THE EFFECTIVENESS AND EFFICIENCY OF A CAD/CAM DESIGNED ORTHODONTIC BRACKET SYSTEM

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ABSTRACT

Matthew W. Brown: The Effectiveness and Efficiency of a CAD/CAM Designed Orthodontic Bracket System
(Under the direction of Tung T. Nguyen)

Introduction: Lawrence F. Andrews introduced the first Straight Wire Appliance over 40 years ago to increase the consistency and efficiency of orthodontic treatment. More recently, CAD/CAM technology has been utilized to create individualized orthodontic appliances. The purpose of this study is to investigate the clinical effectiveness and efficiency of CAD/CAM customized orthodontic appliances compared to direct and indirect bonded stock orthodontic brackets. Methods: This retrospective study included 3 treatment groups: Group 1 patients were direct bonded with self-ligation (Ormco® Damon Q) appliances, Group 2 patients were indirect bonded with self-ligation (Ormco® Damon Q) appliances, and Group 3 patients were indirect bonded with CAD/CAM self-ligation (Ormco® Insignia SL) appliances. Complete pre- and post-treatment records were obtained for all cases. The American Board of Orthodontics (ABO) Discrepancy Index was used to evaluate pre-treatment records, while post-treatment case outcomes were analyzed using the ABO Cast/Radiograph Evaluation. All data collection and analysis was completed by a single evaluator (M.B.). Results: There were no statistically significant differences in the ABO Discrepancy Index or ABO Cast/Radiograph Evaluation among the groups. Treatment times for the 3 groups were significantly different, with the CAD/CAM group being the shortest at 13.8±3.4 months, compared to 21.9±5.0 months and 16.9±4.1 months for the Direct bonded and Indirect bonded groups, respectively. The number of treatment appointments for the CAD/CAM group was significantly less than the Direct bonded group. Conclusion: The CAD/CAM designed orthodontic bracket system evaluated in this study was found to
be as effective in treatment outcome measures as standard brackets bonded both directly and indirectly. The CAD/CAM appliance was more efficient in regards to treatment duration, though the decrease in total arch wire appointments was minimal. Further investigation is needed to better quantify the clinical benefits of CAD/CAM orthodontic appliances.
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<td>ABO</td>
<td>American Board of Orthodontics</td>
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<td>B.C.</td>
<td>Before Christ</td>
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<tr>
<td>CAD/CAM</td>
<td>Computer-Aided Design and Computer-Aided Manufacturing</td>
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<td>CBCT</td>
<td>Cone-Beam Computed Tomography</td>
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<td>FDR</td>
<td>False Discovery Rate</td>
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<td>FPD</td>
<td>Fixed Partial Denture</td>
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<td>PVS</td>
<td>Polyvinyl Siloxane</td>
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<td>SLA</td>
<td>Stereolithography Model</td>
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<td>STL</td>
<td>Stereolithography File</td>
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<td>SWA</td>
<td>Straight Wire Appliance</td>
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## LIST OF SYMBOLS

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<th>Symbol</th>
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A REVIEW OF THE LITERATURE

Historical Perspective

Orthodontics as we think of it today has been around for little more than a century; however, mal-aligned teeth have been a present in humans for thousands of years. Remains recovered from approximately 50,000 B.C. have displayed crowding in the dentition of the Neanderthal man while some Egyptian mummies have been discovered with crude metal bands on their teeth, with speculation that catgut was used to close gaps during this time. Hippocrates mentioned tooth irregularities in written works around 400 B.C., while some of the earliest evidence of intentionally improving the position of teeth belongs to Pliny the Elder (A.D. 23-79), who suggested filing elongated teeth to bring them into proper alignment.¹

Little development in dentistry and tooth movement arose during the Middle Ages but the end of the second millennium saw resurgence in the field, with France emerging as the leader. In the 18th century, Frenchman Pierre Fauchard (1678-1761) described the bandeau, a horseshoe-shaped expansion arch made of precious metal to which teeth were ligated. Entienne Bourdet (1722-1789) improved on Fauchard’s design and also began expanding arches from the lingual. In 1757, Bourdet provided the first written record of recommending serial extraction and extraction of premolars to relieve crowding.¹ Normal occlusion was first described by John Hunter, an English anatomist and surgeon, in an attempt to classify the teeth. He established the difference between teeth and bone, gave the teeth individual names, and was also the first to
describe the growth of the jaws as a scientific investigation. Joachim Lefoulon finally named the science of moving teeth “orthodontosie” in 1841, which translates roughly into “orthodontia”.¹

The 19ᵗʰ century saw continued implementation of tooth moving appliances and concepts, including the introduction of occipital anchorage by J.S. Gunnell in 1822 and the idea that lip and tongue pressures, hereditary factors, and possibly growth could affect the presentation of a patient’s teeth.¹ It was during this time that Edward H. Angle (1855-1930) began to create order from chaos and lay the foundation for orthodontics as a specialty. He introduced the expansion arch and its auxiliaries in 1888, published his classification of malocclusion in 1899 that is still used today, and started The Angle School of Orthodontia in 1900 under the premise:

“…The idea of a postgraduate school was forced upon me because I wished to see those who had a desire to study orthodontia better receive the opportunity to do so.”²

Around this time Angle also worked with the S.S. White Dental Manufacturing Company to distribute his prefabricated “Angle’s System” to broaden the recipient base of orthodontic care, making comprehensive fixed-appliance orthodontic therapy obtainable to a wider patient demography.³

The early 1900s saw an array of standardized orthodontic appliances introduced, including George C. Ainsworth’s regulating system (1904) that incorporated vertical tubes and loop wires, Vincent H. Jackson’s “Jackson Crib” with auxiliary springs to aid in tooth movement, and Charles A. Hawley’s introduction of the retainer in 1908. In addition to the expansion arch, Angle also developed the pin and tube appliance as well as the ribbon arch, both of which utilized vertical slots. Inadequacies in his previous systems led Angle to develop the edgewise appliance in 1928, which incorporated a horizontal slot and quickly became the
mainstay of fixed appliance therapy. With the exception of Raymond Begg’s “Begg appliance”, introduced in the 1930s and peaking in popularity around the 1960s, the edgewise appliance design has remained the design template for the majority of contemporary fixed orthodontic appliances.

**Straight Wire Appliance**

As orthodontics continued to become more widespread in the United States during the middle of the 20th century, there arose a need to define the characteristics of successful orthodontic treatment. Angle’s classical guideline of a proper orthodontic treatment result required the mesiobuccal cusp of the upper permanent first molar to occlude in the groove between the mesial and middle buccal cusps of the lower permanent first molar. He did not contend that this factor alone was enough; however, other global goals of orthodontic treatment had not been clearly defined but rather subjectively discussed and recognized based on clinical experience and observation. Lawrence F. Andrews felt this dilemma must be addressed, and sought to define significant characteristics of dentitions which were judged by professional opinion not to require orthodontic treatment.

From 1960 to 1964, Andrews collected 120 non-orthodontic normal models of teeth that (1) had never had orthodontic treatment, (2) were straight and pleasing in appearance, (3) had a bite which looked generally correct, and (4) would not benefit from orthodontic treatment by his judgement. After examination of these models, Andrews reached tentative conclusions and formulated six characteristics in general terms. From 1965 to 1971 he then evaluated 1,150 cases that were displayed at national orthodontic meetings, representing the most skilled orthodontists in the country, to assess the presence of the six characteristics he defined and how
the absence of any one may adversely affect other aspects of the case. In this way he validated the six qualities he defined, as they were not only present in the non-treated orthodontic normals but also because the lack of one quality was an indication of an incomplete end result in treated cases. These six qualities became the six keys to normal occlusion, and are defined as follows:

1) Molar relationship – The distal surface of the distobuccal cusp of the upper first permanent molar should occlude with the mesial surface of the mesiobuccal cusp of the lower second molar, while the mesiodistal cusp of the upper first permanent molar should fall within the groove between the middle and mesial cusps of the lower first permanent molar

2) Crown angulation, the mesiodistal “tip” – Ideal angulation varies among tooth type, but the gingival portion of the long axis of the crown should be distal to the incisal portion

3) Crown inclination – Proper labiolingual or buccolingual inclination of the long axis of the crowns should be obtained, with the ideal position again varying among tooth types

4) Rotations – The teeth should be free of undesirable rotations

5) Spaces – There should be no spaces; contact points should be tight

6) Occlusal Plane – The plane of occlusion on the non-orthodontic normals varied from generally flat to a slight curve of Spee, however a flat plane should be a treatment goal as a form of overtreatment as there is a natural tendency for the Curve of Spee to deepen with time
Andrews acknowledged that variations in patient cooperation, genetics, and other extenuating circumstances may deem compromised treatment acceptable. However, when these limitations do not exist the six keys of occlusion should be our measure of the static relationship of successful orthodontic treatment.

The “straight-wire concept” is built around the idea that a more consistent and ideal treatment result can be obtained with less drain on the clinician, in less overall time and with less discomfort to the patient, with the use of an appliance that places the primary source of tooth control within the orthodontic attachment rather than in the archwire. Andrew’s vision for the straight wire appliance (SWA) is arguably what brought this concept to the forefront of orthodontic appliance design in the 1970’s; however, the idea was not a new one. In 1928 Angle formed the basis of the straight wire concept when he was quoted,

“Another excellent way of causing the arch to bend within the brackets and anchor sheaths…is to change the positions of the brackets on the bands, thus changing the angles of relation of the slots of the brackets to the long axis of the teeth instead of making vertical bends in the arch. This permits the use of the arch in its simplest form, or that freest from bends, which of course has advantages.”

Following Angle’s original notion, Holdaway stated in 1952,

“The reason artistic positioning bends are necessary at any time is due to the malposition acquired when the brackets are positioned parallel with the long axis of the tooth. It is just as easy to hook the case up with brackets angulated and thus eliminate further those arch wire bends in the vertical plane. If, in conventional bracket placement…is it not
better right from the beginning to have all bracket action gradually align the teeth in correct positions?"\(^6\)

**Indirect Bonding**

The introduction of the SWA coincided with another significant change in orthodontics, which was the incorporation of adhesives to allow direct bonding of fixed appliances. The middle 1960s saw the introduction of various direct bonding cements, though the bond strength of many products was inadequate for the forces created by rectangular archwires. The other main disadvantage with the early adhesive systems was the setting time, as only one or two brackets could be placed simultaneously and positioning was difficult as the brackets were not stable until the cement was fully cured.\(^7\) In 1972, Silverman et al.\(^7\) published the first paper on indirect bonding, citing the ability to overcome the challenges associated with the direct bonding adhesives of the time. The protocol described the placement of brackets on a work model and the subsequent fabrication of a plastic carrier tray. The clinical aspect of the indirect bonding procedure described careful tooth preparation and the application of a chemical cure bonding cement to each bracket base prior to the insertion of the tray into the patient’s mouth. The failure of one or more brackets could be expected in some cases, but the authors felt the success rate of the technique would improve over time as new generations of cements were introduced.\(^7\)

Though the first paper on indirect bonding was published over 40 years ago, it is interesting that the main advantages cited by the authors were decreased patient chair time and improved accuracy of bracket placement.\(^7\) These advantages, specifically the accuracy of bracket placement, have fueled the development of a myriad of indirect bonding protocols in
recent decades to better utilize SWAs. The ultimate goal is to eliminate the need for bracket repositioning and archwire bends.\(^8\)

Many practitioners find that placing brackets on a work model is easier and more accurate than direct bonding due to the elimination of visualization and patient management obstacles; however, the final intraoral bracket position is only as accurate as the indirect carrier tray.\(^8,9\) In 2014, Castilla et al.\(^8\) investigated five of the most commonly used indirect bonding techniques, including double polyvinyl siloxane, double vacuum-form, polyvinyl siloxane vacuum-form, polyvinyl siloxane putty, and single vacuum-form. They analyzed the mesiodistal, occlusogingival, and faciolingual position of the brackets on the working model, then transferred the brackets to an identical stone patient model and re-measured each bracket’s position. All indirect bonding methods showed at least one tooth with significant differences in final bracket position, with the double vacuum-form showing the most discrepancies and the polyvinyl siloxane vacuum-form showing the fewest. The most errors occurred in the occlusogingival position of the brackets, while the mesiodistal position showed the least.\(^8\) The authors concluded that indirect bonding techniques involving the use of polyvinyl siloxane were most accurate, due to the excellent dimensional stability, increased elastic recovery and high rigidity of the material. Techniques involving only the use of vacuum-form trays were found to be least accurate, especially in the occlusogingival dimension, as the tray thickness decreases when the heated vacuum-form plastic is stretched over long clinical crowns.\(^8\)

Another main area of concern with indirect bonding has been the bond strength as compared to direct bonding techniques. Bond strength with indirect bonding can be affected by the adhesion system selected, the carrier tray design, and isolation control during the tray delivery. In 2014, Menini et al.\(^10\) completed a clinical longitudinal study comparing the number
of bracket failures observed in a group of directly bonded patients and a group of indirectly bonded patients over a 15 month period. There was no difference found in the overall bracket failure rate between the two groups, though significantly more brackets failed in the lower posterior in the indirect bonding group. These findings were similar to previous studies, many of which found no difference in bond failure between direct and indirect bonding techniques. The authors concluded that indirect bonding techniques can be predictably used in patients, even when crowded or malpositioned teeth are present.

Overall, indirect bonding procedures have been found to be effective in achieving accurate bracket placement and efficient in reducing patient chair time during bonding. Clinicians have also been shown to be reproducible in their placement of brackets during indirect bonding setups. However, inaccurate bracket placement is just one reason that preadjusted orthodontic appliances have not proven to be true “straight wire” appliances. Creekmore et al. also cited variations in tooth structure, vertical and anteroposterior jaw relationships, and tissue rebound as well as the mechanical deficiencies of edgewise appliances as additional obstacles that must be overcome in the search of a true SWA. Irregular tooth anatomy often necessitates adjustments in the tip, torque, rotation, and height parameters of bracket placement and prescription. Ideal faciolingual inclination of the maxillary incisors varies greatly based on the underlying skeletal relationship of the maxilla and mandible, as Class III patients typically display more procumbent maxillary incisors and upright mandibular incisors while Class II patients display the opposite. In this manner, the finishing goals of a case vary greatly depending on initial skeletal presentation. Tissue rebound after the completion of orthodontic treatment has been shown to cause relapse of rotations, incisal edge heights, tips and torques, necessitating overcorrection of these irregularities during treatment so that the teeth may relapse into ideal
position. These varying adjustments need to be incorporated into the bracket prescription and ultimate bonding position to eliminate archwire adjustments in the finishing stages of treatment and create a true SWA.

The mechanical deficiencies of the edgewise appliance must also be compensated for in the development of an SWA. By necessity, brackets cannot be placed at the center of resistance on the tooth. The resulting application of force by an archwire away from the center of resistance produces additional moments and side effects. These side effects are further exacerbated by the play between the arch wire and arch wire slot that is inherently required if archwires are to be removed and reinserted. The greatest amount of play is in the torquing plane; with about 6° of total play even when “full-sized” archwires are placed. Prescriptions often utilize increased torque values to overcome the play in the system, but this does not eliminate the issue completely. Force diminution, defined as the reduction in the force produced by an archwire that is deflected within its elastics limits as it returns to its original shape, is the third mechanical flaw in the edgewise appliance that must be overcome. Tooth movement will stop when a deflected archwire reaches its minimum threshold of force, meaning that a straight wire never quite becomes straight and thus the prescription and position of the appliances will not be fully expressed.

Combining a well-designed SWA with an accurate indirect bonding technique seems to be beneficial in improving the reproducibility of desirable orthodontic outcomes. However, the ideal placement of a preadjusted orthodontic appliance alone is not enough to create a true SWA. An increase in the customization of orthodontic appliances to account for each patient’s unique tooth anatomy, skeletal relationship, and desired treatment outcome is required if archwire adjustments and bracket repositions are to be eliminated.
Orthodontic Applications of Computer-Aided Design and Computer-Aided Manufacturing

In a continued effort to develop a true straight wire appliance, orthodontic manufacturers turned to a relative veteran engineering technology: Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM). CAD/CAM has been a focus of dental research since the 1980s. Traditionally, much of the dental utilization of CAD/CAM technology has been in the prosthodontics field, specifically in the milling of crowns and fixed partial dentures (FPDs). However, other dental specialties have gained an appreciation for the benefits of CAD/CAM, leading to widespread application of the technology. A recent study cited orthodontic CAD/CAM applications that now include aids for diagnosis and treatment planning, clear aligner therapies, lingual appliances, and titanium Herbst appliances. Customized brackets with patient-specific torque, machine-milled indirect bonding jigs, and robotically bent archwires are among the newest CAD/CAM advances in the specialty. The overarching goal of incorporating CAD/CAM technology into the field of orthodontics can be best summed up as “improving reproducibility, efficiency, and quality of orthodontic treatment.”

In addition to the precise and customized milling of orthodontic appliances, the application of CAD/CAM technology allows the practitioner and patient to utilize virtual treatment planning software to better identify case objectives and visualize treatment outcomes. Practitioners are able to evaluate different treatment plans, including extraction versus non-extraction treatment options or substitution versus prosthetic replacement in cases of missing teeth. The end result is improved communication between the practitioner and patient, allowing for more realistic expectations of treatment outcome and an increased degree of informed consent. Multiple orthodontic systems are now utilizing this technology with success, including labial and lingual fixed appliances as well as removable clear aligner systems.
Align Technology’s Invisalign™

With the goal of offering an esthetic alternative to traditional fixed appliance orthodontic treatment in the form of clear aligner therapy, Align Technology® introduced Invisalign™ in 1998.¹⁹ Utilizing a single VPS impression or intraoral scan, a digital model of the patient’s dentition is created. The 3-D model is then manipulated by the clinician and Invisalign technician to create the desired final position of the teeth. The CAD/CAM process continues as stereolithic (SLA) models corresponding to the planned tooth position at each stage of treatment are printed and a series of removable polyurethane aligners is created. Each aligner is worn for approximately 14 days and is programmed to move a single tooth or small group of teeth 0.25 to 0.33 mm.¹⁹

The outcome from clinical research investigating the efficacy of Invisalign has been highly variable. Orthodontists using the appliance report that 70% to 80% of patients require midcourse correction, case refinement, or conversion to fixed appliances before the end of treatment.¹⁹ Djeu et al.²⁰ found that cases treated with Invisalign scored 13 points worse than cases treated with traditional fixed appliances when evaluated using the American Board of Orthodontics Phase III examination. The correction of large anteroposterior discrepancies and occlusal contacts were areas where Invisalign performed the worst. A follow up study was completed on the sample three years later to evaluate the relapse of patients treated with Invisalign compared to those treated with fixed appliances. The Invisalign patients showed worse relapse in overall alignment and specifically maxillary anterior alignment, though patients in both treatment groups showed some worsening of mandibular anterior alignment in the retention phase.²¹
Multiple improvements have been made to address the clinical shortcomings of early iterations of Invisalign, including updated attachment designs, the introduction of auxiliaries such as Power Ridges and Precision Cuts, and continued adjustments of the aligner material.\textsuperscript{22} In 2014, Simon et al.\textsuperscript{22} investigated the most current Invisalign appliance, specifically looking at translation, rotation, and incisor torque expression. The efficacy of the three movements was found to be 59.3\%, with the velocity and amount of tooth movement planned having the biggest impact on success. Upper incisor torque was found to be particularly difficult to achieve with aligners, with less than 50\% of the planned movement actually achieved.\textsuperscript{22}

*Invisalign* has been shown to be an effective tooth moving appliance when used to treat cases of mild to moderate difficulty, especially if limited extrusion and anteroposterior movements are required. Patient compliance with aligner wear is also a critical component of treatment success. In addition, clinicians should utilize overcorrection in the treatment planning process for difficult tooth movements to improve the finished case outcome. There is still much investigation to be done regarding the biomechanics and clinical efficacy of Invisalign, but the future of the appliance appears promising.\textsuperscript{19,22}

**OraMetrix®’s SureSmile™**

OraMetrix\textsuperscript{®} has been working on its unique approach to CAD/CAM orthodontics since the early 2000s. Similar to other CAD/CAM orthodontic systems, OraMetrix\textsuperscript{®}’s *SureSmile™* provides digital software that the clinician can utilize for diagnosing and treatment planning. The subsequent fabrication of robotically bent archwires is what separates *SureSmile* from other customized appliances.\textsuperscript{23} Interestingly, the *SureSmile* system can be used with any conventional orthodontic brackets and bands, with no special consideration during the delivery of the
appliances. At any time after appliance delivery, the SureSmile process begins with a scan of the patient’s dentition using an intraoral scanner or cone-beam computed tomography (CBCT). The data is used to construct a digital model of the patient’s dentition, including the exact bracket type and location on each tooth. The teeth can then be moved to their desired final position. Afterward, the software calculates the archwire bends needed to create the final dental setup using the precise location of the bracket slot on each individual tooth. Wire-bending robots fabricate the custom archwires in the material and cross-section specified by the orthodontists. Research has shown the error in bends and twists with stainless steel archwires to be less than 1°.23

A robust retrospective study investigating the clinical efficiency of SureSmile was completed by Sachdeva et al. in 201223,24, evaluating the treatment records of 9,390 SureSmile patients and 2,945 conventional patients. The group found that the SureSmile cases finished treatment about 8 months faster than the conventional patients and had 4 less treatment visits.24

Larson et al.23 focused on the effectiveness of the SureSmile appliance in a study completed in 2013, which involved the superimposition of the post-treatment digital model on the initial virtual treatment plan model using best-fit surface-based registration. The superimposition allowed comparison of the planned tooth position and the actual case outcome with respect to six dimensions of tooth movement. Mesiodistal and vertical tooth positions were found be the most accurate movements with the SureSmile system, while crown torque, tip and rotation movements were less predictable. Variations in the dimensional accuracy of bracket slots, bone density, root anatomy, occlusal forces, and patient compliance were cited as possible causes for the discrepancies between planned and final tooth position. Nevertheless, the SureSmile system has been shown to be an effective tooth moving appliance when the initial
diagnosis and treatment plan is correctly established and compensations are built into the treatment plan to overcorrect large tooth movements.\textsuperscript{23}

\textbf{Ormco\textsuperscript{®}'s Insignia™}

One of the most comprehensive CAD/CAM orthodontic appliances on the market is Ormco\textsuperscript{®}'s Insignia™, which is available in standard and self-ligating applications with optional use of esthetic ceramic brackets. The process begins with a polyvinyl siloxane (PVS) impression or intraoral scan of the patient’s dentition, which is sent to Ormco\textsuperscript{®} for creation of digital models of the dental arches. The technicians then complete a virtual setup for ideal archform and occlusion that is sent to the clinician for approval. Utilizing Ormco\textsuperscript{®}'s Insignia Approver software, the clinician can manipulate the digital setup to refine the 3-dimensional position of individual teeth, adjust the archform, alter the smile arc when needed, and detail the dental contacts in final centric occlusion.\textsuperscript{18}

Once the clinician approves the treatment plan and virtual setup, the Insignia system is reverse-engineered in one of several ways depending on the clinician’s choice of bracket. If metal twin brackets are selected then they are individualized by precision-cutting the slots in the milled-in faces, while metal self-ligating brackets are customized by varying the thickness and angulations of the bracket base. The selection of ceramic twin or self-ligating brackets limits the amount of customization that can be achieved; however, stock brackets that most closely match the torque prescriptions in the Insignia Approver software are selected. Further adjustments to the positioning jigs and archwires allows for a high degree of individualization for each Insignia setup.\textsuperscript{18}
The final step of the Insignia system is precisely delivering the customized brackets in the ideal position on each tooth to maximize the effectiveness of the individualized appliance. Bracket transfer jigs are milled to fit the occlusal surfaces of the teeth, allowing for simple and reliable placement of the appliances. The jigs allow for three quarters of the bracket pad edges to be exposed during bonding so that the majority of excess composite can be removed prior to polymerization, minimizing composite flash cleanup time after the jigs are removed.\textsuperscript{18}

Weber et al.\textsuperscript{25} investigatedOrmco®’s Insignia, comparing treatment effectiveness and efficiency of the customized appliances to traditional twin appliances. The final outcome differences between the two treatment groups were widespread, with the Insignia cases showing significantly lower ABO scores, a reduced number of archwire appointments, and shorter overall treatment times. These preliminary findings are promising, but further investigation is required before any real benefits can be supported.

**Conclusion**

Significant advances in orthodontic technology have occurred in recent decades, largely due to the incorporation of CAD/CAM technology into the design and fabrication of orthodontic appliances. The clinical evidence to support the efficiency and effectiveness of these appliances is varied, with no single system emerging clearly superior. Further research into the advantages and disadvantages of the available CAD/CAM orthodontic appliances is needed to gain a better understanding of the technology and how it should be best utilized.

The aim of this project is to expand the existing CAD/CAM orthodontic appliance literature by comparing treatment outcomes and efficiency of three different systems: 1) Direct bonded self-ligation brackets (Damon \(Q\), 2) Indirect bonded self-ligation brackets (Damon \(Q\)
and 3) Indirect bonded CAD/CAM self-ligation brackets (*Insignia SL*). The results may provide insight to the true merit of these customized appliances, including their tangible clinical benefits and overall cost effectiveness.
REFERENCES


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ORTHODONTIC BRACKET SYSTEM

Introduction

The goal of orthodontic treatment is to achieve an exemplary treatment outcome in a reasonable amount of time. Orthodontic treatment should not only be effective but also must be efficient, in terms of total treatment time and number of appointments. A critical component of achieving these goals is an optimal orthodontic bracket placed in the ideal position on each tooth.

Nearly 40 years ago, Lawrence F. Andrews developed the first true Straight Wire Appliance (SWA).\textsuperscript{1} Andrews’ brackets had a specific 1\textsuperscript{st}, 2\textsuperscript{nd}, and 3\textsuperscript{rd} order prescription for each tooth, which increased the consistency of treatment results and improved treatment efficiency because fewer bends were required in both aligning and finishing archwires. A multitude of different straight wire bracket prescriptions are now available, all with a common goal of shortening the aligning and finishing stages of orthodontic treatment by minimizing the amount of wire bending.\textsuperscript{2}

A critical element in the success of any SWA is that each bracket must be accurately positioned on every tooth in the arch; however, this is clinically difficult due to anatomical variations in tooth morphology and human error.\textsuperscript{2,3} Balut et al.\textsuperscript{4} completed a study on direct bonding accuracy, analyzing brackets placed on dental casts mounted in mannequins, and found significant differences in both vertical positioning and angulation of the appliances.
Interestingly, removing clinical obstacles such as patient management, isolation control, and visualization difficulties did not eliminate bonding errors amongst experienced clinicians.

In an effort to decrease direct bonding errors and doctor chair side time during bonding appointments, there has been much experimentation with lab-fabricated indirect bonding trays. Many materials have been used for the indirect delivery system, including polyvinyl siloxane (PVS), prosthodontics putties, silicone gels, and thermoplastic trays. The objective of lab-fabricated indirect bonding protocols is to easily and accurately place brackets extra-oral on a handheld model and then precisely transfer the ideally placed brackets to the patient’s teeth. Indirect bonding techniques have shown good bond strength; however, the accuracy of the technique has demonstrated varying success in multiple investigations. Koo et al. found minimal improvements in accuracy with lab-fabricated indirect bonding techniques as compared to direct bonding and found that both failed to execute ideal bracket placement. In addition to inaccurate bracket placement and variations in tooth anatomy, Creekmore et al. cited variations in vertical and anteroposterior jaw relationships, tissue rebound, and inherent mechanical deficiencies of edgewise orthodontic appliances as other factors that must be addressed in the development of an actual “straight wire” orthodontic appliance.

Computer-aided design and computer-aided manufacturing, better known as CAD/CAM, has been a focus of dental research since the 1980s to minimize human error in dentistry. Traditionally, much of the dental utilization of CAD/CAM technology has focused on the milling of crowns and fixed partial dentures (FPDs). Dental applications of CAD/CAM have expanded in recent years as the benefits of the technology have been realized in new applications. Current uses of CAD/CAM technology in orthodontics include: aids for diagnosis and treatment planning, clear aligner therapies, custom labial and lingual systems, and titanium Herbst
appliances. Customized brackets with patient-specific torque, machine-milled indirect bonding jigs, and robotically generated archwires are among recent CAD/CAM advances in achieving a true SWA. The overarching goal of incorporating CAD/CAM technology into the field of orthodontics can be best summed up as “improving reproducibility, efficiency, and quality of orthodontic treatment.”

The applications of CAD/CAM in orthodontics are undoubtedly growing; unfortunately, the clinical evidence to support the application of the technology has not been able to keep pace. Manufacturers of customized orthodontic appliances delivered with milled indirect bonding jigs claim these appliances reduce total treatment time, improve treatment efficiency, and yield better overall treatment results. However, many of these claims are unsubstantiated by scientific evidence. Weber et al. investigated a commercially available CAD/CAM orthodontic system (Ormco’s Insignia™), comparing treatment effectiveness and efficiency of the customized appliances to traditional twin appliances. The study reported significantly lower American Board of Orthodontic (ABO) scores, a reduced number of archwire appointments, and shorter overall treatment times with the CAD/CAM group. While these findings are promising, the study did not distinguish whether the clinical benefits were due to the indirect bonding of the CAD/CAM group or the actual customized brackets.

The aim of this project is to expand the existing CAD/CAM orthodontic appliance literature by comparing treatment effectiveness and efficiency of three different systems: 1) Direct bonded self-ligation brackets (Damon Q), 2) Indirect bonded self-ligation brackets (Damon Q) and 3) Indirect bonded CAD/CAM self-ligation brackets (Insignia SL). The null hypothesis is there will be no difference in effectiveness or efficiency measures between the three treatment groups.
Materials and Methods

Sample

This retrospective study was approved by the Institutional Review Board at the University of North Carolina at Chapel Hill. All cases were treated by a private orthodontic practitioner, T.B., between March of 2008 and August of 2013. During this time, the practitioner sequentially utilized three bonding protocols for comprehensive cases with no overlap:

- **Group 1.** Direct bonded self-ligation (Ormco® *Damon Q*) appliances (2008-2010)

- **Group 2.** Indirect bonded self-ligation (Ormco® *Damon Q*) appliances (2010-2011)

- **Group 3.** Indirect bonded CAD/CAM self-ligation (Ormco® *Insignia SL*) appliances (2011-2013)

Consecutively treated cases from these three treatment groups were identified and the following inclusion and exclusion criteria were applied:

**Inclusion Criteria:**

1. Complete maxillary and mandibular fixed appliances were used.

2. Treatment included only intraoral, intra-arch, and/or inter-arch mechanics.

3. Complete chart entries, pre- and post-treatment digital casts, pre-treatment cephalometric radiographs, and post-treatment panoramic radiographs were available.
Exclusion Criteria:

1. Functional appliances, growth modification, extractions, temporary skeletal anchorage, impacted teeth (other than third molars), or orthognathic surgery was involved in treatment.

2. Post-orthodontic restorative treatment was required.

3. Pre- or post-treatment records were incomplete.

After the inclusion and exclusion criteria were applied to potential cases, Group 1 contained 31 patients, Group 2 contained 33 patients, and Group 3 contained 32 patients. The sequential cases evaluated for inclusion in the study were selected from the middle range of each treatment group patient list to minimize the learning curve effects associated with a new treatment protocol.

Data Collection

Demographic data for study participants included gender and age at the beginning of treatment. Treatment data consisted of the number of treatment appointments (including bonding, archwire adjustments, and debond), duration of treatment (months), initial and final clinic photos, initial cephalometric radiographs, final panoramic radiographs, and pre- and post-treatment E-Model digital casts. The post-treatment digital models were converted from E-Model’s proprietary software file format into a stereolithography (STL) file and then printed on a 3-D printer (iPro 8000, 3D Systems, Rockhill, SC). All subjects and treatment data were assigned a random coded number by a research assistant to blind the evaluator (M.B.) during data scoring and analysis.
The ABO Discrepancy Index (Figure 1) was performed on pre-treatment digital casts using E-Model’s software analysis program and by evaluation of the initial cephalometric radiographs. The ABO Discrepancy Index score established a numerical value correlating to the relative severity of orthodontic problems associated with each case. The stereolithography (SLA) post-treatment models and final panoramic radiographs were evaluated using the ABO Cast/Radiograph Evaluation (Figure 2) to objectively quantify the treatment outcome of each individual case. Prior to data collection, the evaluator was trained and calibrated on both the ABO Discrepancy Index and ABO Cast/Radiograph Evaluation techniques. The evaluator performed all measurements and case analyses.

One week after completion of the data collection, the ABO Cast/Radiograph Evaluation was repeated on 10 randomly selected cases to assess intra-examiner reliability. The intra-class correlation coefficient (ICC) was 0.91, which shows almost perfect correlation and demonstrates the reliability and consistency of the PI with the evaluation techniques.

**Statistical Analysis**

Statistical analysis was performed using SPSS version 22.0 (Clearwater, FL). A two-tailed t-test was used to analyze subject age between the groups at beginning of treatment. The Kruskal-Wallis Test was used to analyze the ABO Discrepancy Index values, the ABO Cast/Radiograph categorical values and overall scores, treatment duration (in months), and number of treatment appointments. The Benjamini-Hochberg test was then applied to control for the false discovery rate (FDR). A multiple comparison test was used for post-hoc analysis.
**Results**

The median age at the beginning of treatment for Group 1 was 13.58, Group 2 was 13.92, and Group 3 was 13.42 (Table 1). There were no significant differences in median age between the treatment groups (p=0.57). Group 1 was composed of 15 females and 16 males, Group 2 consisted of 17 females and 16 males, and Group 3 contained 17 females and 15 males (Table 1). The ABO Discrepancy Index was 16.0±9.1 for Group 1, 15.9±8.1 for Group 2, and 16.8±6.5 for Group 3 (Table 2). These differences in ABO Discrepancy Index were not statistically significant (p=0.56).

**Effectiveness**

The final ABO Cast/Radiograph Evaluation score was 28.5±8.5 for Group 1, 32.3±7.8 for Group 2, and 32.2±9.3 for Group 3 (Table 2). No statistically significant difference was found between the three treatment groups (p=0.13). In addition, none of the eight categories comprising the ABO Cast/Radiograph Evaluation were found to be significantly different among the treatment groups (Figure 3).

**Efficiency**

The mean treatment time (in months) was significantly different (p<0.05) among all groups (Group 1 = 21.9±5.0, Group 2 = 16.9±4.1, Group 3 = 13.8±3.4) (Table 2, Figure 4). The mean number of appointments during treatment was 16.5±4.0 for Group 1, 14.9±3.7 for Group 2, and 14.1±3.9 for Group 3 (Table 2). Group 1 and Group 3 were found to be significantly different (p<0.05), while neither Group 1 and Group 2 nor Group 2 and Group 3 was found to be statistically different from the other (Table 3, Figure 4).
Discussion

This retrospective study analyzed 96 orthodontic patients distributed among three treatment groups, each containing consecutively treated cases, to compare the effectiveness and efficiency of direct bonded stock appliances, indirect bonded stock appliances, and indirect bonded CAD/CAM appliances. The demographic data and initial ABO Discrepancy Index was not significantly different among the three groups; therefore, it can be assumed that the distribution and severity of the initial orthodontic problems was similar among the treatment protocols.

One of the major goals of CAD/CAM orthodontic appliances is to improve the final case outcome. The utilization of virtual treatment planning combined with precise milling of indirect bonding jigs and customized brackets should lead to accurate tooth movement. Intuitively, these systems should reduce the effects of human error during orthodontic treatment, account for anatomical variations present in tooth shape, and improve the overall finished case quality. However, in this study there was no significant difference found between the ABO Cast/Radiograph Evaluation scores for any of the treatment groups. In addition, none of the eight individual categories that comprise the final evaluation score were found to be significantly different. Interestingly, the mean ABO Cast/Radiograph Evaluation was nearly 4 points lower for the Direct bonded group when compared to the Indirect bonded and CAD/CAM groups. Though the difference was not statistically significant, it is surprising that the treatment protocol with the least patient customization also had the lowest mean ABO Cast/Radiograph Evaluation score. A possible explanation is that the Direct bonded group had the longest mean treatment time, thus the finishing archwires may have had increased time to more fully express the prescription of the appliance and potentially improve the case outcomes.
In contrast to treatment effectiveness, the overall treatment efficiency varied substantially among the treatment groups and highlighted the potential merit of CAD/CAM orthodontic appliances. The total treatment time for the CAD/CAM group was over 8 months shorter than the Direct bonded group and about 3 months shorter than the Indirect bonded group. The 8 month difference in treatment time between CAD/CAM appliances and direct bonded stock appliances translates to about a 36% reduction in treatment duration, which is significant to both practitioners and patients. The Indirect bonded group showed a 5 month reduction in treatment time when compared to the Direct bonded group and treatment times were only 3 months longer than the CAD/CAM group, suggesting the indirect bonding process had a bigger impact on treatment duration than the customized appliances.

The other measure of treatment efficiency investigated was the number of appointments required to complete each case. The three treatment groups were fairly similar, with the only significant difference coming from the comparison of the CAD/CAM group to the Direct bonded group. On average, the CAD/CAM cases finished treatment with about 2.5 less appointments, a reduction of approximately 15%, compared to the Direct bonded group.

Though overall treatment time varied significantly among the treatment groups, the minimal variation in the number of appointments means that the interval between visits was shorter for the CAD/CAM group. In other words, the CAD/CAM cases finished treatment in a fewer number of months but this was at least partly because these patients were seen more frequently. A reduction in overall treatment time potentially benefits patients by reducing the total time they experience the oral hygiene and trauma risks associated with orthodontic treatment, and patients typically desire a decreased duration of the esthetic impact of fixed appliances. However, the minimal difference in number of appointments means that patients in
all treatment groups still had to undergo a similar burden of orthodontic treatment in regard to missing school and work as well as time and expense spent traveling to their orthodontist’s office. From a practitioner’s standpoint, shorter overall treatment times can reduce the volume of patients in fixed appliances at a given time, possibly allowing room for practice growth, and may be viewed as a positive attribute of the practice by prospective patients. However, the small decrease in treatment appointments means that a similar amount of chair time is required for patients treated with any of the three protocols investigated, which minimizes the true increase in clinical efficiency of the CAD/CAM designed appliances.

The reduction in total treatment time for the CAD/CAM group is similar to the findings by Weber et al.\textsuperscript{14}; however, the significant decreases in number of archwire appointments and ABO Cast/Radiograph Evaluation scores differ from the findings in this study. One possible explanation is that the previous study combined data from two clinicians to obtain adequate power while a single clinician treated all cases in this study. Clinicians often have different criteria for debonding cases and vary in appointment scheduling preferences, which likely affected the outcome measures of effectiveness and efficiency in both studies. Furthermore, the sample size of the Direct bonded group in their study was smaller (N=11) and more subject to variability.

This study analyzed digital models created from scanned impressions and high definition SLA models, as opposed to plaster casts which were used in the study by Weber et al.\textsuperscript{14}. In 2013, Wiranto et al.\textsuperscript{15} investigated the validity, reliability, and reproducibility of digital models created from scanned alginate impressions, concluding that digital models are acceptable for obtaining dental measurements for diagnostic purposes. Hazeveld et al.\textsuperscript{16} investigated the accuracy and reproducibility of digital models converted into physical models using rapid prototyping,
including the jetted photopolymer technique that was utilized in this study. The SLA models were found to have accuracy within 0.05-0.08mm. These recent findings validate the use of the digital and 3-dimensional models utilized in this study and eliminate the possibility of systematic error.

Further investigation of CAD/CAM orthodontic appliances is needed and ideally would require prospective randomized clinical trials. An important factor in future studies would involve standardization of appointment intervals between different treatment groups to better identify potential differences in clinical efficiency. In addition, increasing the sample size of the treatment groups would minimize the effects of the clinician’s clinical judgment, patient compliance, and individual biological response to orthodontic treatment on the measures of clinical effectiveness and efficiency. Another area of interest would involve the comparison of CAD/CAM appliances to CAD/CAM archwires to provide more insight as to whether customized brackets or customized wires have a bigger impact on treatment outcomes. The use of robotically bent archwires allows clinicians to use an orthodontic bracket of their choice and also select as many or as few custom archwires as they desire based on the progress of the case, which may increase the applications of the technology.17,18

Ultimately, the success of a true SWA requires appropriate treatment planning and the correct identification of treatment outcomes before appliance design or delivery begins. Additionally, the play between the archwire and the bracket slot of an ideally positioned bracket must be minimized and the full-sized archwire should be left in place long enough to fully express the position and prescription of each bracket. Unfortunately, the force diminution of current archwire materials means that calculated overcorrection of more difficult tooth movements is also critical, but the degree of overcorrection is difficult to determine as resistance
to tooth movement is often multifactorial and patient-specific. Orthodontic technology is improving rapidly and the incorporation of CAD/CAM has been positive for the specialty; however, the didactic and clinical skill of the practitioner will remain paramount as thoughtful treatment planning and mid-treatment adjustments of appliances and archwires are critically important even with the newest orthodontic systems.

**Conclusions**

The null hypothesis was confirmed for measures of treatment effectiveness but rejected in respect to treatment efficiency, leading to the following conclusions:

- CAD/CAM orthodontic appliances produce similar treatment outcomes compared to direct and indirect bonded appliances.

- The CAD/CAM group had shorter treatment times compared to the Direct and Indirect bonded groups, while the decrease in treatment appointments was minimal.

- Further investigation is needed to better quantify the clinical benefits of CAD/CAM orthodontic appliances.
Table 1. Sample Demographic Data

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Median Age</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>31</td>
<td>13.58</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Group 2</td>
<td>33</td>
<td>13.92</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Group 3</td>
<td>32</td>
<td>13.42</td>
<td>17</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 1 displays the age and gender distribution of the 3 treatment groups (p=0.57).

Table 2. ABO Discrepancy Index and Treatment Outcomes

<table>
<thead>
<tr>
<th></th>
<th>0%(MIN)</th>
<th>25%</th>
<th>50%(MEDIAN)</th>
<th>75%</th>
<th>100%(MAX)</th>
<th>MEAN</th>
<th>SD</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABO DI</td>
<td>Group 1</td>
<td>2</td>
<td>12</td>
<td>15</td>
<td>19</td>
<td>44</td>
<td>16</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>Group 2</td>
<td>4</td>
<td>12</td>
<td>14</td>
<td>19</td>
<td>40</td>
<td>15.9</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>Group 3</td>
<td>5</td>
<td>13</td>
<td>17</td>
<td>20</td>
<td>33</td>
<td>16.8</td>
<td>6.5</td>
</tr>
<tr>
<td>ABO CRE</td>
<td>Group 1</td>
<td>15</td>
<td>21.5</td>
<td>28</td>
<td>34.5</td>
<td>47</td>
<td>28.5</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>Group 2</td>
<td>18</td>
<td>26</td>
<td>34</td>
<td>37</td>
<td>52</td>
<td>32.3</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>Group 3</td>
<td>17</td>
<td>26.5</td>
<td>34</td>
<td>39</td>
<td>49</td>
<td>32.2</td>
<td>9.3</td>
</tr>
<tr>
<td>Treatment Time</td>
<td>Group 1</td>
<td>12</td>
<td>19</td>
<td>22</td>
<td>25</td>
<td>33</td>
<td>21.9</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Group 2</td>
<td>9</td>
<td>15</td>
<td>18</td>
<td>19</td>
<td>30</td>
<td>16.9</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>Group 3</td>
<td>8</td>
<td>11</td>
<td>13</td>
<td>17</td>
<td>21</td>
<td>13.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Treatment Apps</td>
<td>Group 1</td>
<td>10</td>
<td>14</td>
<td>16</td>
<td>19</td>
<td>28</td>
<td>16.5</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Group 2</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td>18</td>
<td>25</td>
<td>14.9</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Group 3</td>
<td>8</td>
<td>11</td>
<td>13</td>
<td>17</td>
<td>23</td>
<td>14.1</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Table 2 displays the American Board of Orthodontics Discrepancy Index (ABO DI), American Board of Orthodontics Cast/Radiograph Evaluation (ABO CRE), Treatment Time (in months), and Number of Treatment appointments for the 3 treatment groups. Statistical significance was set at p<0.05.

Table 3. Multiple Comparisons Test of Treatment Appointments

<table>
<thead>
<tr>
<th>Comparisons</th>
<th>Observed Difference</th>
<th>Critical Difference</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups 1-2</td>
<td>12.212121</td>
<td>16.92799</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Groups 1-3</td>
<td>19.742424</td>
<td>16.92799</td>
<td>Significant</td>
</tr>
<tr>
<td>Groups 2-3</td>
<td>7.530303</td>
<td>16.92799</td>
<td>Not Significant</td>
</tr>
</tbody>
</table>

Table 3 displays the statistical difference for number of appointments between the three treatment groups. The level for critical difference was set at 16.92799.
Figure 1. ABO Discrepancy Index Form

<table>
<thead>
<tr>
<th>EXAM YEAR</th>
<th>ABO DISCREPANCY INDEX</th>
<th>PATIENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABO ID #</td>
<td>Version 2011-2013</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL D.I. SCORE**

<table>
<thead>
<tr>
<th>OVERBITE</th>
<th>LINIAL POSTERIOR X-BITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 6 mm, (angle to angle)</td>
<td>1 pt. per tooth</td>
</tr>
<tr>
<td>7 - 9 mm.</td>
<td>0.5 pt. per tooth</td>
</tr>
<tr>
<td>10 - 12 mm.</td>
<td>0.25 pt. per tooth</td>
</tr>
<tr>
<td>&gt; 12 mm.</td>
<td>0.1 pt. per tooth</td>
</tr>
</tbody>
</table>

**ANTERIOR OPEN BITE**

<table>
<thead>
<tr>
<th>OVERBITE</th>
<th>2 pts. per mm. per tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 3 mm.</td>
<td>Total</td>
</tr>
<tr>
<td>4 - 5 mm.</td>
<td>0.5 pt.</td>
</tr>
<tr>
<td>6 - 7 mm.</td>
<td>0.25 pt.</td>
</tr>
</tbody>
</table>

**LINGUAL POSTERIOR X-BITE**

<table>
<thead>
<tr>
<th>OVERBITE</th>
<th>1 pt. per tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 3 mm.</td>
<td>Total</td>
</tr>
<tr>
<td>4 - 5 mm.</td>
<td>0.5 pt.</td>
</tr>
<tr>
<td>6 - 7 mm.</td>
<td>0.25 pt.</td>
</tr>
</tbody>
</table>

**MARGINAL RIDGES**

<table>
<thead>
<tr>
<th>OVERBITE</th>
<th>1 pt. per mm. per tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 2 mm.</td>
<td>Total</td>
</tr>
<tr>
<td>3 - 4 mm.</td>
<td>0.5 pt.</td>
</tr>
<tr>
<td>5 - 6 mm.</td>
<td>0.25 pt.</td>
</tr>
</tbody>
</table>

**OCCLUSION**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>OVERBITE</th>
<th>1 pt. per mm. per tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>0 - 2 mm.</td>
<td>Total</td>
</tr>
<tr>
<td>Class II</td>
<td>&gt; 2 mm.</td>
<td>0.5 pt.</td>
</tr>
<tr>
<td>Class III</td>
<td>&gt; 4 mm.</td>
<td>0.25 pt.</td>
</tr>
</tbody>
</table>

**INSTRUCTIONS:** Place score beside each deficient tooth and enter total score for each parameter in the white box. Mark extracted teeth with “X”. Second bicuspid should be in occlusion.

Figure 2. ABO Cast/Radiograph Evaluation Form

[Image of ABO Cast/Radiograph Evaluation Form]

[Diagram showing various dental parameters for evaluation]
Figure 3. ABO Cast/Radiograph Evaluation
Figure 4. Treatment Time (in months) and Number of Treatment Appointments
REFERENCES


