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Orthodontics on autopilot through digital customization and Programmed Non-Sliding Mechanics

Hongsheng Tong [a,b,*], Robert J. Lee [c,d], Andre Weissheimer [a,e], John Pham [f]

[a] Clinical Assistant Professor, Advanced Orthodontic Program, Herman Ostrow School of Dentistry, Los Angeles, California
[b] Co-Founder and Principal Orthodontic Scientist for InBrace, Irvine, California
[c] Clinical Assistant Professor, Division of Orthodontics, University of California San Francisco, San Francisco, California
[d] Co-Inventor and Senior Clinical Advisor for InBrace, Irvine, California
[e] Senior Medical Scientist for InBrace, Irvine, California
[f] Co-Founder and Chief Medical Officer for InBrace, Irvine, California

A R T I C L E I N F O

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A B S T R A C T

Orthodontic tooth movement occurs in six degrees of freedom, which includes opening and closing spaces. Traditionally, opening and closing spaces are achieved with auxiliaries such as power chains or springs because all traditional bracket systems cannot achieve this tooth movement by themselves. The InBrace system has the capability to program tooth movement in all six degrees of freedom, including opening and closing spaces, through digital customization and its use of Programmed Non-Sliding Mechanics.

1. Introduction

Orthodontic tooth movement can be broken down into the six degrees of freedom (torque, tip, rotations, in/out, up/down, opening/closing spaces), where each type of movement is necessary to achieve an aesthetic, stable, and functional occlusion [1,2]. Traditionally, tooth movement in all six degrees of freedom has been a manual and labor-intensive process achieved with a combination of the edgewise appliance and auxiliaries [3]. With Angle's zero prescription standard edgewise appliance, detailing each individual tooth position required a manual wire bend in a rectangular archwire [4]. To reduce the amount of manual wire bending, Andrews developed the preadjusted straight-wire appliance, which consisted of brackets with customized prescriptions based on a study population of untreated ideal occlusions [5]. Though this system offered a variety of bracket prescriptions, these prescriptions were generated based on a generic population norm rather than being customized to each individual patient. The straight-wire appliance lessened the number of wire bends needed, but because of its limitations, it generally still required either bracket repositioning or wire bending mid-treatment to address any detailing still needed. A further limitation of the edgewise and straight-wire appliance is that both only can achieve tooth movement in five degrees of freedom (torque, tip, rotations, in/out, up/down) by themselves. To achieve the sixth degree of freedom (opening/closing spaces) with the straight-wire appliance, a manual process of adding auxiliaries such as power chains or springs via sliding mechanics is required.

In recent years, the orthodontic field has progressively moved towards custom digital fixed appliance systems, such as SureSmile, Lightforce, and KLOwen, which have addressed many limitations and inconveniences because of the increasing customizability and advancement of three-dimensional (3D) technology [6,7]. Although all these systems improve tooth movement in five degrees of freedom reducing the amount of manual wire bending required, none of these systems address opening and closing spaces. Hence,

Abbreviations: PNM, Programmed Non-Sliding Mechanics; DE, Digital Enhancement; IDB, Indirect bonding; FEA, Finite element analysis.

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* Corresponding author: Graduate Orthodontic Program, University of Southern California, 925 West 34th Street, Los Angeles, California 90089.
E-mail address: drhstong@gmail.com (H. Tong).

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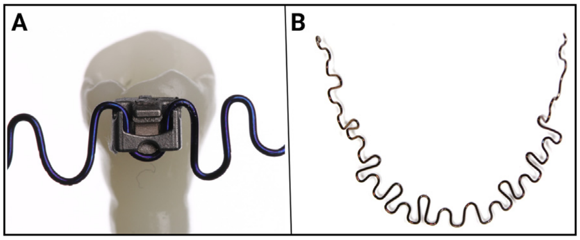

Fig. 1. The InBrace appliance.
(A) The InBrace bracket surrounds the Locking Loop.
(B) The InBrace Smartwire is digitally programmed and composed of alternating Locking Loops and Interproximal Loops.

they are all still dependent on auxiliaries which necessitates frequent follow-up appointments to reactivate the auxiliary used. Clear aligner therapy, on the other hand, has also become increasingly popular as a treatment option. Although clear aligners allow tooth movement in all six degrees of freedom, complex cases often involve multiple attachments, sometimes even on the anterior teeth, which greatly decreases the invisibility of treatment. Moreover, clear aligner therapy requires a huge compliance aspect, for treatment only progresses if the aligners are worn [8]. Because the number of adult patients seeking orthodontic care has increased, there is an increasing trend towards more aesthetic and compliance-free treatment, which makes attachments and the compliance aspect of clear aligner therapy a huge concern for this population [9].

Tooth movement on autopilot requires a fixed, compliance-free orthodontic system that has the capability of moving teeth to their programmed positions in all six degrees of freedom with minimal orthodontist intervention. The first orthodontic system to achieve tooth movement on autopilot is the InBrace system via Programmed Non-Sliding Mechanics (PNM) [10]. PNM, where there is programmed tooth movement in all six degrees of freedom and spaces are opened and closed without any sliding movements, is enabled by the InBrace appliance design, which can be broken down to the InBrace Smartwires and brackets (Fig. 1). The Smartwire is a custom designed NiTi archwire that is digitally programmed to reach the planned ideal occlusion. Each Smartwire consists of two customized loop systems: Locking Loops and Interproximal Loops. Locking Loops are surrounded by the InBrace bracket, with walls on the mesial and distal surfaces, unlike a traditional edgewise bracket with a horizontal slot. Because of the interaction of the Locking Loop with the mesial and distal walls of the bracket, the Locking Loop does not slide when opening or closing spaces resulting in friction-free tooth movement.

The programmed component of PNM is particularly critical to achieving autopilot of tooth movement. The Smartwire Interproximal Loops are present between each InBrace bracket. They are the driving force of tooth movement in all six degrees of freedom because of the programmed shape memory change from their malocclusion configuration to their programmed ideal configuration. The Smartwire Interproximal Loops also allow for space opening and closing through their interaction with the InBrace bracket that prevents sliding. The Interproximal Loops are programmed to vary in size, length, and shape based on the type of tooth movement required. For the programmed tooth movement to express predictably in all six degrees of freedom and to to achieve autopilot in orthodontic treatment, there are several digital customization factors necessary to program the Smartwires properly. This article will discuss the different digital customization factors that enable InBrace to move teeth on autopilot.

2. Digital customization to achieve autopilot

2.1. Virtual setup

To design the custom Smartwires, a patient-specific virtual ideal setup is generated and approved by the treating doctor. InBrace brackets are virtually positioned on the patient-specific ideal setup (Fig. 2). Special care is taken to ensure that there are no interferences between the brackets and teeth in the setup when possible. The custom-fabricated Smartwires are then digitally designed and fabricated based on the approved virtual ideal setup and bracket positions.

Finite element analysis (FEA) is a widely used numerical approximation technique to predict how a product reacts to real-world conditions [11]. After the virtual ideal setup is approved, FEA can be used to simulate tooth movement, which guides the adjustment and optimization of the size, shape, and length of the Interproximal Loops (Fig. 3). The FEA model in Fig. 3 shows the programmed Interproximal Loop designed for the virtual ideal setup and the force it experiences as it is stretched to be engaged at malocclusion.

2.2. Digital indirect bonding

After approval of the virtual ideal setup and bracket positions, the virtually positioned brackets from the virtual ideal setup are

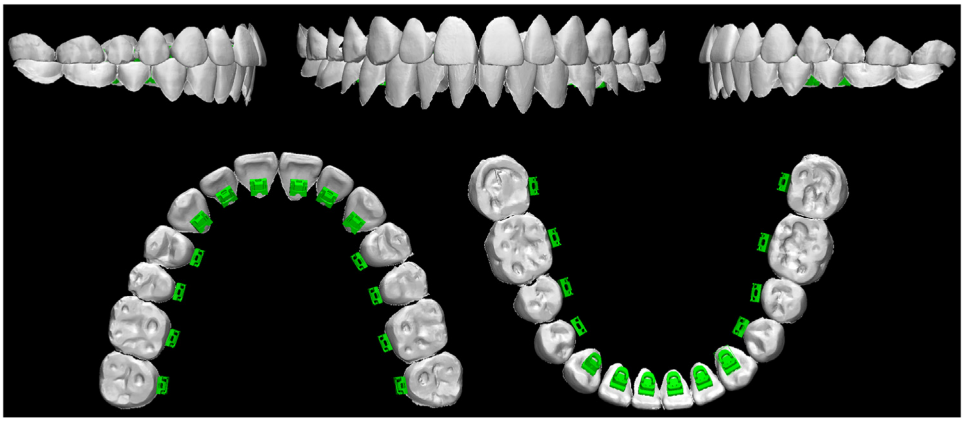

Fig. 2. Virtual ideal setup with virtual bracket positioned.

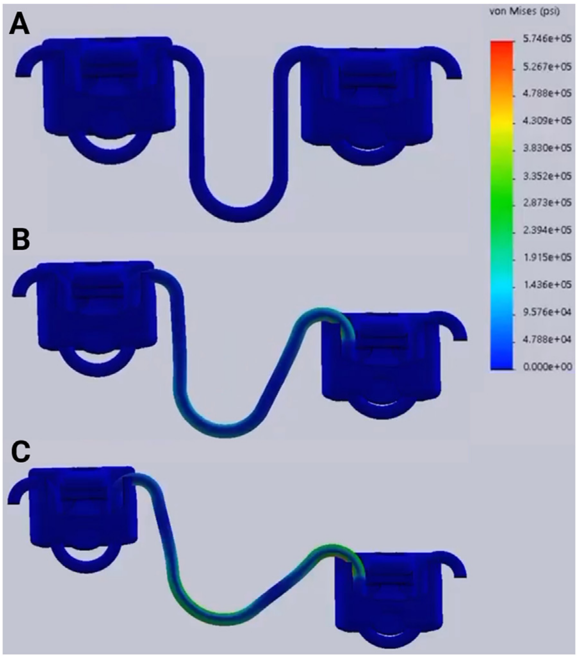

Fig. 3. Finite element analysis simulation of the programmed InBrace Interproximal Loops.
(A) Designed Inteproximal Loop based on the approved virtual ideal setup;
(B) Von Mises stress experienced when the Interproximal Loop is partially stretched;
(C) Von Mises stress experienced when the Interproximal Loop is stretched to engage the Locking Loop at malocclusion.

individually superimposed onto the teeth of the malocclusion intraoral scan, maintaining the bracket-tooth relationship (Fig. 4). An indirect bonding (IDB) tray was digitally designed, and 3D printed based on this malocclusion model with virtually positioned brackets. The IDB trays are 3D printed using two different resin materials, which allows for ease of use, a reliable fit of the tray, and custom patient labeling. After IDB is performed, an immediate intraoral scan may be taken to verify accurate bracket transfer (Fig. 5). This post-bonding intraoral scan was superimposed onto the malocclusion model with virtually positioned brackets to verify accurate bracket placement. For the patient case in Fig. 5, all bracket positions between the two models were inspected in all six degrees of freedom and were measured to be accurate within 0.1 mm using color displacement maps. Accurate bracket transfer is essential because the Smartwires are designed off the virtual planned bracket positions, so any inaccuracy in bracket position will affect the accuracy of the planned tooth movement.

2.3. Orthodontic tooth movement with PNM

After bonding of the InBrace appliance, the InBrace treatment sequence is broken down into three stages: Stage I, Stage II, and an optional Digital Enhancement (DE). In Stage I, the purpose is to use the light and flexible Smartwire 1 to achieve initial leveling and aligning. In Stage II, the purpose is to use the more rigid Smartwire 2 to complete any remaining leveling and aligning and perform inter-arch mechanics. In DE, the purpose is to update the virtual ideal setup to fabricate a DE-Smartwire 2 to perform any final detailing if needed.

Figure 6 illustrates the expression of orthodontic tooth movement on autopilot via PNM. In this case, Smartwire 1 was inserted into both the upper and lower arches at the initial bonding appointment. Because each Smartwire is designed off the virtual ideal setup where all spaces are closed, the Interproximal Loops are stretched when engaging the Locking Loops in between teeth with spacing. The unloading force of the stretched Interproximal Loops to return to their programmed shape results in a space-closing force. At 4 months, the majority of spaces had closed from the programmed shape memory change in the Smartwires. At this appointment, the more rigid Smartwire 2 was engaged, and buttons were placed to start anterior box elastics (5/16″, 4.5-ounces) to support closing of the anterior open bite. At 10 months, all spaces were closed by the Interproximal Loops, and the anterior open bite had closed sufficiently to remove the composite buttons. This case is now ready for final detailing through DE.

2.4. Digital Enhancement

A DE may be ordered when final detailing is required in a case. In the DE process, a new DE virtual ideal setup to serve as the template for DE Smartwires would be generated. The DE virtual setup has the benefit of incorporating the actual clinical bracket positions captured by an intraoral scan at the end of Stage II. Although good accuracy of bracket position is generally verified, as previously shown in Fig. 5, the actual clinical bracket positions may deviate slightly from the virtual planned bracket positions because of any error in the IDB process leading to mild inaccuracy in tooth movement from Stages I and II Smartwires (Fig. 7). DE resolves this by designing the DE Smartwires from the clinical bracket positions captured by the intraoral scan. This removes any error from IDB, resulting in improved predictability of tooth movement.

For InBrace cases with pretreatment cone beam computed tomography scans, additional root information may be incorporated into the DE Setup without the need for an additional cone beam computed tomography scan (Fig. 8). Adding the roots to a virtual ideal setup has been shown to improve the accuracy of the setup which translates to more predictable tooth movement [12]. This process to monitor root position by generating an Expected Root Position setup without the need for additional radiation to the patient has been well-documented [13–16].

3. Discussion

Throughout the history of orthodontics, fixed edgewise appliances using straight archwires, sliding mechanics, and auxiliaries to open and close space have become the primary mechanism of practicing orthodontics [3]. The InBrace appliance fundamentally differs from the traditional edgewise and straight-wire appliance with its use of PNM, where digitally programmed tooth movement in all six degrees of freedom occurs without any sliding because of the InBrace bracket and Smartwire design. As demonstrated in Fig. 6, tooth movement occurs in all six degrees of freeom, including closing spaces, with the InBrace system as a result of the programmed shape memory change in the Smartwire. This reduces the number of reactivation appointments for auxiliaries like power chains which allows the patient to be seen in longer inter-appointment intervals.

Advancements in several facets of digital orthodontics have allowed for the programmed Smartwires to express predictable tooth movement on autopilot. Virtual setups and FEA have significantly improved the predictability of programmed tooth movement, and further improvements in modeling the alveolar complex, the periodontal ligament, etc., will allow for further optimization of orthodontics on autopilot [17]. Digital bracket position with an accurate indirect transfer is integral for customized appliances where 3D printing of the IDB trays significantly improves this accuracy by

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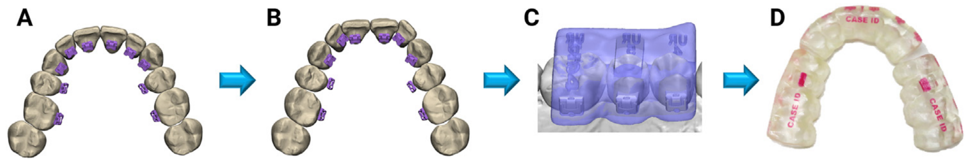

Fig. 4. Indirect bonding tray fabrication process.
(A) Brackets virtually positioned on virtual ideal setup;
(B) Bracket position transferred to the malocclusion model; (C) IDB trays digitally designed;
(D) IDB trays 3D printed.

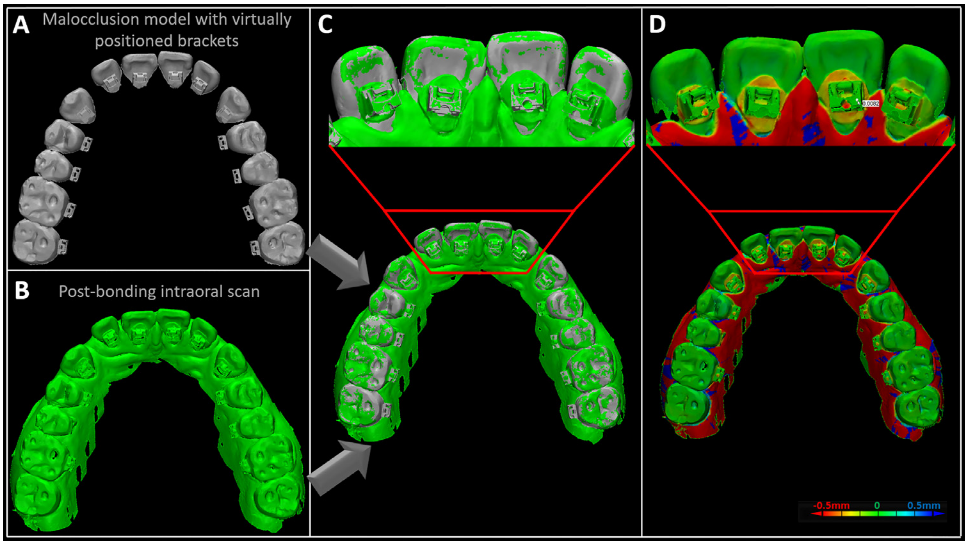

Fig. 5. Indirect bonding accuracy.
(A) Malocclusion model with virtually positioned brackets;
(B) Post-bonding intraoral scan;
(C) Superimposition of malocclusion model with virtually positioned brackets and post-bonding intraoral scan to verify accurate bracket placement;
(D) Color displacement map comparing the bracket position of the malocclusion model with virtually positioned brackets and the post-bonding intraoral scan.

Fig. 6. Tooth movement expressed in all six degrees of freedom through the programmed shape memory change in the Smartwires.

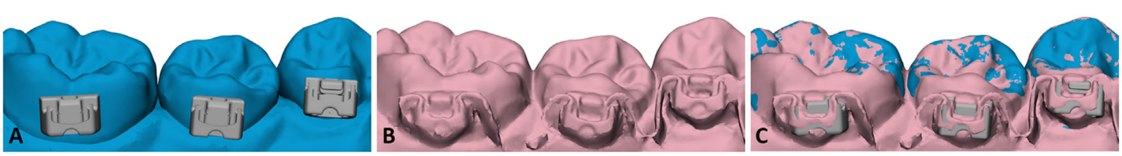

Fig. 7. Benefit of incorporating clinical bracket positions with Digital Enhancement.
(A) virtual planned bracket positions on the malocclusion model;
(B) Post-bonding intraoral scan at the initial bonding appointment showing the actual clinical bracket positions;
(C) Superimposition demonstrates that minor bracket placement deviations occur between the virtual planned bracket positions and the actual clinical bracket positions.

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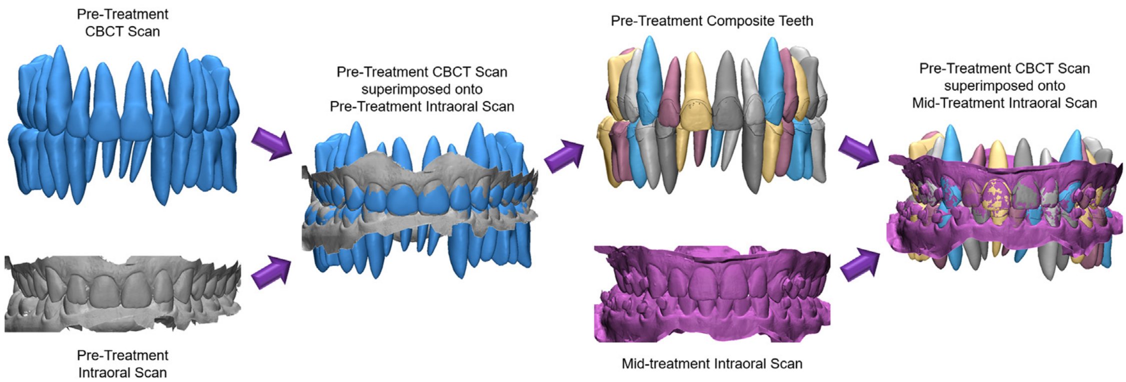

Fig. 8. Method to generate an Expected Root Position setup for Digital Enhancement. The pretreatment cone beam computed tomography (CBCT) scan, and intraoral scan are superimposed and stitched together to create individual composite teeth. The pre-treatment composite teeth can be superimposed at any mid-treatment intraoral scan to monitor the root position without any additional radiation.

reducing the number of steps required for IDB tray fabrication. Previously, IDB was viewed as a technique-sensitive procedure because of the many steps in the laboratory and clinic that all increase the error of bracket placement [18–20]. In addition, any inaccuracy in tooth movement from the mild discrepancy in bracket position between the planned and actual bracket positions is resolved with the DE process, which fabricates the DE Smartwires from the clinical bracket positions captured by the intraoral scan.

Although the InBrace system allows for tooth movement on autopilot in all six degrees of freeom, as with any vehicle, a driver is needed to start the engine, potentially take control and make adjustments in the navigation, and finish the trip by parking the vehicle. With InBrace, the orthodontist is needed to initially start the case with proper digital treatment planning with the virtual ideal setup. From there, the customized Smartwires allow the treatment to progress and cruise on autopilot, where the orthodontist may occasionally need to take control to make sure it stays on the right path, such as by adding inter-arch elastics. Once the patient is close to the final destination, the orthodontist is needed to finish the case out with a DE, settling elastics, enameloplasty, or other finishing adjustments.

4. Conclusion

The InBrace system allows for tooth movement on autopilot because it is a fixed, compliance-free orthodontic system that has the capability of moving teeth to their programmed position in all six degrees of freedom, including opening or closing spaces.

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