AJO-DO

Effectiveness and efficiency of a CAD/CAM orthodontic bracket system

Matthew W. Brown,[a] Lorne Koroluk,[b] Ching-Chang Ko,[c] Kai Zhang,[d] Mengqi Chen,[e] and Tung Nguyen[f]
Kinston and Chapel Hill, NC

Introduction: The first straight-wire appliance was introduced over 40 years ago to increase the consistency and efficiency of orthodontic treatment. More recently, computer-aided design and computer-aided manufacturing (CAD/CAM) technology has been used to create individualized orthodontic appliances. The purpose of this study was to investigate the clinical effectiveness and efficiency of CAD/CAM customized orthodontic appliances compared with direct and indirect bonded stock orthodontic brackets. **Methods:** This retrospective study included 3 treatment groups: group 1 patients were direct bonded with self-ligating appliances, group 2 patients were indirect bonded with self-ligating appliances, and group 3 patients were indirect bonded with CAD/CAM self-ligating appliances. Complete pretreatment and posttreatment records were obtained for all patients. The American Board of Orthodontics (ABO) Discrepancy Index was used to evaluate the pretreatment records, and the posttreatment outcomes were analyzed using the ABO Cast-Radiograph Evaluation. All data collection and analysis were completed by 1 evaluator. **Results:** There were no statistically significant differences in the ABO Discrepancy Index or the ABO Cast-Radiograph Evaluation among the groups. Treatment times for the 3 groups were significantly different; the CAD/CAM group was the shortest at 13.8 $\pm$ 3.4 months, compared with 21.9 $\pm$ 5.0 and 16.9 $\pm$ 4.1 months for the direct bonded and indirect bonded groups, respectively. The number of treatment appointments for the CAD/CAM group was significantly fewer than for the direct bonded group. **Conclusions:** The CAD/CAM orthodontic bracket system evaluated in this study was as effective in treatment outcome measures as were standard brackets bonded both directly and indirectly. The CAD/CAM appliance was more efficient in regard to treatment duration, although the decrease in total archwire appointments was minimal. Further investigation is needed to better quantify the clinical benefits of CAD/CAM orthodontic appliances. (Am J Orthod Dentofacial Orthop 2015;148:1067-74)

The goal of orthodontic treatment is to achieve an exemplary treatment outcome in a reasonable amount of time. Orthodontic treatment should be not only effective, but also 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, Andrews[1] developed the first true straight-wire appliance. Andrews' brackets had specific first-, second-, and third-order prescriptions for each tooth; this increased the consistency of the treatment results and improved the treatment efficiency because fewer bends were required in both aligning and finishing archwires. Many 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.[2]

A critical element in the success of any straight-wire appliance is that each bracket must be accurately positioned on every tooth in the arch; however, this is clinically difficult because of anatomic variations in tooth morphology and human error.[2,3] Balut et al[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,

[a]Private practice, Kinston, NC.
[b]Associate professor and chairman, Department of Orthodontics, University of North Carolina, Chapel Hill, NC.
[c]Distinguished professor and program director, Department of Orthodontics, University of North Carolina, Chapel Hill, NC.
[d]Assistant professor, Department of Statistics and Operations Research, University of North Carolina, Chapel Hill, NC.
[e]PhD candidate, Department of Statistics and Operations Research, University of North Carolina, Chapel Hill, NC.
[f]Assistant professor, Department of Orthodontics, University of North Carolina, Chapel Hill, NC.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Address correspondence to: Tung Nguyen, Department of Orthodontics, UNC School of Dentistry, CB#7450, Chapel Hill, NC 27599-7450; e-mail, tung_nguyen@unc.edu.
Submitted, May 2015; revised and accepted, July 2015.
0889-5406/$36.00

http://dx.doi.org/10.1016/j.ajodo.2015.07.029

removing clinical obstacles such as patient management, isolation control, and visualization difficulties did not eliminate bonding errors by experienced clinicians.

To decrease direct bonding errors and doctor chairside time during bonding appointments, there has been much experimentation with laboratory-fabricated indirect bonding trays. Many materials have been used for the indirect delivery system, including polyvinyl siloxane, prosthodontics putties, silicone gels, and thermoplastic trays.[5] The objective of laboratory-fabricated indirect bonding protocols is to easily and accurately place brackets extraorally 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 had varying success in several investigations.[5-8] Koo et al[9] found minimal improvements in accuracy with laboratory-fabricated indirect bonding techniques compared with direct bonding; both failed to execute ideal bracket placement. In addition to inaccurate bracket placement and variations in tooth anatomy, Creekmore and Kunik[2] 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 (CAD/CAM) have 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.[10] 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.[11] 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 straight-wire appliance. The overarching goal of incorporating CAD/CAM technology into orthodontics can be best summed up as "improving reproducibility, efficiency, and quality of orthodontic treatment."[12]

The applications of CAD/CAM in orthodontics are undoubtedly growing; unfortunately, the clinical evidence to support the applications of the technology has not kept pace. Manufacturers of customized orthodontic appliances delivered with milled indirect bonding jigs claim that these appliances reduce total treatment time, improve treatment efficiency, and yield better overall treatment results.[13] However, many of these claims are unsubstantiated by scientific evidence. Weber et al[14] investigated a commercially available CAD/CAM orthodontic system comparing treatment effectiveness and efficiency of the customized appliances to traditional twin appliances. The study reported significantly lower American Board of Orthodontic (ABO) scores, fewer archwire appointments, and shorter overall treatment times in the CAD/CAM group. Although these findings are promising, the study did not distinguish whether the clinical benefits were due to indirect bonding in the CAD/CAM group or the actual customized brackets.

The aim of our study was to expand the existing CAD/CAM orthodontic appliance literature by comparing treatment effectiveness and efficiency of 3 systems: (1) direct bonded self-ligating brackets, (2) indirect bonded self-ligating brackets, and (3) indirect bonded CAD/CAM self-ligating brackets. The null hypothesis was there will be no difference in effectiveness or efficiency measures among the 3 treatment groups.

MATERIAL AND METHODS

This retrospective study was approved by the institutional review board at the University of North Carolina at Chapel Hill. All patients were treated by a private orthodontic practitioner between March 2008 and August 2013. During this time, the practitioner sequentially used 3 bonding protocols for comprehensive patients with no overlap: group 1, direct bonded self-ligating (Damon Q; Ormco, Orange, Calif) appliances (2008-2010); group 2, indirect bonded self-ligating (Damon Q; Ormco) appliances (2010-2011); and group 3, indirect bonded CAD/CAM self-ligating (Insignia SL; Ormco) appliances (2011-2013).

Consecutively treated patients from these 3 treatment groups were identified, and the following criteria were applied. The inclusion criteria were (1) complete maxillary and mandibular fixed appliances were used; (2) treatment included only intraoral, intra-arch, or interarch mechanics; and (3) complete chart entries, pretreatment and posttreatment digital casts, pretreatment cephalometric radiographs, and posttreatment panoramic radiographs were available. The exclusion criteria were (1) functional appliances, growth modification, extractions, temporary skeletal anchorage, impacted teeth (other than third molars), or orthognathic surgery was involved in treatment; (2) postorthodontic restorative treatment was required; and (3) pretreatment or posttreatment records were incomplete.

After the inclusion and exclusion criteria were applied to the potential subjects, group 1 contained 31 patients,

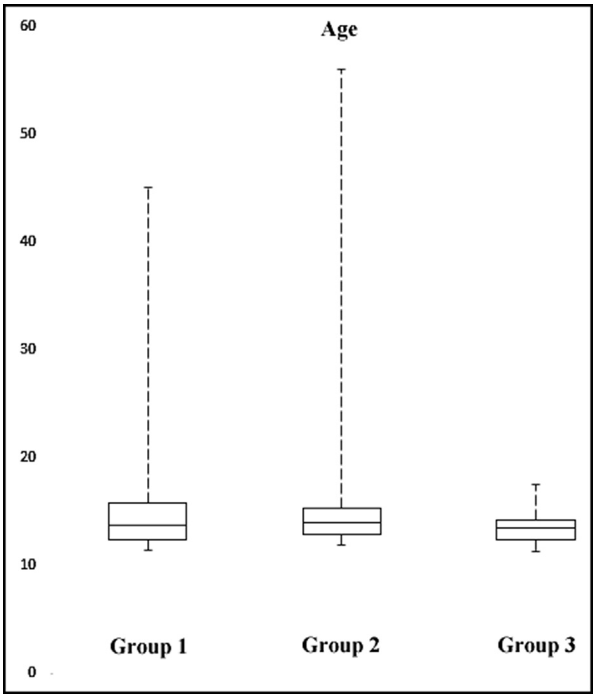

Fig 1. Box plots comparing the ages of the 3 treatment groups. There was no statistical difference between the groups.

group 2 contained 33 patients, and group 3 contained 32 patients. The sequential patients evaluated for inclusion in the study were selected from the middle range of the patient list of each treatment group to minimize the learning-curve effects associated with a new treatment protocol.

Demographic data for the study participants included sex and age at the beginning of treatment. Treatment data consisted of the number of treatment appointments (including bonding, archwire adjustments, emergencies, and debonding), duration of treatment (months), initial and final clinical photographs, initial cephalometric radiographs, final panoramic radiographs, and pretreatment and posttreatment eModel digital casts (GeoDigm Corp, Falcon Height, Minn). Emergencies were counted as appointments if brackets were replaced or wires changed, but not if long wires extending out of molar tubes were clipped. Although digital measures of overjet, overbite, and crowding have been validated, marginal ridge, buccolingual inclination, and occlusal contacts have not. Therefore, the posttreatment digital models were converted from eModel's proprietary software file format into a stereolithography file and then printed on a 3-dimensional 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.W.B.) during data scoring and analysis.

Table I. Sample demographic data

	n	*Median age (y)*	*Females (n)*	*Males (n)*
Group 1	31	13.58	15	16
Group 2	33	13.92	17	16
Group 3	32	13.42	17	15

The Kruskal-Wallis test showed no significant difference between the groups ($P = 0.251$).

The ABO Discrepancy Index was used on the pretreatment digital casts using eModel's software analysis program and by evaluation of the initial cephalometric radiographs. The ABO Discrepancy Index score established a numeric value correlating to the relative severity of the orthodontic problems of each subject. The stereolithography posttreatment models and final panoramic radiographs were evaluated using the ABO Cast-Radiograph Evaluation to objectively quantify the treatment outcome of each patient. Before data collection, the evaluator was trained and calibrated on both the ABO Discrepancy Index and the ABO Cast-Radiograph Evaluation techniques. He performed all measurements and case analyses.

One week after completion of the data collection, the ABO Discrepancy Index and Cast-Radiograph Evaluation were repeated on 10 randomly selected subjects to assess intraexaminer reliability. The intraclass correlation coefficient values were 0.95 for the ABO Discrepancy Index and 0.91 for the ABO Cast-Radiograph Evaluation scores; these show almost perfect correlations and demonstrate the reliability and consistency of the principal investigator with the evaluation techniques.

Statistical analysis

Statistical analysis was performed using SPSS software (version 22.0; IBM, Armonk, NY). The age distribution of the groups at the beginning of treatment is shown in Figure 1. Age, ABO Discrepancy Index values, ABO Cast-Radiograph categorical values and overall scores, treatment duration (months), and number of treatment appointments did not pass normality testing; therefore, the Kruskal-Wallis test was used for statistical analysis. The Benjamini-Hochberg test was then applied to control for the false discovery rate. A multiple comparison test was used for the post hoc analysis.

RESULTS

The median ages at the beginning of treatment were 13.58, 13.92, and 13.42 years for groups 1, 2, and 3, respectively (Table 1; Fig 1). There were no significant differences in the median ages between the groups

Table II. ABO discrepancy index and treatment outcomes

	0% (minimum)	*25%*	*50% (median)*	*75%*	*100% (maximum)*	*Mean*	*SD*	*P value*
ABO DI								0.56
Group 1	2	12	15	19	44	16.0	9.1	
Group 2	4	12	14	19	40	15.9	8.1	
Group 3	5	13	17	20	33	16.8	6.5	
ABO CRE								0.13
Group 1	15	21.5	28	34.5	47	28.5	8.5	
Group 2	18	26	34	37	52	32.3	7.8	
Group 3	17	26.5	34	39	49	32.2	9.3	
Treatment time (mo)								<0.001
Group 1	12	19	22	25	33	21.9	5.0	
Group 2	9	15	18	19	30	16.9	4.1	
Group 3	8	11	13	17	21	13.8	3.4	
Treatment appointments (n)								0.02
Group 1	10	14	16	19	28	16.5	4.0	
Group 2	9	12	14	18	25	14.9	3.7	
Group 3	8	11	13	17	23	14.1	3.9	

Statistical significance was set at $P < 0.05$.
ABO DI, American Board of Orthodontics Discrepancy Index; *ABO CRE*, American Board of Orthodontics Cast-Radiograph Evaluation.

($P = 0.252$). Group 1 consisted of 15 females and 16 males, group 2 consisted of 17 females and 16 males, and group 3 consisted of 17 females and 15 males (Table I). The ABO Discrepancy Index values were 16.0 ± 9.1 for group 1, 15.9 ± 8.1 for group 2, and 16.8 ± 6.5 for group 3 (Table II). These differences were not statistically significant ($P = 0.56$).

For effectiveness, the final ABO Cast-Radiograph Evaluation scores were 28.5 ± 8.5 for group 1, 32.3 ± 7.8 for group 2, and 32.2 ± 9.3 for group 3 (Table II). No statistically significant difference was found among the 3 treatment groups ($P = 0.13$). In addition, none of the 8 categories comprising the ABO Cast-Radiograph Evaluation was significantly different among the groups (Fig 2).

For efficiency, the mean treatment times (months) were significantly different ($P < 0.05$) among the groups (group 1, 21.9 ± 5.0; group 2, 16.9 ± 4.1; group 3, 13.8 ± 3.4) (Table II). The mean numbers of appointments during treatment were 16.5 ± 4.0 for group 1, 14.9 ± 3.7 for group 2, and 14.1 ± 3.9 for group 3 (Table II). Groups 1 and 3 were significantly different ($P < 0.05$), whereas neither groups 1 and 2 nor groups 2 and 3 were found to be statistically different from the other (Table III; Fig 3). The appointment intervals were different among the groups (group 1, 1.1 months; group 2, 1.3 months; group 3, 1.4 months) (Fig 4; Table IV).

DISCUSSION

In this retrospective study, we analyzed 96 orthodontic patients distributed among 3 treatment groups, each containing consecutively treated patients, 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 were not significantly different among the 3 groups; therefore, it can be assumed that the distribution and severity of the initial orthodontic problems were similar among the treatment protocols.

One major goal of CAD/CAM orthodontic appliances is to improve the final outcome. The use 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 anatomic variations in tooth shape, and improve the overall finished treatment quality. However, in this study, there was no significant difference between the ABO Cast-Radiograph Evaluation scores for any of the treatment groups. In addition, none of the 8 categories that comprise the final evaluation score was significantly different. Interestingly, the mean ABO Cast-Radiograph Evaluation was nearly 4 points lower for the direct bonded group than for the indirect bonded and the CAD/CAM groups. Although 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 outcome.

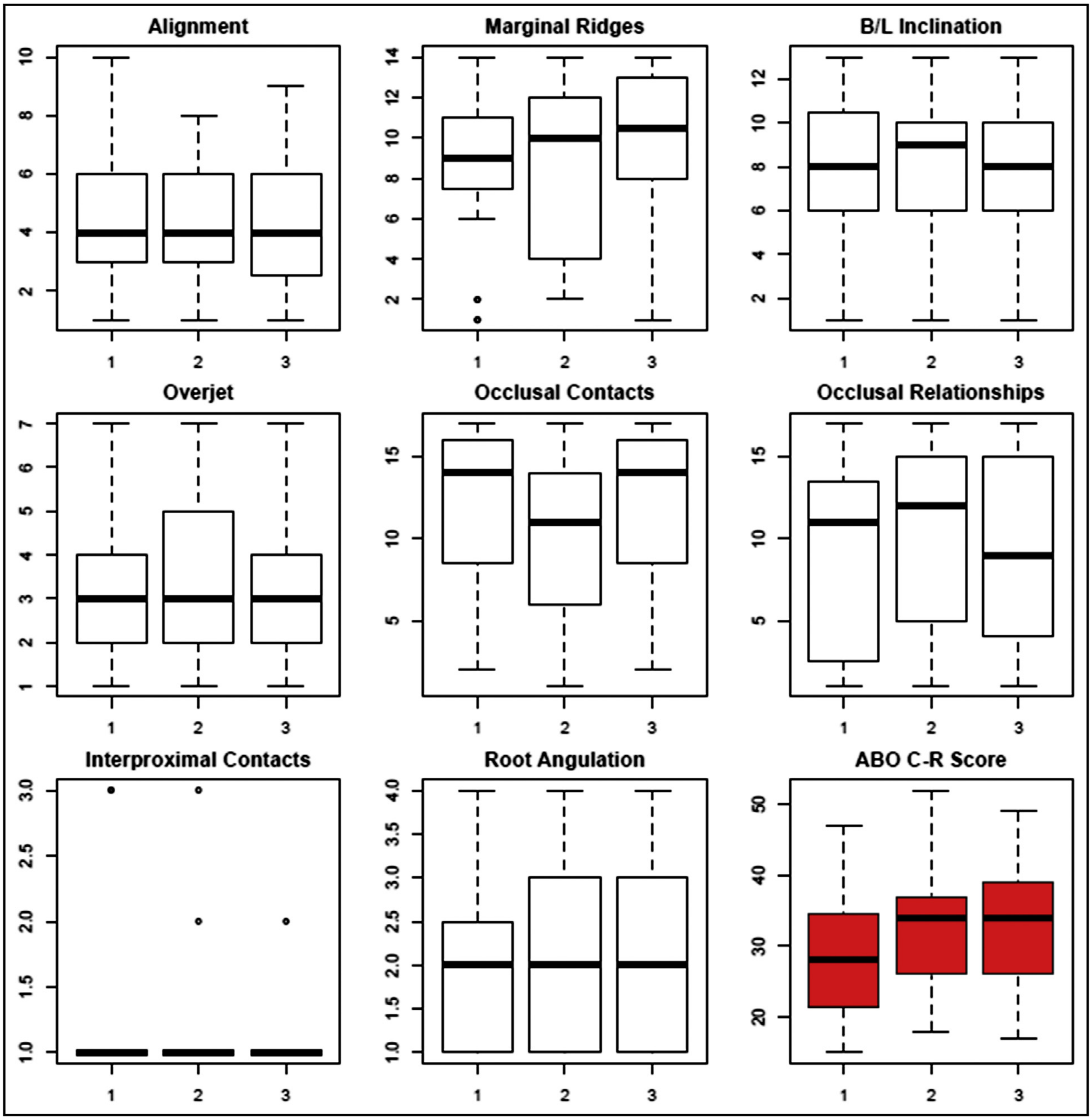

Fig 2. Box plots comparing the criteria of the ABO Cast-Radiograph Evaluation for the 3 treatment groups. There was no statistical difference between the groups.

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 more than 8 months shorter than for the direct bonded group and about 3 months shorter than for 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 with the direct bonded group, and treatment times were only 3 months longer than the CAD/CAM group, suggesting that the indirect bonding process had a

Table III. Multiple comparisons test of treatment appointments

Comparisons	*Observed difference*	*Critical difference*	*Difference*
Groups 1-2	12.21	16.93	Not significant
Groups 1-3	19.74	16.93	Significant
Groups 2-3	7.53	16.93	Not significant

Statistical differences for number of appointments between the groups. The level for critical difference was set at 16.93.

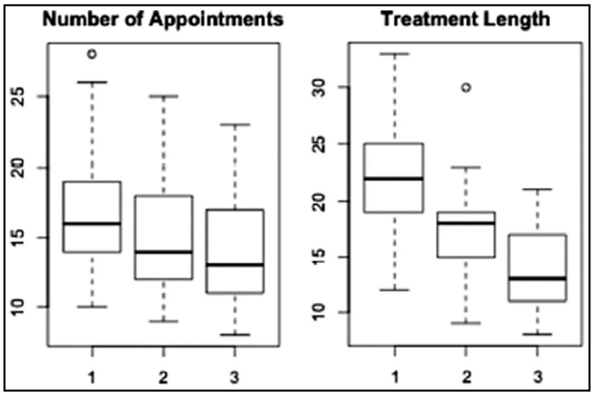

Fig 3. Box plots comparing the numbers of appointments and treatment times (months) for the 3 treatment groups. Groups 1 and 3 were statistically significant for numbers of appointments. Groups 1, 2, and 3 were all statistically significant for treatment length.

greater impact on treatment duration than did the customized appliances. It can be inferred that the CAD/CAM process with custom torque, tip, and wires accounted for only a 3-month reduction in treatment time.

The other measure of treatment efficiency investigated was the number of appointments required to complete each patient's treatment. The 3 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 subjects finished treatment with about 2.5 fewer appointments, a reduction of approximately 15% compared with the direct bonded group.

Although overall treatment time varied significantly among the treatment groups, there were small differences among the numbers of appointments. The average intervals between appointments for the groups were 1.4 months (direct bonded), 1.3 months (indirect bonded), and 1.1 months (CAD/CAM). In other words, the CAD/CAM patients finished treatment in fewer months, but this was at least partly because they were seen more frequently. A reduction in overall treatment time potentially benefits patients by reducing the total

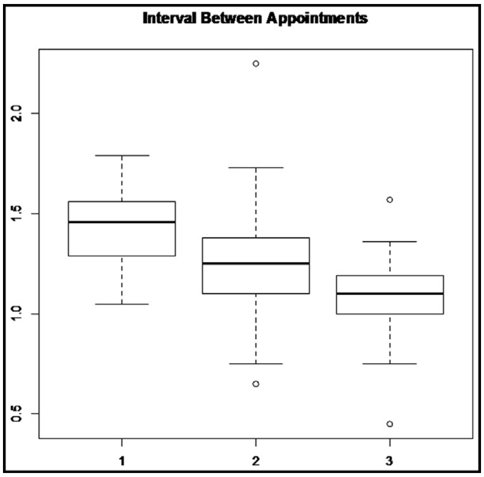

Fig 4. Box plot comparing appointment intervals (months) for the 3 treatment groups. All 3 groups were statistically different.

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 the 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 3 protocols investigated; this minimizes the true increase in the clinical efficiency of the CAD/CAM appliances. We could not determine whether the shorter appointment interval for the CAD/CAM group, which had an effect on total treatment time, was due to faster alignment and leveling or a change in clinician preference. Future studies need to standardize the treatment intervals between groups to accurately evaluate treatment efficiency.

The reduction in total treatment time for the CAD/CAM group is similar to the findings by Weber et al[14]; however, the significant decreases in the 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 2 clinicians to obtain adequate power, whereas 1 clinician treated all patients in this study. Clinicians often have different criteria for debonding and

Table IV. Multiple comparisons test of appointment intervals

Comparison	*Observed difference*	*Critical difference*	*Difference*
Groups 1-2	21.53	16.93	Significant
Groups 1-3	40.15	16.93	Significant
Groups 2-3	18.62	16.93	Significant

Statistical differences for appointment intervals between groups. The level for critical difference was set at 16.93.

vary in appointment scheduling preferences; these most 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.

We analyzed digital models created from scanned impressions and high-definition stereolithography models, rather than plaster casts, which were used in the study by Weber et al.[14] In 2013, Wiranto et al[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[16] investigated the accuracy and reproducibility of digital models converted into physical models using rapid prototyping, including the jetted photopolymer technique that was used in this study. The stereolithography models were found to have accuracy within 0.05 to 0.08 mm. These recent findings validate the use of the digital and 3-dimensional models 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 controlled trials. An important factor in future studies would involve standardization of appointment intervals between the treatment groups to better identify potential differences in clinical efficiency. In addition, increasing the sample sizes of the groups would minimize the effects of the clinician's clinical judgment, patient compliance, and individual biologic response to orthodontic treatment on the measures of clinical effectiveness and efficiency. Another area of interest would involve the comparison of CAD/CAM appliances with CAD/CAM archwires to provide more insight as to whether customized brackets or customized wires have a greater impact on treatment outcomes. Robotically bent archwires allow 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; this might increase the applications of the technology.[17,18]

Ultimately, the success of a true straight-wire appliance requires appropriate treatment planning and the correct identification of treatment outcomes before 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 the prescription of each bracket. Unfortunately, the force diminution of current archwire materials means that calculated overcorrection of more challenging tooth movements is also critical, but the degree of overcorrection is difficult to determine because 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 because thoughtful treatment planning and midtreatment 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 for treatment efficiency, leading to the following conclusions.

1. CAD/CAM orthodontic appliances produce similar treatment outcomes compared with direct and indirect bonded appliances.
2. The CAD/CAM group had shorter treatment times than the direct and indirect bonded groups, whereas the decrease in treatment appointments was minimal.
3. Further investigation is needed to better quantify the clinical benefits of CAD/CAM orthodontic appliances.

ACKNOWLEDGMENTS

We thank Tim Bandeen for providing the patient records and his valuable input, and the American Association of Orthodontists Foundation and the Southern Association of Orthodontists for their support.

REFERENCES

1. Andrews LF. The straight-wire appliance. Explained and compared. J Clin Orthod 1976;10:174-95.
2. Creekmore TD, Kunik RL. Straight wire: the next generation. Am J Orthod Dentofacial Orthop 1993;104:8-20.
3. Dellinger EL. A scientific assessment of the straight-wire appliance. Am J Orthod 1978;73:290-9.

4. Balut N, Klapper L, Sandrik J, Bowman D. Variations in bracket placement in the preadjusted orthodontic appliance. Am J Orthod Dentofacial Orthop 1992;102:62-7.
5. Castilla AE, Crowe JJ, Moses JR, Wang M, Ferracane JL, Covell DA. Measurement and comparison of bracket transfer accuracy of five indirect bonding techniques. Angle Orthod 2014;84:607-14.
6. Silverman E, Cohen M, Gianelly AA, Dietz VS. A universal direct bonding system for both metal and plastic brackets. Am J Orthod 1972;62:236-44.
7. Nichols DA, Gardner G, Carballeyra AD. Reproducibility of bracket positioning in the indirect bonding technique. Am J Orthod Dentofacial Orthop 2013;144:770-6.
8. Menini A, Cozzani M, Sfondrini MF, Scribante A, Cozzani P, Gandini P. A 15-month evaluation of bond failures of orthodontic brackets bonded with direct versus indirect bonding technique: a clinical trial. Prog Orthod 2014;15:70.
9. Koo BC, Chung CH, Vanarsdall RL. Comparison of the accuracy of bracket placement between direct and indirect bonding techniques. Am J Orthod Dentofacial Orthop 1999;116:346-51.
10. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent Mater J 2009;28:44-56.
11. Al Mortadi N, Eggbeer D, Lewis J, Williams RJ. CAD/CAM applications in the manufacture of dental appliances. Am J Orthod Dentofacial Orthop 2012;142:727-33.
12. Muller-Hartwich R, Prager TM, Jost-Brinkmann PG. SureSmile—CAD/CAM system for orthodontic treatment planning, simulation and fabrication of customized archwires. Int J Comput Dent 2007;10:53-62.
13. Insignia advanced smile design. Available at: http://Ormco.com/products/insignia-custom/index.php. Accessed February 9, 2015.
14. Weber DJ 2nd, Koroluk LD, Phillips C, Nguyen T, Proffit WR. Clinical effectiveness and efficiency of customized vs. conventional preadjusted bracket systems. J Clin Orthod 2013;47:261-6.
15. Wiranto MG, Engelbrecht WP, Tutein Nolthenius HE, van der Meer WJ, Ren Y. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. Am J Orthod Dentofacial Orthop 2013;143:140-7.
16. Hazeveld A, Huddleston Slater JJ, Ren Y. Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. Am J Orthod Dentofacial Orthop 2014;145:108-15.
17. Larson B, Vaubel C, Grünheid T. Effectiveness of computer-assisted orthodontic treatment technology to achieve predicted outcomes. Angle Orthod 2013;83:557-62.
18. Sachdeva RC, Aranha SL, Egan ME, Gross HT, Sachdeva NS, Currier GF, et al. Treatment time: SureSmile vs conventional. Orthodontics (Chic.) 2012;13:72-85.