Computer-Aided Design/Computer-Aided Manufacturing Technology in Customized Orthodontic Appliances

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You may have heard recently about customization of orthodontic appliances. What does customized orthodontic appliance mean? New three-dimensional technology in the design and production process allows manufacturers to produce brackets individualized to each patient; these technologies will be the focus of this article.

Why would the orthodontist want to customize treatment? Current bracket systems are based on an average tooth shape—but only a small percentage of our patients will have average teeth. When was the last time you had an average patient? The inter- and intra-individual variation is the reason why orthodontists must adapt their treatment to the patient's specific tooth shape and morphology in order to achieve ideal alignment, esthetics, and occlusion.

With fixed appliances, tooth movement occurs as a result of the engagement of the wire in the bracket slot. A system of forces and moments is generated and is transmitted to the tooth and its surrounding periodontal ligament. There are three customization approaches to generate a theoretical ideal force system and produce the desired tooth displacement:

1 Individualized arch wire
2 Individualized bracket slot/bracket base
3 A combination of the first two approaches

Customized systems allow orthodontists to initiate treatment with the final goal in mind, and streamline mechanics towards a pre-established result. These techniques start by creating a setup of the desired outcome that serves as a diagnostic aid and is used for appliance fabrication. The aim of this article is to present the currently available customized orthodontic treatment systems, and explain the concepts behind these new technologies.

DIGITALLY GENERATED INDIRECT BONDING SYSTEMS

These systems—the eModel eplacement (Geodigm Corporation, Chanhassen, MN, USA) and IQ (OrthoCad, Cadent, Carlstadt, NJ, USA) among others—involve customizing the bracket base via addition of a composite resin pad between the machined bracket base and tooth surface. In other words, the three-dimensional position of a slot in an average bracket is modified in order to produce ideal tooth movement.

Digital models are generated from impressions acquired before treatment. These are used to create a digital setup of the desired outcome. Non-customized brackets according to the orthodontist preference are placed virtually on the setup model. Their location is optimized to be as close to the tooth surface as possible while preserving the three-dimensional spatial position

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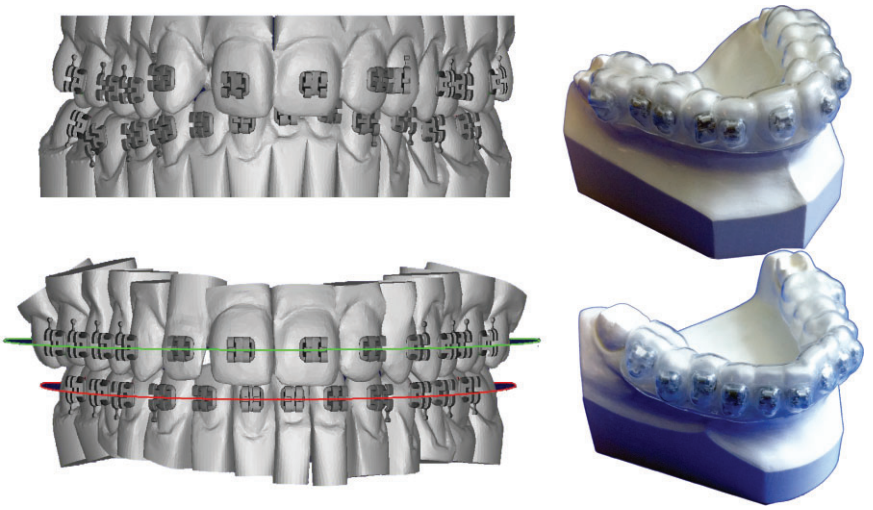

FIGURE 1. Digitally generated indirect bonding system by eModel eplacement (Geodigm Corporation, Chanhassen, MN, USA). Virtual brackets according to the orthodontist's preference are placed on a virtual setup of the desired outcome. Indirect bonding trays are fabricated to transfer the position of each bracket into the patient's mouth.

of the slot. The discrepancy between the machined bracket base and the tooth surface will be filled with composite resin that will serve as the customized bracket base. The setup is sent to the orthodontist for refinement and approval. The relative position of a bracket to its tooth is recorded on the setup and transferred to the initial model. An indirect bonding tray is created to transfer the virtual position of the bracket to the patient's mouth (Figure 1). Orthodontic treatment will proceed by arch wire progression.

As with any customized orthodontic treatment, tooth movement is optimized to the desired final position. Bracket transfer into the patient's mouth is faster and more precise than with conventional direct bonding systems.[1–4] The orthodontist can use his/her preferred bracket system. If a bracket is accidentally debonded during treatment, the transfer tray can be sectioned to include only the portion corresponding to that tooth and the same or a new bracket can be used as a replacement. Disadvantages include the potential for error in bracket positioning, either virtually or during transfer to the mouth.

INSIGNIA

The Insignia system (Ormco, Orange, CA, USA) uses a customized slot that is cut into the bracket at the desired position. Bracket bases are standard; slots are custom created to produce the desired tooth movement via arch wire progression to a straight final arch wire. Some customization, in terms of arch form, is also incorporated into the wire based on the width of the dental arch at the beginning of treatment.

Digital models are generated from impressions acquired before treatment. These are used to create a virtual setup of the desired outcome. This setup is sent to the orthodontist for refinement and approval. Once approved, brackets without slots are placed virtually on the teeth. The slots are cut into the actual brackets based on their position on the tooth in the setup (Figure 2). This will allow for insertion of a straight final full-size wire. The relative position of a bracket to its tooth is recorded on the setup and transferred to the initial model. An indirect bonding tray composed of bracket transfer jigs is created to transfer the virtual position of the bracket to the patient's mouth. Orthodontic treatment will proceed by arch wire progression.[5]

The main advantage of this system is the customization of the bracket slot.[6] Cutting a slot into a bracket blank is potentially more precise than a slot created by injection molding. The thinner interface of bonding material—not needed to customize the base of the bracket but only for adhesion and compensation of the

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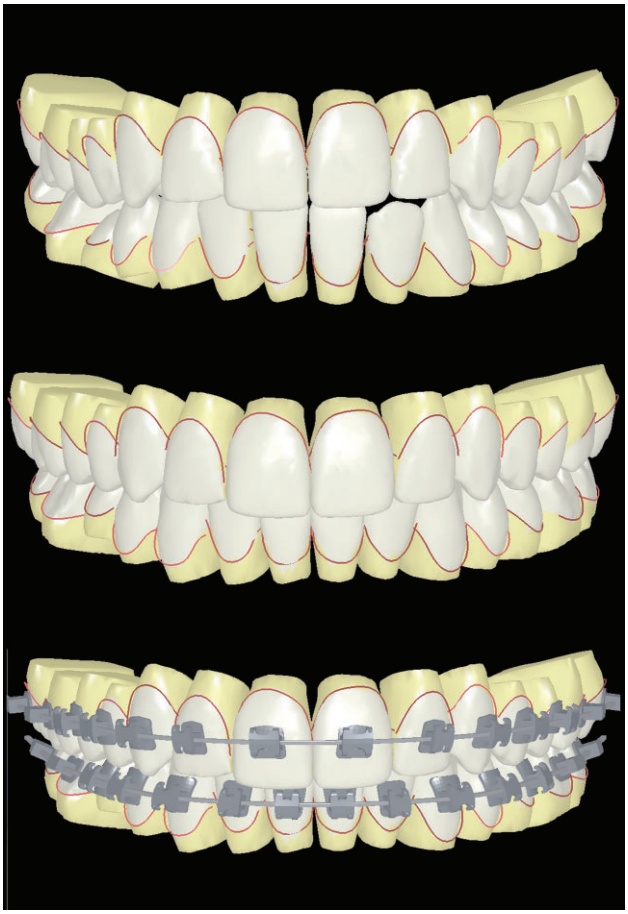

FIGURE 2. Digital models are created in order to design a setup of the desired final tooth positions (Insignia Approver, Ormco, Orange, CA, USA). Virtual appliances are placed on the teeth so that straight arch wire can be used (all slots are on the same plane).

difference between the machine bracket base and tooth surface—may enhance bond strength. The movement of the tooth no longer depends on the position of the bracket, but on the position of the slot. The treatment theoretically can be achieved with straight wires that, if needed, allow sliding of teeth along the wire. Disadvantages include the potential for error in bracket positioning, either virtually or during transfer to the mouth. Given that a customized bracket is used, if a bracket is lost, a new one must be ordered.

SURESMILE

SureSmile (Orametrix, Inc., Richardson, TX, USA) uses customized arch wires with conventional brackets to compensate for individual tooth anatomy among patients and errors in bracket placement. As opposed to other systems, SureSmile customization takes place in the finishing stages of orthodontic treatment.

The orthodontist scans the patient's dentition before treatment and a diagnostic setup is created. This setup is used for patient communication and allows the orthodontist to visualize the end result prior to bracket bonding. Conventional brackets are bonded according to orthodontist preference and the first stage of orthodontic treatment—leveling and aligning—is completed in the usual manner. Once aligned, a second intraoral scan of the dentition and brackets is acquired. The position of the teeth relative to each other and the position of the individual bracket slots relative to their teeth are recorded. A second setup is produced and sent to the orthodontist for refinement and approval. Once approved, a wire bending robot forms a wire that will individualize the treatment to achieve the desired outcome.[7] Custom wires are sent to the orthodontist.

The main advantage of the SureSmile system is that the orthodontist can use his/her preferred bracket system of choice and increase precision during the finishing stages.[8] Necessary positional information to create the customized wires can be obtained through intra-oral scans of the dental arches or cone beam computed tomography (CT) acquisition (Figure 3).[9] It remains to be seen whether the increase in precision warrants the additional radiation exposure associated with cone beam CT acquisition. Disadvantages include potential for accidental debonding after arch wire customization and before completion of treatment, and the potentially long and technique-sensitive intraoral scanning procedure.

INCOGNITO

Incognito (3M-Unitek, Monrovia, CA, USA) combines individualization of bracket bases, slots, and arch wires to create fully customized lingual orthodontic appliances. Bracket bases are individualized to the tooth anatomy and initial position of the tooth in the dental arch. Bracket slots are customized to produce ideal

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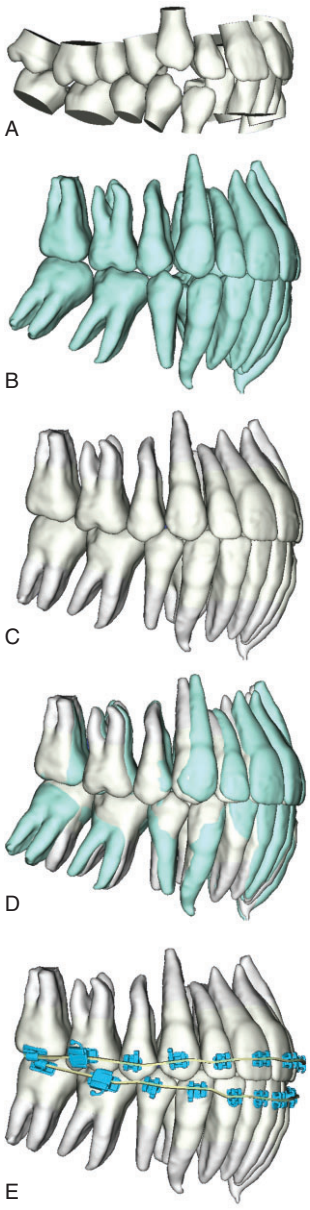

FIGURE 3. In the SureSmile process, a first scan of the dentition is acquired before treatment (A). After alignment, leveling, and closure of extraction spaces, a second scan is obtained; in this instance, a cone-beam computed tomography (CBCT) image is used to generate segmentations (three-dimensional volumes) of both crowns and roots. (B) Based on these intermediate tooth positions, a setup is generated in which the teeth are positioned in ideal alignment and occlusion. (C) The difference between the obtained CBCT scan and the setup are evident when both three-dimensional models of the dentition are superimposed in space (D, light blue is the scan and white is the setup). Based on the desired tooth position and the location of the brackets' slots relative to their teeth, a wire is formed (E) (images courtesy of Dr. R. Moles).

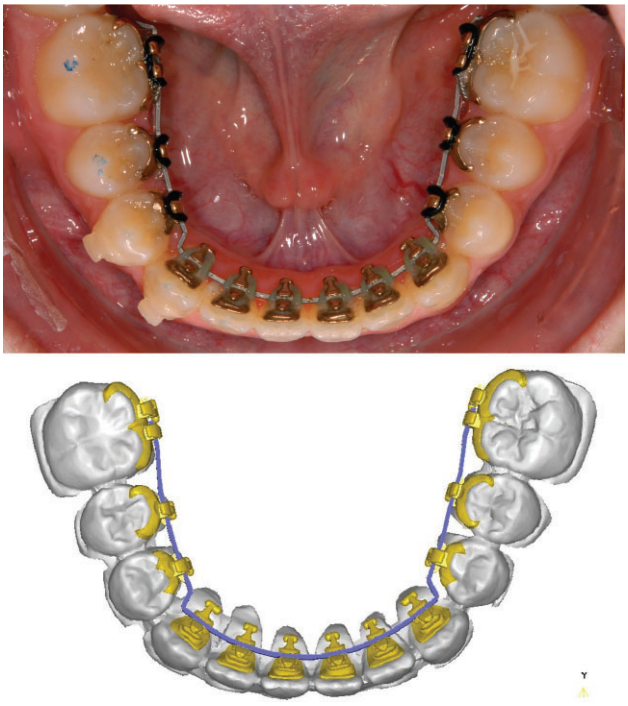

FIGURE 4. Occlusal view of a patient in the final stages of treatment with Incognito lingual system (3M-Unitek, Monrovia, CA, USA). Incognito is the only system where bracket bases are custom designed to fit the lingual surface of teeth. Note that the position of the teeth and dental arch form coincides with the planned tooth position in the setup made at the beginning of treatment.

tooth movement, and wires are formed to minimize the overall thickness of the appliance in the mouth.[10,11]

Impressions are acquired before treatment and a setup (either laboratory or virtual) is created. Based on an optical scan of the laboratory setup or on the digital setup, custom bracket bases are created and attached to virtual bracket bodies. The position of the bracket body on the digital setup is optimized to achieve ideal tooth movement and maximum comfort. Wax patterns of the customized brackets are produced by a three-dimensional printer and these are cast in a gold alloy. A series of wires are formed according to the position of the brackets' slots in the virtual setup. An indirect bonding tray is created in order to transfer the virtual position of the bracket to the patient's mouth. Orthodontic treatment will proceed by arch wire progression (Figure 4).[12]

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Incognito is the only fully customized lingual orthodontic treatment available. Main advantages include optimum esthetic appearance, great accuracy in final results,[13] less incidence of white spot lesions,[14] less discomfort over other lingual systems,[15] and relatively easy and precise direct rebonding of accidentally debonded brackets because of good adaptation of the custom bracket bases. Disadvantages include potential for error in bracket positioning during fabrication of the indirect bonding tray, and need to re-order any lost bracket or fractured wire.

CUSTOMIZED REMOVABLE APPLIANCES

Although the focus of this article is customized fixed orthodontic appliances, it is appropriate to at least briefly discuss the application of computer-aided design/computer-aided manufacturing (CAD/CAM) technologies for fabrication of customized removable appliances. By far the most widely used and well-known customized removable orthodontic appliance is the Invisalign system (Align Technology, San Jose, CA, USA), which involves the fabrication of a series of clear plastic aligners that are used to gradually move teeth to a predetermined position.

Impressions are acquired before treatment and a virtual setup is created. Following approval of the proposed setup and treatment plan by the orthodontist, a series of clear plastic aligners are fabricated on stereolithographic models of the progressive correction of the malocclusion. Each aligner is designed to gradually move specific teeth in small increments towards the predefined end point (Figure 5).[16]

Main advantages include esthetic appearance, relatively high patient comfort because of smooth aligners, and less plaque retention and associated negative periodontal implications than fixed appliances.[17] Disadvantages include reliance on excellent patient cooperation with wearing the aligners, and lack of precise control of force systems compared with fixed appliances. It has been demonstrated that the actual amount of tooth movement achieved is significantly less than what is planned in the initial virtual setup.[18,19]

CONCLUSION

Technological advances in orthodontics are not limited to customized appliances but extend also to diagnostic

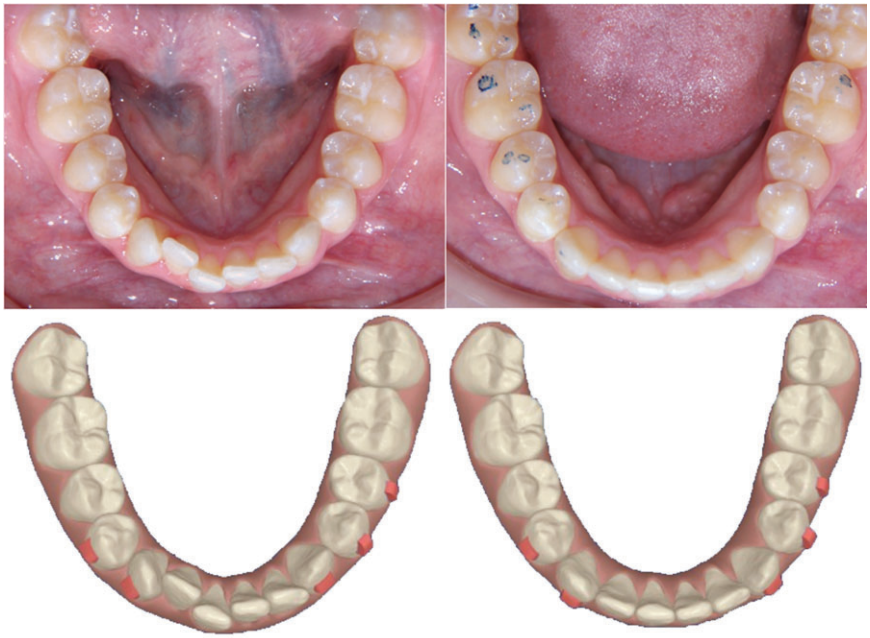

FIGURE 5. Pre- to post-treatment digital models and clinical images of a patient treated with Invisalign system (Align Technology, San Jose, CA, USA). Interproximal reduction was performed in addition to the use of aligners in order to achieve this result.

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and treatment planning tools. These are beyond the scope of this article but are worth mentioning here. Intraoral scanners have the potential to replace impressions in the long run. Three-dimensional imaging—cone-beam CT and three-dimensional cameras—will enhance our diagnostic and treatment planning possibilities. In the future, the customization of orthodontic technique will not only be based on tooth and dental arch anatomy but in the relation of the teeth to the smile and to the face. This area is under development in all the described systems.

In a well-established team, these systems provide the potential for higher quality of orthodontic treatment based on the accuracy in finishing and the efficiency of treatment. However, it is important to mention that these are not "auto-pilot" techniques, and sound diagnosis and treatment planning are as important if not more so than in conventional orthodontics.

DISCLOSURE

The authors do not have any financial interest in any of the companies whose products are discussed in this article.

REFERENCES

1. Aguirre MJ, King GJ, Waldron JM. Assessment of bracket placement and bond strength when comparing direct bonding to indirect bonding techniques. Am J Orthod 1982;82:269–76.
2. Joiner M. In-house precision bracket placement with the indirect bonding technique. Am J Orthod Dentofacial Orthop 2010;137:850–4.
3. 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.
4. Shpack N, Geron S, Floris I, et al. Bracket placement in lingual vs labial systems and direct vs indirect bonding. Angle Orthod 2007;77:509–17.
5. Ormco. Increasing clinical performance with 3D interactive treatment planning and patient-specific appliances. Orange, CA: Ormco; 2008.
6. Scholz RP, Sarver DM. Interview with an Insignia doctor: David M. Sarver. Am J Orthod Dentofacial Orthop 2009;136:853–6.
7. Scholz RP, Sachdeva RC. Interview with an innovator: SureSmile Chief Clinical Officer Rohit C. L. Sachdeva. Am J Orthod Dentofacial Orthop 2010;138:231–8.
8. Alford TJ, Roberts WE, Hartsfield JK, et al. Clinical outcomes for patients finished with the SureSmile method compared with conventional fixed orthodontic therapy. Angle Orthod 2011;81:383–8.
9. Lin YE, Getto P. SureSmile applies CBCT to custom orthodontic therapy: SureSmile. 2008.
10. Wiechmann D. A new bracket system for lingual orthodontic treatment. Part 1: theoretical background and development. J Orofac Orthop 2002;63:234–45.
11. Wiechmann D. A new bracket system for lingual orthodontic treatment. Part 2: first clinical experiences and further development. J Orofac Orthop 2003;64:372–88.
12. Wiechmann D, Rummel V, Thalheim A, et al. Customized brackets and archwires for lingual orthodontic treatment. Am J Orthod Dentofacial Orthop 2003;124:593–9.
13. Grauer D, Proffit WR. Accuracy in tooth positioning with a fully customized lingual orthodontic appliance. Am J Orthod Dentofacial Orthop 2011;140:433–43.
14. van der Veen MH, Attin R, Schwestka-Polly R, Wiechmann D. Caries outcomes after orthodontic treatment with fixed appliances: do lingual brackets make a difference? Eur J Oral Sci 2010;118:298–303.
15. Wiechmann D, Gerss J, Stamm T, Hohoff A. Prediction of oral discomfort and dysfunction in lingual orthodontics: a preliminary report. Am J Orthod Dentofacial Orthop 2008;133:359–64.
16. Beers AC, Choi W, Pavlovskaia E. Computer-assisted treatment planning and analysis. Orthod Craniofac Res 2003;6(Suppl 1):117–25.
17. Miethke RR, Brauner K. A comparison of the periodontal health of patients during treatment with the Invisalign system and with fixed lingual appliances. J Orofac Orthop 2007;68:223–31.
18. Kravitz ND, Kusnoto B, BeGole E, et al. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. Am J Orthod Dentofacial Orthop 2009;135:27–35.
19. Krieger E, Seiferth J, Saric I, et al. Accuracy of Invisalign® treatments in the anterior tooth region. First results. J Orofac Orthop 2011;72:141–9.

EDITOR'S NOTE

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