusal Relationship 3 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Occlusal Relationship 1 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Overjet 1 plaster	Overjet 2 plaster
Spearman's rho	Overjet 1 plaster	Correlation Coefficient	1.000	.981(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Overjet 2 plaster	Correlation Coefficient	.981(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Overjet 2 plaster	Overjet 3 plaster
Spearman's rho	Overjet 2 plaster	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Overjet 3 plaster	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Overjet 3 plaster	Overjet 1 plaster
Spearman's rho	Overjet 3 plaster	Correlation Coefficient	1.000	.978(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Overjet 1 plaster	Correlation Coefficient	.978(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Interproximal Contacts 1 plaster	Interproximal Contacts 2 plaster
Spearman's rho	Interproximal Contacts 1 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Interproximal Contacts 2 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Interproximal Contacts 2 plaster	Interproximal Contacts 3 plaster
Spearman's rho	Interproximal Contacts 2 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Interproximal Contacts 3 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Interproximal Contacts 3 plaster	Interproximal Contacts 1 plaster
Spearman's rho	Interproximal Contacts 3 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Interproximal Contacts 1 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			ABO Score 1 plaster	ABO Score 2 plaster
Spearman's rho	ABO Score 1 plaster	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	ABO Score 2 plaster	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			ABO Score 2 plaster	ABO Score 3 plaster
Spearman's rho	ABO Score 2 plaster	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	ABO Score 3 plaster	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			ABO Score 3 plaster	ABO Score 1 plaster
Spearman's rho	ABO Score 3 plaster	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	ABO Score 1 plaster	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

APPENDIX 9

Spearman's Rank Coefficient

Nonparametric Correlations

Correlations

			Alignment 1 orthocad	Alignment 2 orthocad
Spearman's rho	Alignment 1 orthocad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Alignment 2 orthocad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Alignment 2 orthocad	Alignment 3 orthocad
Spearman's rho	Alignment 2 orthocad	Correlation Coefficient	1.000	.991(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Alignment 3 orthocad	Correlation Coefficient	.991(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Alignment 3 orthocad	Alignment 1 orthocad
Spearman's rho	Alignment 3 orthocad	Correlation Coefficient	1.000	.991(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Alignment 1 orthocad	Correlation Coefficient	.991(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Marginal Ridges 1 orthocad	Marginal Ridges 2 orthocad
Spearman's rho	Marginal Ridges 1 orthocad	Correlation Coefficient	1.000	.968(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Marginal Ridges 2 orthocad	Correlation Coefficient	.968(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Marginal Ridges 2 orthocad	Marginal Ridges 3 orthocad
Spearman's rho	Marginal Ridges 2 orthocad	Correlation Coefficient	1.000	.965(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Marginal Ridges 3 orthocad	Correlation Coefficient	.965(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Marginal Ridges 3 orthocad	Marginal Ridges 1 orthocad
Spearman's rho	Marginal Ridges 3 orthocad	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Marginal Ridges 1 orthocad	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Buccolingual Incllination 1 orthocad	Buccolingual Incllination 2 orthocad
Spearman's rho	Buccolingual Incllination 1 orthocad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Buccolingual Incllination 2 orthocad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Buccolingual Incllination 2 orthocad	Buccolingual Incllination 3 orthocad
Spearman's rho	Buccolingual Incllination 2 orthocad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Buccolingual Incllination 3 orthocad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Buccolingual Incllination 3 orthocad	Buccolingual Incllination 1 orthocad
Spearman's rho	Buccolingual Incllination 3 orthocad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Buccolingual Incllination 1 orthocad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Contacts 1 orthocad	Occlusal Contacts 2 orthocad
Spearman's rho	Occlusal Contacts 1 orthocad	Correlation Coefficient	1.000	.988(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Occlusal Contacts 2 orthocad	Correlation Coefficient	.988(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Contacts 2 orthocad	Occlusal Contacts 3 orthocad
Spearman's rho	Occlusal Contacts 2 orthocad	Correlation Coefficient	1.000	.978(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Occlusal Contacts 3 orthocad	Correlation Coefficient	.978(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Contacts 3 orthocad	Occlusal Contacts 1 orthocad
Spearman's rho	Occlusal Contacts 3 orthocad	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Occlusal Contacts 1 orthocad	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Relationship 1 orthocad	Occlusal Relationship 2 orthcad
Spearman's rho	Occlusal Relationship 1 orthocad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Occlusal Relationship 2 orthcad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Relationship 2 orthcad	Occlusal Relationship 3 orthocad
Spearman's rho	Occlusal Relationship 2 orthcad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Occlusal Relationship 3 orthocad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Relationship 3 orthocad	Occlusal Relationship 1 orthocad
Spearman's rho	Occlusal Relationship 3 orthocad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	Occlusal Relationship 1 orthocad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Overjet 1 orthocad	Overjet 2 orthocad
Spearman's rho	Overjet 1 orthocad	Correlation Coefficient	1.000	.994(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Overjet 2 orthocad	Correlation Coefficient	.994(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Overjet 2 orthocad	Overjet 3 orthocad
Spearman's rho	Overjet 2 orthocad	Correlation Coefficient	1.000	.994(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Overjet 3 orthocad	Correlation Coefficient	.994(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Overjet 3 orthocad	Overjet 1 orthocad
Spearman's rho	Overjet 3 orthocad	Correlation Coefficient	1.000	.994(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	Overjet 1 orthocad	Correlation Coefficient	.994(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Interproximal Contacts 1 orthocad	Interproximal Contacts 2 orthocad
Spearman's rho	Interproximal Contacts 1 orthocad	Correlation Coefficient	.	.
		Sig. (2-tailed)	.	.
		N	10	10
	Interproximal Contacts 2 orthocad	Correlation Coefficient	.	.
		Sig. (2-tailed)	.	.
		N	10	10

Correlations

			Interproximal Contacts 2 orthocad	Interproximal Contacts 3 orthocad
Spearman's rho	Interproximal Contacts 2 orthocad	Correlation Coefficient	.	.
		Sig. (2-tailed)	.	.
		N	10	10
	Interproximal Contacts 3 orthocad	Correlation Coefficient	.	.
		Sig. (2-tailed)	.	.
		N	10	10

Correlations

			Interproximal Contacts 3 orthocad	Interproximal Contacts 1 orthocad
Spearman's rho	Interproximal Contacts 3 orthocad	Correlation Coefficient	.	.
		Sig. (2-tailed)	.	.
		N	10	10
	Interproximal Contacts 1 orthocad	Correlation Coefficient	.	.
		Sig. (2-tailed)	.	.
		N	10	10

Correlations

			ABO Score 1 orthocad	ABO Score 2 orthocad
Spearman's rho	ABO Score 1 orthocad	Correlation Coefficient	1.000	1.000(**)
		Sig. (2-tailed)	.	.
		N	10	10
	ABO Score 2 orthocad	Correlation Coefficient	1.000(**)	1.000
		Sig. (2-tailed)	.	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			ABO Score 2 orthocad	ABO Score 3 orthocad
Spearman's rho	ABO Score 2 orthocad	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	ABO Score 3 orthocad	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			ABO Score 3 orthocad	ABO Score 1 orthocad
Spearman's rho	ABO Score 3 orthocad	Correlation Coefficient	1.000	.997(**)
		Sig. (2-tailed)	.	.000
		N	10	10
	ABO Score 1 orthocad	Correlation Coefficient	.997(**)	1.000
		Sig. (2-tailed)	.000	.
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Appendix 10

Intra-class Correlation Coefficient Intraoperator Plaster

Plaster
ABO Intra-operator stats

Reliability Statistics

Intra-class Correlation Coefficient

Time 1: time 2

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.998(b)	.992	1.000	1018.103	9.0	9	.000
Average Measures	.999(c)	.996	1.000	1018.103	9.0	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intra-class correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intra-class Correlation Coefficient

Time 2: time 3

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.996(b)	.983	.999	464.082	9.0	9	.000
Average Measures	.998(c)	.991	.999	464.082	9.0	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intra-class correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intra-class Correlation Coefficient

Time 3: time 1

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.996(b)	.982	.999	451.500	9.0	9	.000
Average Measures	.998(c)	.991	.999	451.500	9.0	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intra-class correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

APPENDIX 11

Intra-class Correlation Coefficient

Intra-operator Digital

Digital
ABO Intra-operator stats

Reliability Statistics

Intra-class Correlation Coefficient

Time 1: time 2

	Intra-class Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.994(b)	.977	.999	339.625	9.0	9	.000
Average Measures	.997(c)	.988	.999	339.625	9.0	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intra-class correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intra-class Correlation Coefficient

Time 2: time 3

	Intra-class Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.994(b)	.978	.999	354.600	9.0	9	.000
Average Measures	.997(c)	.989	.999	354.600	9.0	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intra-class correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Intra-class Correlation Coefficient

Time 3: time 1

	Intra-class Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.996(b)	.983	.999	480.818	9.0	9	.000
Average Measures	.998(c)	.992	.999	480.818	9.0	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intra-class correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

APPENDIX 12

Spearman's Rank Coefficient

Nonparametric Correlations

Correlations

			Alignment plaster	Alignment orthocad
Spearman's rho	Alignment plaster	Correlation Coefficient	1.000	.927(**)
		Sig. (2-tailed)	.	.000
		N	36	36
	Alignment orthocad	Correlation Coefficient	.927(**)	1.000
		Sig. (2-tailed)	.000	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Marginal Ridges plaster	Marginal Ridges orthocad
Spearman's rho	Marginal Ridges plaster	Correlation Coefficient	1.000	.954(**)
		Sig. (2-tailed)	.	.000
		N	36	36
	Marginal Ridges orthocad	Correlation Coefficient	.954(**)	1.000
		Sig. (2-tailed)	.000	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Buccolingual Incllination plaster	Buccolingual Incllination orthocad
Spearman's rho	Buccolingual Incllination plaster	Correlation Coefficient	1.000	.977(**)
		Sig. (2-tailed)	.	.000
		N	36	36
	Buccolingual Incllination orthocad	Correlation Coefficient	.977(**)	1.000
		Sig. (2-tailed)	.000	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Contacts plaster	Occlusal Contacts orthocad
Spearman's rho	Occlusal Contacts plaster	Correlation Coefficient	1.000	.666(**)
		Sig. (2-tailed)	.	.000
		N	36	36
	Occlusal Contacts orthocad	Correlation Coefficient	.666(**)	1.000
		Sig. (2-tailed)	.000	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Occlusal Relationship plaster	Occlusal Relationship orthocad
Spearman's rho	Occlusal Relationship plaster	Correlation Coefficient	1.000	.971(**)
		Sig. (2-tailed)	.	.000
		N	36	36
	Occlusal Relationship orthocad	Correlation Coefficient	.971(**)	1.000
		Sig. (2-tailed)	.000	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Overjet plaster	Overjet orthocad
Spearman's rho	Overjet plaster	Correlation Coefficient	1.000	.525(**)
		Sig. (2-tailed)	.	.001
		N	36	36
	Overjet orthocad	Correlation Coefficient	.525(**)	1.000
		Sig. (2-tailed)	.001	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Interproximal Contacts plaster	Interproximal Contacts orthocad
Spearman's rho	Interproximal Contacts plaster	Correlation Coefficient	1.000	.907(**)
		Sig. (2-tailed)	.	.000
		N	36	36
	Interproximal Contacts orthocad	Correlation Coefficient	.907(**)	1.000
		Sig. (2-tailed)	.000	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

Correlations

			ABO Score plaster	ABO Score orthocad
Spearman's rho	ABO Score plaster	Correlation Coefficient	1.000	.860(**)
		Sig. (2-tailed)	.	.000
		N	36	36
	ABO Score orthocad	Correlation Coefficient	.860(**)	1.000
		Sig. (2-tailed)	.000	.
		N	36	36

** Correlation is significant at the 0.01 level (2-tailed).

APPENDIX 13

Wilcoxon Rank Sum Test

Test Statistics(c)

	Alignment orthocad - Alignment plaster	Marginal Ridges orthocad - Marginal Ridges plaster	Buccolingual Incllination orthocad - Buccolingual Incllination plaster	Occlusal Contacts orthocad - Occlusal Contacts plaster	Occlusal Relationship orthocad - Occlusal Relationship plaster	Overjet orthocad - Overjet plaster	Interproximal Contacts orthocad - Interproximal Contacts plaster	ABO Score orthocad - ABO Score plaster
Z	-3.337(a)	-1.613(b)	-.577(a)	-2.149(a)	-.816(a)	-5.030(a)	-1.000(b)	-5.025(a)
Asymp. Sig. (2-tailed)	.001	.107	.564	.032	.414	.000	.317	.000

a Based on negative ranks.
b Based on positive ranks.
c Wilcoxon Signed Ranks Test

APPENDIX 14

Intra-class Correlation Coefficient

Alignment

Reliability Statistics

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.953(b)	.910	.976	41.585	35.0	35	.000
Average Measures	.976(c)	.953	.988	41.585	35.0	35	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Marginal Ridges

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.969(b)	.940	.984	63.812	35.0	35	.000
Average Measures	.984(c)	.969	.992	63.812	35.0	35	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Buccolingual Inclination

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.981(b)	.964	.990	106.654	35.0	35	.000
Average Measures	.991(c)	.982	.995	106.654	35.0	35	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Occlusal Contacts

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.713(b)	.506	.843	5.976	35.0	35	.000
Average Measures	.833(c)	.672	.915	5.976	35.0	35	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Occlusal Relationship

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.983(b)	.967	.991	117.604	35.0	35	.000
Average Measures	.991(c)	.983	.996	117.604	35.0	35	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Overjet

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.518(b)	.233	.722	3.153	35.0	35	.001
Average Measures	.683(c)	.378	.838	3.153	35.0	35	.001

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Interproximal Contact

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.974(b)	.950	.987	77.114	35.0	35	.000
Average Measures	.987(c)	.975	.993	77.114	35.0	35	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate computed assuming interaction effect is absent, because it is not estimable otherwise.

ABO Score

Intra-class Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.842(b)	.712	.916	11.646	35.0	35	.000
Average Measures	.914(c)	.832	.956	11.646	35.0	35	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.
a Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.
b The estimator is the same, whether the interaction effect is present or not.
c This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

APPENDIX 15

Paired t-test

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Alignment plaster - Alignment orthocad	-.556	.843	.141	-.841	-.270	-3.953	35	.000
Pair 2	Marginal Ridges plaster - Marginal Ridges orthocad	.167	.609	.102	-.040	.373	1.641	35	.110
Pair 3	Buccolingual Incllination plaster - Buccolingual Incllination orthocad	-.056	.583	.097	-.253	.142	-.572	35	.571
Pair 4	Occlusal Contacts plaster - Occlusal Contacts orthocad	-1.167	2.903	.484	-2.149	-.184	-2.411	35	.021
Pair 5	Occlusal Relationship plaster - Occlusal Relationship orthocad	-.056	.410	.068	-.194	.083	-.813	35	.422
Pair 6	Overjet plaster - Overjet orthocad	-3.972	2.646	.441	-4.867	-3.077	-9.009	35	.000
Pair 7	Interproximal Contacts plaster - Interproximal Contacts orthocad	.028	.167	.028	-.029	.084	1.000	35	.324
Pair 8	ABO Score plaster - ABO Score orthocad	-5.611	4.976	.829	-7.295	-3.928	-6.766	35	.000

APPENDIX 16

Consent Form

Acknowledgement of Informed Consent

I hereby acknowledge that the major treatment considerations and potential risks of orthodontic treatment have been presented to me. I have read and understand this form and also understand that there may be other problems that occur less frequently or are less severe, and that the actual results may be different from the anticipated results.

Dr(s). _____
has(have) discussed the orthodontic treatment
for _____
with me. I have been asked to make a choice about that treatment. I have been presented information to aid in the decision-making process, and I have been given the opportunity to ask the above doctor(s) all questions I have about the proposed orthodontic treatment and information contained in this form.

Consent to Undergo Orthodontic Treatment

I hereby consent to the making of diagnostic records, including x-rays, before, during and following orthodontic treatment, and to the above doctor(s) and, where appropriate, staff providing orthodontic treatment described by the above doctor(s) for the above individual. I fully understand all of the risks associated with the treatment.

Authorization for Release of Patient Information

I hereby authorize the above doctor to provide other health care providers with information regarding the above individual's orthodontic care as deemed appropriate. I understand that once released, the above doctor(s) and staff has(have) no responsibility for any further release by the individual receiving this information.

Surgical Supplement

If the orthodontic treatment plan includes correction of the malocclusion by orthodontic appliance (braces) therapy in conjunction with orthognathic (corrective jaw) surgery, I understand that oral surgery is necessary in conjunction with the above patient's orthodontic treatment. I authorize the office(s) of the above doctor(s) to communicate with the surgeon and release information from the above patient's treatment record to the designated surgeon. I acknowledge that expenses incurred from the surgery are separate from orthodontic treatment expenses, and I will be responsible to the surgeon and hospital for all such expenses.

I understand that if I do not complete the surgical component of the treatment plan that I may have a compromised treatment result and other complications. I hereby agree not to hold the above doctor(s) and staff liable for any compromised treatment resulting from my failure for any reason to follow the treatment plan.

OFFICE COPY

Signature

Signature/Patient, Parent or Guardian _____ Date _____

Signature (Orthodontist) _____ Date _____

Witness _____ Date _____

Patient's Authorized Representative

If you are consenting to the care of another: I have the legal authority to sign this on behalf of _____

Relationship to Patient _____

Signature _____ Date _____

Witness _____ Date _____

OPTIONAL

Consent to Use of Records

I hereby give my permission for the use of orthodontic records, including photographs, made in the process of examinations, treatment, and retention for purposes of professional consultations, research, education, or publication in professional journals.

I have the legal authority to sign this on behalf of _____

Relationship to Patient _____

Signature _____ Date _____

Witness _____ Date _____

Case Western Reserve University
School of Dental Medicine

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