DRASTIC PLASTIC: ENHANCING THE PREDICTABILITY OF CLEAR ALIGNERS

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ABSTRACT

Once limitations of clear aligner treatments were identified, conceptualizing techniques to improve the predictability in producing desired results was the next logical step. A variety of concepts, methods, and adjuncts have subsequently been introduced to enhance the efficiency and effectiveness of clear aligners. As a consequence, the scope of biomechanics and type of malocclusions that can be more predictably treated has increased. As one example, the inclusion of miniscrew temporary skeletal anchorage has permitted the addition of direct and indirect anchorage to support and control more predictable programmed tooth movements with aligners. After reviewing the reported shortcomings of plastic aligners, this chapter explores possibilities for improving predictability of aligner therapy.

KEY WORDS: Clear Aligners, Miniscrews, Bootstrap Elastic, Attachments, Bonded Buttons

INTRODUCTION

It has been 20 years since the introduction of a commercialized clear aligner product to the orthodontic marketplace. Based on suggestion by Harold D. Kesling over 50 years earlier, Invisalign and later, increasingly numerous propriety alternatives have come to pass; including the exponential growth of so-called direct-to-consumer (DTC or DIY) offerings [1]. From the original questions of whether even "acceptable" results could be obtained from a sequence of aligners, these queries have now evolved into: Is an orthodontist even needed to be interjected between the manufacturer's plastic and their "customers?"

So, the idea of moving teeth with plastic was nothing new, but the use of software to attempt to predict desired tooth movement and the associated 3D representations of individual tooth position were innovative. This enabled the replacement of the labor-intensive process of cutting and creating plaster set-ups and was followed by the game-change of using digital intraoral scanners, instead of the imperfections of impressions. Complementing the evolution of aligners was the development of composite "attachments," applied to the teeth to increase the surface area contacted by the plastic trays. During this growth and development of clear aligners as a viable alternative to traditional "braces," the providers themselves created ever-improving treatment planning with an eye to mimicking the results from a century of brackets and wires.

This evolution has been hampered by an unfortunately and unnecessarily tedious evaluation of treatment changes by the orthodontists attempting to assess their results and render improvements. In other words, an innovator would apply an altered digital set-up, anticipating a positive change. Unfortunately, the effects could not be assessed for long periods of treatment time. This, despite the fact that highly accurate digital representations of the initial malocclusion could have been compared with not only progress "refinement" scans, but also successful final results of similar patients treated around the world. Align Technologies could have been the archivist for the largest preserve of final orthodontic records in our specialty's history. From that massive archive, changes that actually produced consistent positive improvements could have be gleaned and shared with practitioners, rather than the primitive and individual trial-and-error "testing of ideas" that each of us have had to conduct in private. The corporation could have accomplished this quite simply by commissioning "final records" from orthodontists, made available for research: *Quare sequitur*: What works, what doesn't?

Instead, information has been divvied and disseminated by key opinion leaders (KOL), each with a selection of their own case reports of what their own isolated trials have revealed with only filtered experience as a guide. Later, these anecdotes were compiled into cohorts, retrospective evaluations subject to influence from various biases, a smattering of prospective investigations, and as would be expected, an ever-growing number of meta-analyses and systematic reviews, looking at virtually the same limited data. All of these reports, when evaluated *en masse*, confirm many of the issues commonly exasperating isolated docs. Some of their responses have been to throw-up their hands and quit, or ignore and live with the compromises, or dig into their armamentaria of orthodontic devices and biomechanical concepts and press forward.

As an active participant in this oddly frustrating progression of clear aligner developments that included starts-and-stops, controversy-and-conundrums, there has been a continual thirst for improvement and enhancement. Sadly, proprietary squabbles among the "companies" have held sway over genuine interest in improving the quality of care for actual patients (not "customers").

If one takes the time to consider the body of evidence on clear aligners along with guidance from a select few gurus, the undeniable question comes to mind, "Just how predictable is plastic?"

JUST HOW PREDICTABLE ARE CLEAR ALIGNERS?

We have all likely seen innumerable celebrities and professional athletes wearing plastic aligners but probably haven't been aware, unless they decided to "show-off" in social media and pop culture. Bryan Cranston's "attachments" were visible in *Breaking Bad*, Sebastian Stan's (Bucky Barnes) smile transformed during *Captain America: The Winter Soldier*, the Kardashians' (and wannabes') flashed their plastic, as did Oprah. Anna Kendrick's aligner case was labelled "Anna's Grillz" by her crew, a young Justin Bieber mugged his plastic, Ashton Kutcher placed his aligner cases on public display when eating, and Billie Eilish immortalized the removal of her plastic just as she started recording a song. Although Atlanta Falcons' Julio Jones was pictured playing football while using his plastic, more impressively, Kansas City Chiefs' Patrick Mahomes won the Super Bowl and the MVP in 2020 wearing Invisalign as his "mouth guard" (as reported by his girlfriend on Instagram). Actress, Katherine Heigl was photographed removing her aligners and provides the ideal transition into our discussion with her quote, "I like predictability because I know what I'm getting into."

Aligner Reports and Results

During the first few years of aligners, early adopters began treatments for patients with this esthetic alternative to braces with varying degrees of success. Some teeth got straighter, some malocclusions improved, but the limits were assumed to be Class I malocclusions with mild to moderate crowding or spacing. Class IIs and IIIs were thought to be verboten and, don't even think about deep or openbites. As the literature was reviewed, it was essential to continually remind oneself of the following quote as it seems evanescent in discussions regarding the effectiveness and predictability of clear aligners:

Compliance is the single most important factor in treatment success.
-Buzz Behrents

Kravitz et al. published a prospective clinical study in 2005 that echoes the question: "How well does Invisalign work?" Is it important to note that this and many of the following investigations were conducted in the era of the original product (plastics and attachments) [2]. In those early days, assumptions were made about the responses of teeth to the vectors of force based on predictions of the resultant, expected movement. The research workers concluded that only 41% of the tooth movement goals were achieved. Shouldn't we assume that subsequent investigations would provide more optimistic results?

So, it wouldn't be a surprise that nine years later, Chisari et al. did observe 57% of tooth movement goals were achieved [3]. Then in 2017, workers from the University of Ferrara noted a mean predictability of 74% [4]. Each of these studies and several others also described the predictability for specific types of tooth movement. For instance, Houle et al. concluded that there was 73% predictability for maxillary expansion and 88% accuracy for the mandible [5]. In contrast, Solano-Mendoza stated that expansion was not predictable[6]. Incisor intrusion was translated (from the predicted "set-up") at between 73-79**%** accuracy but in a contrasting report, incisor intrusion was said to be "the most inaccurate movements identified" [7, 8].

A systematic review by Rossini et al. in 2015 confirmed what was reported a decade earlier by Kravtiz et al., namely, that incisor extrusion is highly unpredictable [2, 9]. In fact, desired extrusion was only 30% accurate. At this point in the review, the question might arise, "why were teeth not translating accurately based on the 3D computer-generated predictions?" Just because you can move around the drawings of teeth in virtual software "cartoons" doesn't mean that the teeth will watch the cartoons and move in response. There are a whole host of accumulated "errors" that are responsible: errors in the impression/scan, in developing the 3D models, plastic molding/heating/"suction" problems, manufacturing tolerances, flexing, distortion, imperfect planned tooth movement, unrealistic expectations, insufficient surface area contact (e.g., short-round teeth), lack of adequate space, and the obvious, nagging specter of unpredictable patient compliance (not to mention the rate of "drop-outs").

Effectiveness and Efficiency of Plastic

Plastic can produce results that patients favor, but how effective, efficient, and predictable are these outcomes? Buschang et al. reported that aligners were more time efficient than braces, offsetting the greater cost and doctor time when using plastic [10]. In comparison, Zheng et al. concluded evidence was lacking regarding claims of aligner effectiveness [22]. Leake et al. stated there was insufficient support for aligners as an alternative to braces [12]. A review from Mahidol University also affirmed the same as aligners were found to be especially deficient in correcting large A-P discrepancies and producing occlusal contacts [12]. A further systematic review also determined "the lack of ability to correct A-P, occlusal contacts, extrusion, and rotations greater than 15 degrees [13]."

Robertson et al. published a systematic review in 2019, concluding that aligners demonstrate low to moderate efficiency in regard to specific tooth movements and cautioned that due to that unpredictability, "more than one set of trays (refinements)" will likely be necessary [15]. Finally, the mean overall efficacy of aligners was pronounced to be only 59% by Simon et al. Bear in mind that's at least a bit more favorable than the 42% probability of an overall win when playing "blackjack," but it certainly seems that there is still considerable room for improvement in plastic care [15].

Plastic vs. Braces

So how do treatments with aligners stack up to those with traditional methods? Results from a meta-analysis detailed limitations in effectiveness of plastic in terms of occlusion, torque, and retention [17]. Kuncio et al. also curiously found more relapse with aligners, postulated due to the amount of dental tipping movement with plastic appliances [18].

In an investigation employing the PAR Score, it appeared that aligners were not as effective as fixed appliances in achieving "great improvement" in a malocclusion compared to braces [19]. This was basically the same conclusion from a systematic review published by researchers in Spain [20]. When the ABO objective grading system was applied to the outcomes of braces and aligners, it was concluded that aligners "did not treat malocclusions as well as braces;" especially in terms of buccolingual inclination, A-P, occlusal contacts, and overjet [21]. These findings confirmed those of Wiboonsirikul et al. and also reiterated by a recent meta-analysis in 2019 [13, 22]. Considering that some folks have predicted that plastic will completely supplant metal braces soon, current findings hardly support those prognostications.

The reports of my death are greatly exaggerated
-cable sent by Mark Twain after his obituary was mistakenly published.

Direct-to-Consumer (DTC)

Marketing claims for DTC are plentiful, evidence is lacking. For an example, "Teledentistry employs the same level of professional services as traditional orthodontics and is proven to have equal or better outcomes." Bold and inescapably disputable words. For instance, if a "customer" purchases an impression "putty" kit as a first step in ordering a series of trays, are they actually capable of generating an accurate foundation to base the rest of the entire process upon? In a university-based investigation, laypersons were given the opportunity to use the same putty materials to take their own impression. It was determined that folks with no dental experience cannot take an accurate, acceptable impression on themselves [23]. That finding is absolutely no surprise to orthodontists who have been exasperated with having even experienced assistants attempt to get quality polyvinyl siloxane (PVS) impressions for aligners.

Therefore, will the consumer's impression be sufficient for a technician to generate accurate models and ultimately a series of aligners? More importantly, will the resulting set-up models reflect the consumer's final results? Investigators at Baylor University found that ClinCheck digital set-up models do not accurately reflect the patient's final occlusion. Izhar and co-workers also determined that predicted software models are not accurate in reflecting final tooth positions [24, 25]. These findings would seem to be somewhat disconcerting if accuracy is a goal.

When is good enough, just good enough? "Customers" are said to be thirsting for plastic treatments so that they might "treat" themselves without a professional interposed in the orderly conduct of commerce. Specifically, the social six teeth might get relatively straighter, but what about that nagging "bite?" The conversation often goes as follows: "Doc, I just want this one tooth fixed, I don't care about my bite." They may return not as a "consumer" anymore, but now as a disappointed "patient" with a complaint that, "my teeth feel funny when I bite down." That's awkward at minimum. Look, patients don't crave dispensed or mail-order plastic; they actually desire results [26]. Perhaps, just advertising straighter front teeth (bite be damned) should be taken seriously by the consumer. *Caveat emptor*, especially in the absence of an in-person examination and informed consent.

ANNOYING LIMITATIONS OR STIMULUS FOR INNOVATION

"Learn to view limitations not as annoyances but as welcome editors that force you to think creatively."
-Garr Reynolds

A prospective follow-up to Kravitz et al. [2] on the efficacy of tooth movement with aligners was published in 2020 by Haouili et al. [27]. They concluded that although the mean accuracy for all tooth movements was 50%, that was only a 9% improvement in results in an 11-year period since the original publication. It's not surprising that Rossini et al. had concluded that clear aligner treatments cannot be based on a sequence of plastic trays alone [7]. There is much more than just dispensing plastic. Clear aligner treatment has clearly progressed in terms of attachment design, supplemental auxiliaries, inter proximal reduction (IPR), elastics, adjunct appliances including braces, miniscrews, and even individualizing aligners [28-36].

Some lack of predictability, effectiveness, and efficiency has, in many instances, been overcome by the perseverance of determined and inventive practitioners. Innovations are defined as a new idea, device, or method as well as the act or process of introducing them, in this case, into the specialty of orthodontics. One simple example is the Aligner Chewie* that was introduced early on in the evolution of clear aligners (Figure 1) [31, 37]. When delivering a new aligner in a series, often they fit quite tight and do not seat completely onto the teeth. The Aligner Chewie was designed to replace the use of chewing on dental cotton rolls to assist in pushing the aligner into place as kind of makeshift, "mini-tooth positioner" (Figure 2) [31, 37].

Figure 1. Aligner Chewies* are designed to assist in seating ill-fitting aligners. (Dentsply Raintree Essix, Sarasota, FL).

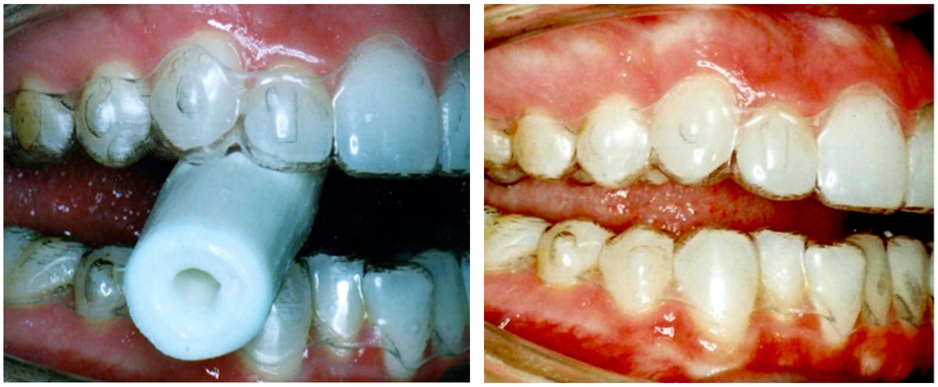


Figure 2 A,B. Chewies are used to reduce "lag" or "air-gaps" indicating the teeth are not "tracking" along with the aligners.

Another innovation was the introduction of a set of instruments designed specifically for individualization of a patient's aligners. The Clear Collection* (Hu-Friedy, Chicago, IL) was specifically designed to customize aligners to enhance desired biomechanics, and to streamline the addition of individualized adjunctive forces during the course of treatment [30-32, 38, 39]. Specifics regarding these instruments have been detailed in previous publications, but examples are shown below (Figure 3).

Figure 3. The Clear Collection* (Hu-Friedy, Chicago) instruments were designed to individualize or customize aligners.

Lessons from the Invisalign Teen Research Team

The Invisalign Teen Study was initiated in 2008 with 4 practitioners treating 60 teen patients using clear aligners. The original ClinCheck set-ups were found to be problematic and significant refinements were required by nearly all. Data collection for the sample ended in 2010 as treatments were completed (and some patients also simply left the study). Results were published in 2009 and 2012 [40, 41]. Interestingly enough, the TEEN product was introduced to the market in 2009, prior to any collated and published conclusions. In other words, by the time answers were provided, no one much cared what the questions originally were. Perhaps, the TEEN findings may have helped inform the necessity of innovations and improvements for aligners in general. The most important finding from the work: if aligners were consistently worn, then they did "something." If not, then the patients got "nothing" at all and may have either moved on to traditional braces or just stopped treatment altogether.

Simple conclusions from the study include:

1) Compliance Indicators seemed limited to serving as a "policing tool," but did not incentivize or motivate patient cooperation (Note: awareness of monitoring may not increase compliance) [42].
2) Torque Ridges worked, however, adding substantial amounts of torque to a digital set-up are required to see any effect.
3) Eruption tabs (for molars) were useless annoyances and were cut-off.
4) Eruption baskets for yet unerupted teeth were fine, but it may be advisable to simply wait until those few teeth erupt before starting treatment.
5) Surprisingly, most teens did wear the aligners, but those that didn't received no improvement, and either were offered a braces alternative, or they elected to forego any orthodontic treatment. As was anticipated, compliance was still the coin of the realm and the best predictor of success.

IMPROVING PREDICTABILITY FOR CLASS II'S

To follow are some suggestions for improving the predictability of clear aligners by enhancing the application of the forces involved. In the early years, treating anything more than some crowding or spacing was frowned upon. Afterall, there seemed no mechanisms that could be applied to aligners to affect changes in antero-posterior (AP) or transverse dimensions. Furthermore, incisor torque, intrusion, and extrusion were not predicted to be successful. The more adventurous began to test those borders, but as noted previously, the predictability was not confidence-inducing. Some were disenchanted and others, challenged.

Class II malocclusions have been subjected to a diverse assortment of remedies for over 100 years. How would any of them be easily added to clear aligners? Phase I dentofacial orthopedics prior to plastic with headgear or functionals? We have recently seen the introduction of removable aligner versions of "MARA's" and "TwinBlock's" (the latter unfortunately lead us right back to an emphasis on compliance as king for the correction). There must be something else, especially, since none of these approaches are "growing mandibles."

Sequential Molar Distalization

Some initial attempts at correcting Class II malocclusions involved two primary strategies. The first was simply applying Class II elastics to the aligners by: 1) bonding buttons onto the aligners themselves, 2) cutting notches into the aligners using rotary dental handpieces burs, 3) employing " nail clippers" to cut slits in the plastic, or 4) prescribing cuts in the set-up (Figure 4) [18, 43, 44]. Ultimately, these options have been replaced with The Hole Punch* instrument from Hu-Friedy (Figure 5) that is used to create a "half-moon" shaped cut at the gingival margin of the aligners to permit the direct bonding of "button" to the tooth (e.g., mandibular first molar for Class II elastics) [30, 33, 40, 41]. Then the set-up software was occasionally programmed to provide a "bite jump" at some point in treatment, anticipating there had been some kind of positive change in growth differential between the jaws.

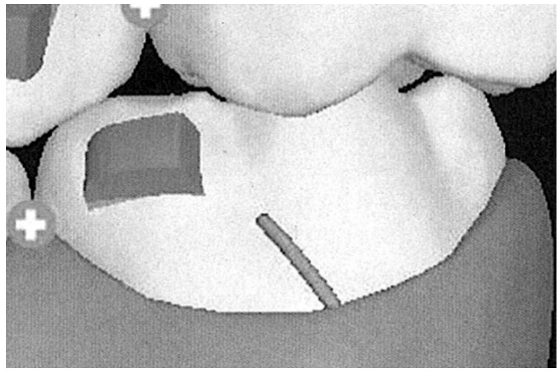
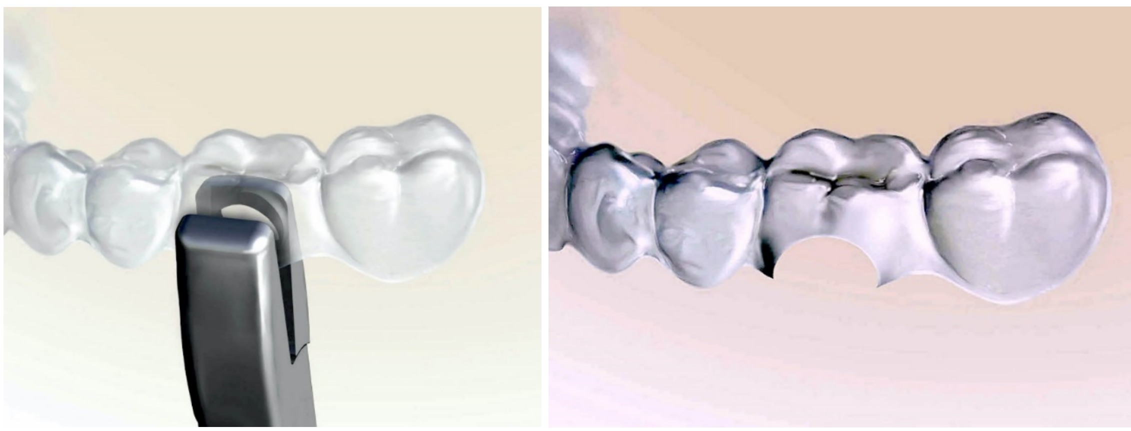


Figure 4. Notches at the gingival margin of the aligners can be used to add typical orthodontic elastics [44].



A B

Figure 5 A,B. The Hole Punch instrument (Hu-Friedy, Chicago) is used to cut plastic in a semi-circle for the application of a bonded button for elastics.

A second option was designed to mimic typical maxillary molar distalization techniques that had proven successful with traditional orthodontic fixed braces featuring specialized appliances (e.g., Pendulum, Distal Jet, Jones Jig, etc.) [16, 45, 46]. Sequential maxillary molar distalization begins with a digital set-up to reflect pushing back each of the teeth in a posterior segment from 2nd molar forward [44]. The intent of producing a Class I occlusion in this scenario involves using the plastic to direct this sequence of individual tooth movement, based on the idea that there would be less "anchorage strain" (i.e., labial tipping of anterior teeth in response) due to the full-coverage "capping" of plastic. It became sorely obvious that something more was necessary to add to this equation--traditional Class II elastics would be required, just as had been employed in the "bite jump" alternative. Consequently, the posterior tooth movement was directed by plastic, but forced by Class II elastics (Figure 6) [47]**.** As an aside, Calvin S. Case provided clear provenance to his introduction of "Intermaxillary Force," introducing elastics into orthodontics at least as early as 1904 [48]. This is in direct contradiction to Edward Angle who later, inappropriately coined the term, "Baker Anchorage."

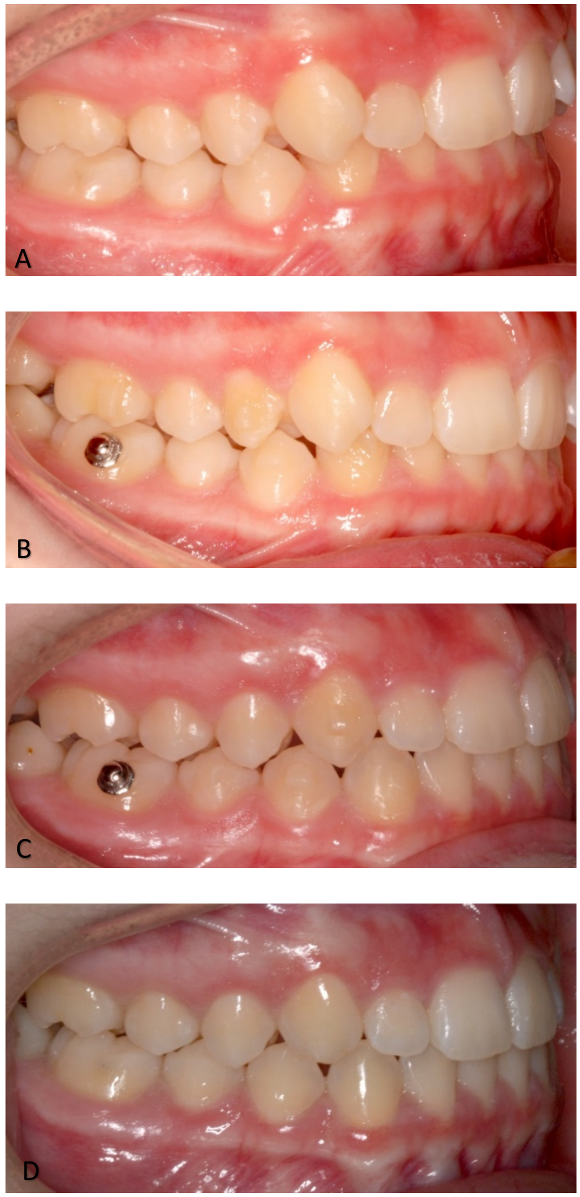


Figure 6 A-D. A,B. Teen female treated with sequential molar distalization, supported by Class II elastics connected to a bonded button on the lower first molar, and a notch at the mesio-gingival margin of the aligner at the upper cuspid. C,D. After achieving a "super" Class I molar relationship, spaces were closed with aligners.

How predictable was this scenario? Klein examined a sample of patients that had been treated using sequential molar distalization with elastic support and reported that the average amount of first molar distal movement was only about 1.4 (+/- 0.8) mm, $p<0.001$ [49]. If combined with programmed 1st molar distal rotation around the palatal root (Figure 7), this might be enough to resolve mild ½ step Class II molars, obviously, dependent completely on wearing the aligners and the elastics. Ravera et al. followed-up with a multi-center retrospective and found slightly more (2.25 mm, $p<0.27$) movement [40]. That is still significantly less than the amounts produced by "non-compliance" fixed distalizers [45, 51-53].

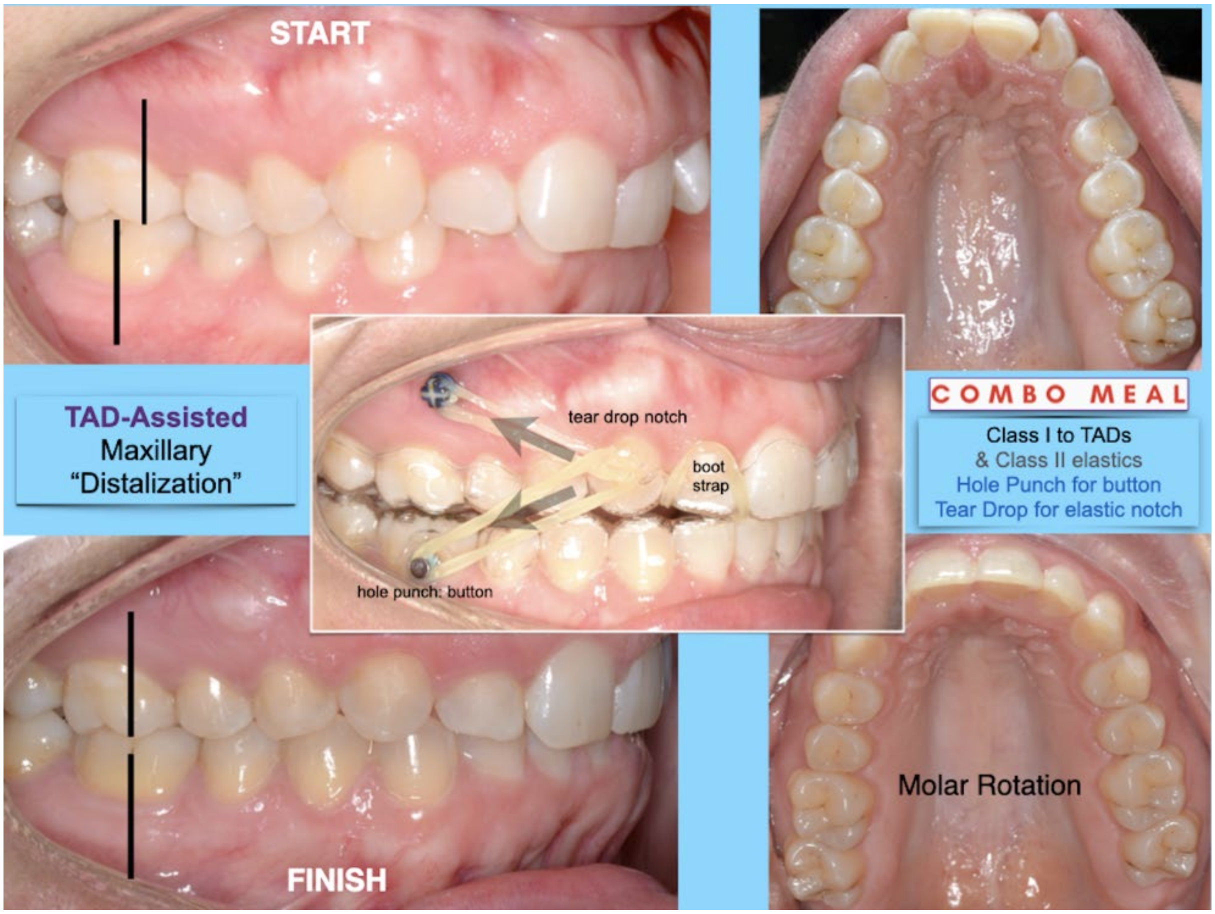


Figure 7. Adult female Class II treated using "TAD-assisted" sequential molar distalization, supported by Class I intramaxillary elastics from a miniscrew to a notch in the aligner at the maxillary cuspid combined with Class II intermaxillary elastics and distal rotation of the maxillary first molars.

Segmental Molar Distalization

If correction of Class IIs using full coverage aligners is limited in capacity to correct anything more than milder AP discrepancies, then resolution may need to involve some type of pre-aligner treatment. Perhaps, using fixed or removable functionals, distalizers, or headgear could be considered as prerequisites to initiating aligners.

The direct bonding of a section of orthodontic wire from maxillary molar to a helix cuspid hook could provide a means to connect Class II elastics (anchored by a lower lingual arch, braces, or even lower aligner), to move a segment of upper teeth distally. This very simple mechanical concept is employed by the Carriere distalizer (Figure 8). In the recent commercial environment focused on "airway-friendly concepts" (i.e., anything that might be considered "backward pushing" could be conceived as impinging upon the airway), this device was rebranded: "Motion," although by any other name, these "bars" cannot independently move anything. Compliance with elastics is required and untoward side-effects include clockwise rotation of the occlusal plane as mandibular molar and marked maxillary canine extrusion can occur.

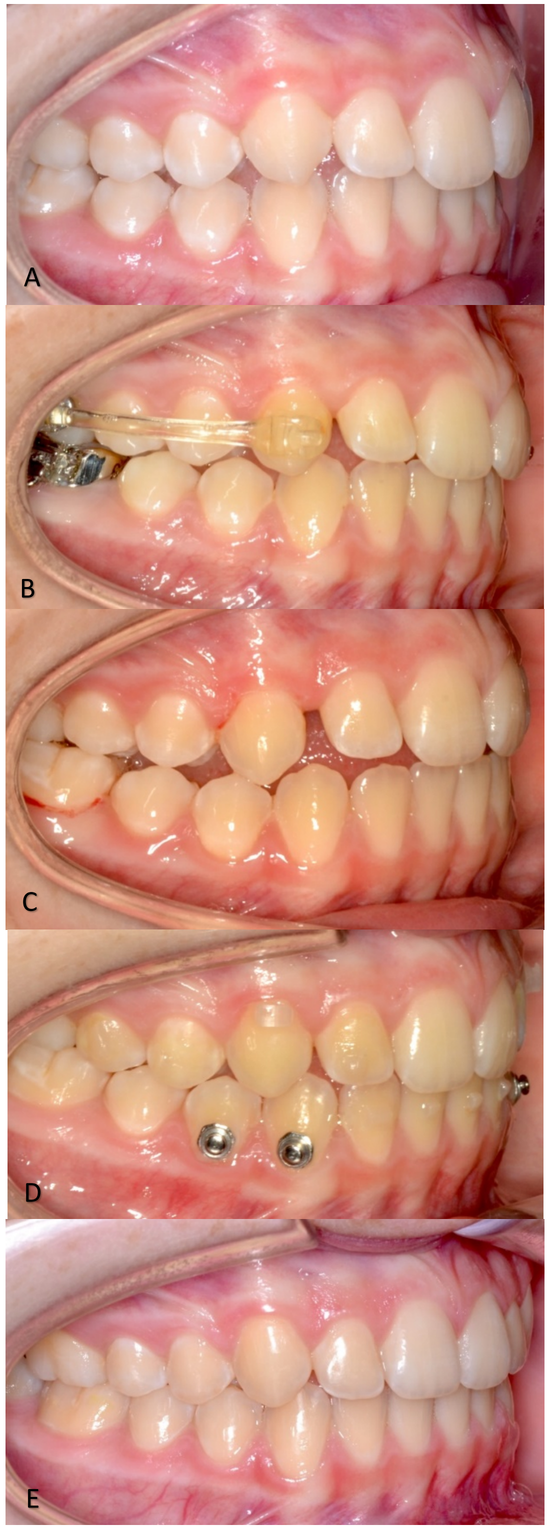


Figure 8 A-E. A,B. Teen female treated by first using distal movement of the posterior segment of maxillary teeth supported by a Carriere and Class II elastics to a lower lingual arch. C. "Super" Class I molar relationship was achieved. D,E This was followed by clear aligners, still supported by Class II elastics, and then finishing with Delta or Triangle elastics from bonded buttons on upper and lower cuspids and lower first premolars.

Although the claim of “Sagittal First” accompanies this product, it is again important to acknowledge provenance for the origins of this concept to Calvin S. Case. In his textbook in 1921, Case introduced “Span-Hooks” for the application of his Class II elastics to move posterior segments of teeth posteriorly [48]. Seems that there is nothing new under the Sun. Furthermore, claims of stimulating mandibular growth with these mechanics is no more accurate than for any other method of Class II correction.

For better or worse, all approaches for growing Class IIs affect the resolution by interrupting dentoalveolar compensation. Interestingly enough, the amount of mandibular response contributing to that correction is the same (give or take a silly 1 mm, if even measurable) among all interventions. It is a bit disheartening to consider that during the past four decades of our specialty we have been slogging it out with the supposition that numerous methods of holding mandibles in a forward position provided something extra beyond normal growth. In other words, we’ve wasted huge sums of money and time trying to find ways of “turning water into wine” (growing jaws) to no avail. That isn’t to say that Class IIs haven’t been corrected with functional approaches. Nevertheless, it certainly seems that while some were railing that the lower jaw was the “right jaw” to address, it slipped by most that the only “action”—the only place that orthodontics can make a difference—has been in the upper [53].

Adding a Spike in the Ice

The application of miniscrew temporary implants as anchorage for both indirect and direct mechanics have stimulated innovators to create new methods of orthodontic treatment (including with aligners) [30-36, 54-60]. Specifically, molar distalization within a Class II treatment became more predictable as reliance upon patient compliance with removable devices or headgear has diminished. The insertion of miniscrews in the buccal alveolus between upper 1st molar and 2nd premolar became a more common “post” to support so-called “Class I” intramaxillary elastic forces [30, 47, 61-63].

Traditional braces mechanisms for correction of Class II for either growing or adult individuals benefited from the use of constant forces from the screws to the dentition for retraction. That could take the form of sequential molar distalization, segmental movements, and even *en masse* retraction encompassing all of the upper dentition. For “growers,” the actual correction primarily involves the interruption of dentoalveolar compensation, while adults require actual distal dental movements.

It did not take much imagination to adapt miniscrews into the world of aligners, at least as far back as 2003 [61, 62]. Sinking anchor “posts” in the buccal alveolus as support for elastics or elastic chain improved the predictability of aligner-directed movement. Perhaps, this concept could be considered as a type of non-compliance “headgear” that can be employed during aligner wear. Taking it a step further, Class II intermaxillary elastics can also be combined with the Class I intramaxillary elastics to generate a net distalizing vector of force for the maxillary dentition—a “Combo Meal” approach (Figure 7, 9)

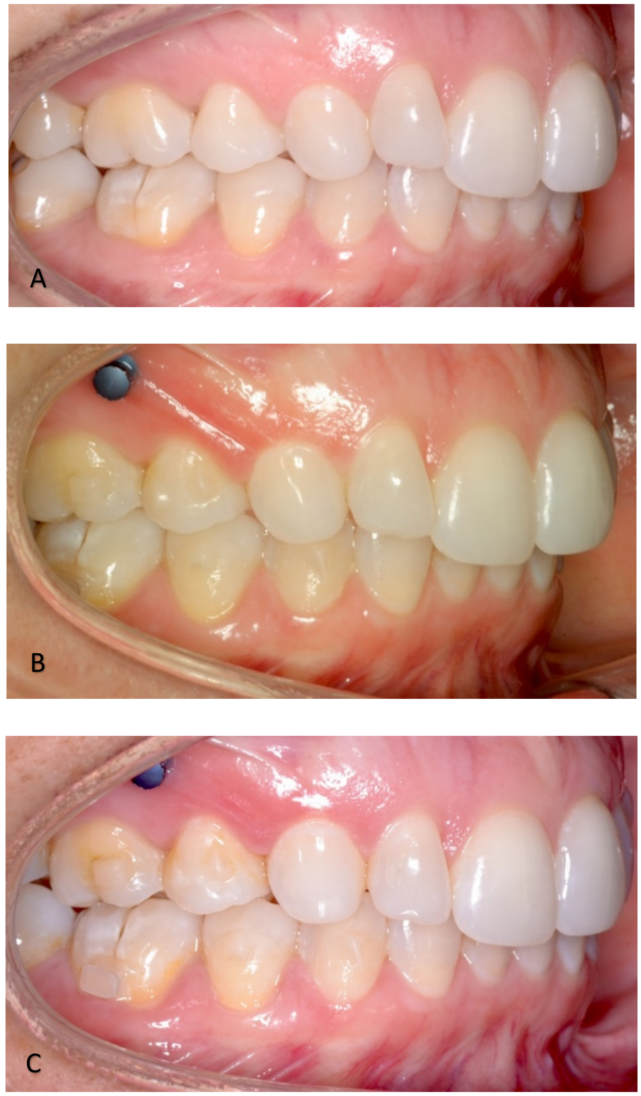


Figure 9 A-C. A,B Adult female with mild Class II and crowding, treated using aligners with a Class I elastic worn from a Tear Drop notch at the maxillary cuspid to a miniscrew inserted in the buccal alveolus between the 1st molar and 2nd premolar. C. Additionally, a typical Class II elastic was worn from the same cuspid to a button bonded on the mandibular 1st molar (plastic was cleared for the button using The Hole Punch instrument (Figure 5)).

Combo Meal Approach

When segmental distalization is desired in an aligner "precursor" scenario, using the "combo meal" concept of applying Class I elastic chain from the hook on the cuspid to the miniscrew, along with Class II elastics, may provide the best of both worlds (Figure 7). This concept encompasses using the cuspid hook on the Carriere device (or a homemade likeness) mentioned earlier (Figure 10). A light, constant force from the elastic chain reduces compliance concerns and also aids in counteracting some of the previously mentioned side-effects. Once the desired distal molar movement is achieved, then the transition to aligners is made to retract the remaining anterior teeth; supported still by the Class II elastics and Class I elastics from the miniscrews. Better directional forces and predictability are the results in this permutation.

Figure 10 A-C. A. Class II Division 2 male with "peg" laterals treated using pre-aligner Carriere with elastic chain stretched to a miniscrew in the maxillary buccal alveolus along with Class II elastics. B. Upon producing a "super" Class I molar relationship, clear aligners were worn, still supported by elastics to the miniscrew and mandibular molars. C. Final results.

Modifications of Transpalatal Arches (TPAs)

Simple modifications of TPAs, combined with miniscrews, have been introduced as adjuncts to improve predictability for correction of some types of all three Angle Classes of malocclusions [34, 61, 62]. Specifically, the TPA- design permits the addition of simple forces to support retraction of segments of teeth and/or to produce *en masse* retraction for Class IIs. Miniscrews are inserted into the palatal alveolus between the 2nd premolar and 1st molar, independent from the appliance framework. The TPA+ is used to protract posterior teeth and/or *en masse* protraction in mild Class IIIs. One additional "hook" is added at the mesial of the first molars and vertical intrusive forces can be combined with either TPA design to maintain vertical dimension and/or assist in closing anterior openbites by intrusion of the posterior teeth (Figure 11) [63]. With some inventiveness and ingenuity, these adjuncts can be employed prior to or during clear aligner treatments to improve predictability of mechanics.

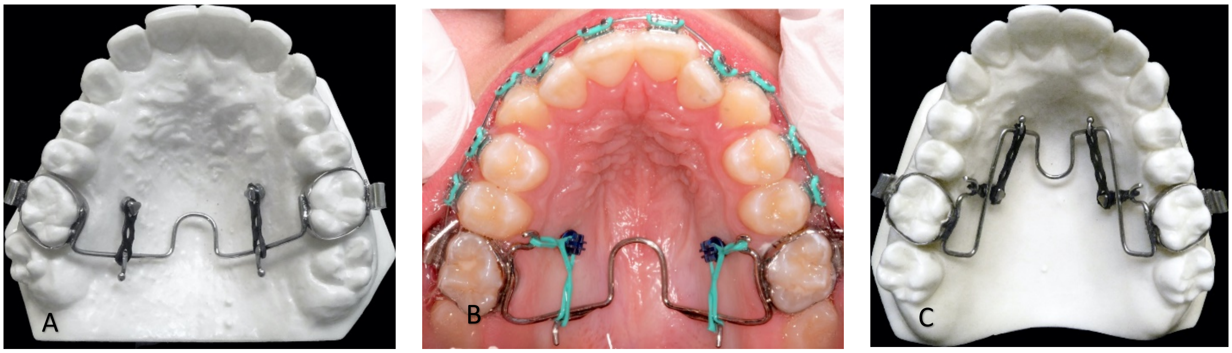


Figure 11 A-C. Simple modifications of transpalatal arches designed to employ miniscrews (inserted into the palatal alveolus) and elastic chain to direct forces for: A. The TPA+ for simple maxillary protraction for mild Class IIIs or instances of missing premolars or lateral incisors; B. Protraction can be combined with intrusion or either, alone, by orienting elastic chain appropriately; C. The TPA- for simple maxillary retraction and intrusion for mild Class IIs or either, alone, by applying elastic chain as necessitated. These TPAs can be used in conjunction with clear aligners or as precursors to plastic treatments.

More Comprehensive Miniscrew-Supported Distalization

The Horseshoe Jet, miniscrew-supported distalizer, offers an option for more difficult Class II situations (Figure 12) [46, 51, 64-67]. This appliance is housed in the maxillary palate where miniscrew insertions have shown to have less failure rates. Molars are pushed by open coil springs on a tracking "horseshoe-shaped" wire, anchored independently by the miniscrews. As there is no indirect anchorage from a palatal Nance or from supports on any teeth anterior the molars in question, no anchorage loss is possible. Distal movement can be accomplished prior to starting aligners or the upper aligners can be sectioned at the 2nd premolars and worn simultaneously. When a "Super-Class I" over-correction is achieved, the Horseshoe Jet is "locked" and becomes a miniscrew-supported holding arch for retraction of the remaining teeth.

The "abbreviated" upper aligners are then targeted for retraction, back to the miniscrew-anchored 1st molars, using Class I elastics or elastic chain to hooks or buttons at the cuspids. Once the upper spaces are closed and cuspids are now in Class I relationship, the Horseshoe Jet is removed for further finishing with aligners. It is important to note that the addition of miniscrews is merely to improve the predictability of the aligner treatment. It may seem obvious that the aligner treatments that involve the extraction of teeth would also significantly benefit from the addition of miniscrew anchorage during aligner therapy (Figure 13).

Figure 12. The Horseshoe Jet is a miniscrew-supported maxillary molar distalization appliance. Miniscrews, inserted in the palatal alveolus, provide anchorage for compressed coil springs to push molars posteriorly without any anchorage loss. In this arrangement, the miniscrews are locked-into any framework and can be checked for integrity or replaced easily with making a new appliance. After distalization is complete, the setscrews are tightened to stop further molar movement and the appliance now serves as a miniscrew-supported holding arch for subsequent retraction of the remaining teeth.

Figure 13 A,B,C,D. Male teen with Class II malocclusion started treatment with a The Horseshoe Jet simultaneously while initiating clear aligner treatment. The maxillary aligners were ended distal to the 2nd premolars to allow the molars to move posteriorly.

Figure 13 E,F,G,H, I. Upon achieving a Class I molar relationship, the Horseshoe Jet setscrews were locked in place and this miniscrew supported holding arch was used to apply Class I intramaxillary elastics from the molars to notches in the aligners at the cuspids. H, I. The remaining maxillary teeth were retracted en-masse with the aligners, then the appliance was removed, and typical Class II elastics were applied for finishing.

TOOTH MOVEMENT LAG

Dating back to the origins of aligners, there has been clear frustration associated with teeth simply not following the marching orders apportioned for specific movements by the software.[31,34] What we predict in a digital set-up is often simply not translated [28, 68]. Perhaps, the most perplexing and disconcerting failures with plastic are found in the esthetic zone. The most common of these smile-apparent disappointments are rotations of cuspids and lateral incisors although rotations of lower premolars have also been described as unpredictable [2, 4, 8, 24, 69].

Another issue that seems to crop-up regularly during treatment is the visible lack of "tracking" or tooth movement "lag." When teeth are lagging, the aligner features an airgap: a visible space between the plastic and the tooth or teeth [31]. Consequently, the tooth is no longer seated into the plastic "socket" where the crown is supposed to be positioned (Figure 14). Therefore, the tooth is not following the prescribed movement as dictated by the plastic trays. Even more disconcerting is when rotations and vertical issues are both lagging simultaneously, especially when it is noted by a disappointed patient. The creation of Aligner Chewies as a possible preventive measure (as noted previously) was a direct result of these common enigmas (Figure 1,2) [31, 37].

Figure 14 A-D. A,B. Aligner "lag" or loss of tracking is noted when a tooth is no longer seated into the aligner, resulting in an airgap between the tooth and the plastic. C,D. In this situation, elastics were used in a "bootstrap arrangement" of extrude laterals and intrude central incisors.

These irritating annoyances seem to appear out of nowhere with no rhyme nor reason, especially for maxillary lateral incisors. In this regard, Class II Division 2 upper lateral incisors are notorious offenders. They often are crowded, rotated, more apical than the centrals, and require substantial lingual root torque. That is one serious assemblage of complex tooth movements to expect to be modelled predictability with software.

Various remedies have been suggested to assist in correction of rotated or poorly tracking laterals, most often involving larger and more prominent composite attachments. The idea is to increase the contact real estate of plastic on the tooth by adding adhesive attachments; analogous to adding a bigger handle. Nicozisis has popularized the so-called "sash" attachment as one possible solution. A prominent beveled and rectangular block of composite is rotated on the face of the lateral to direct the desired movement (Figure 15). The appearance reminds one of a beauty pageant winner's ribbon or sash [70]. A further potential alternative involves the application of attachments on the lingual of the teeth in question [71].

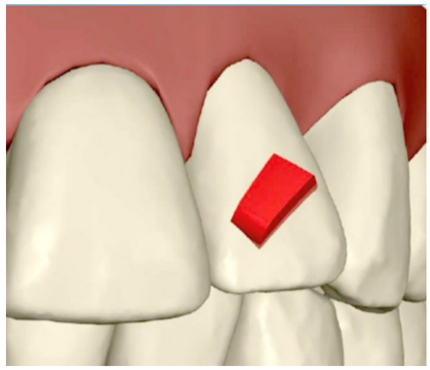


Figure 15. The “sash” attachment [70] to assist in rotating and/or extruding an incisor is prescribed as prominent, rectangular, gingivally-beveled and rotated on the tooth as desired.

Despite large attachments, loss of tracking is still a familiar occurrence [33]. Insufficient mesio-distal space for a particular rotated or lagging tooth is frequent but may not be readily identified as the source of failure (Figure 16). Operators are likely to simply expect that if the teeth are straight in the digital set-up that they will eventually just get to where they’re supposed to be. However, if there is not enough space, the tooth will never follow along and, in fact, will often begin to intrude.

Figure 16. The maxillary cuspid is not “tracking” despite two large attachments. The issue is actually that there is insufficient space for the width dimension of the tooth to fit into the available aligner width. The cuspid is actually being “squeezed” apically by the adjacent lateral and 1st premolar. In other words, the situation cannot improve and will continue to worsen at least until space is created.

In the case of the lowly upper lateral, the two adjacent teeth (cuspid and central) are quite large in comparison. They also feature a rounded anatomy where they contact the lateral on the mesial and distal surface that tends to squeeze the lateral *apically*, often making the situation progressively worse. If space is not created in the set-up for the lateral, then it is unlikely that massive attachments will make much difference. Such is the fate of blade-shaped, short, and especially the microdont or "peg" lateral incisor (Figure 17). Recall that the predictability of both intrusion and especially extrusion of anterior teeth was found to be wanting [2,8,9]. Then, what is one to do when typical efforts have failed? Can we force the issue?

Figure 17 A-D. A. Late teen female with peg-shaped lateral incisors treated with aligners. B. Space was opened adjacent to the laterals for future composite restorations. C,D. So-called "boot-strap" elastics used to direct the eruption of the laterals and intrusion of the central incisors.

Bootstrapping Your Way to Success

When tooth movement has run "off the tracks," are there means to easily salvage the situation with or without another "refinement" round of aligners (Figure 14)? The process of "refinement" involves new impressions/scans >> new set-up >> more aligners fabricated—not a very efficient process if multiple repetitions are required. In response, a "bail-out" option of adding orthodontic elastics to direct the movement of a specific tooth was developed. Tear drop-shaped notches are cut into the plastic (Figure 18) using The Tear Drop* (Hu-Friedy) at the mesial and distal gingival embrasures to permit the lodging of a small elastic prior to seating the trays in the mouth [30, 31, 38, 39]. On the lingual of the lateral, a bondable "button" is placed near the gingival margin and the plastic on the lingual is cleared (using The Hole Punch instrument)(Figure 5,19) to provide sufficient space for that button (and the tooth) to be slowly pulled incisally [30, 31, 38, 39].

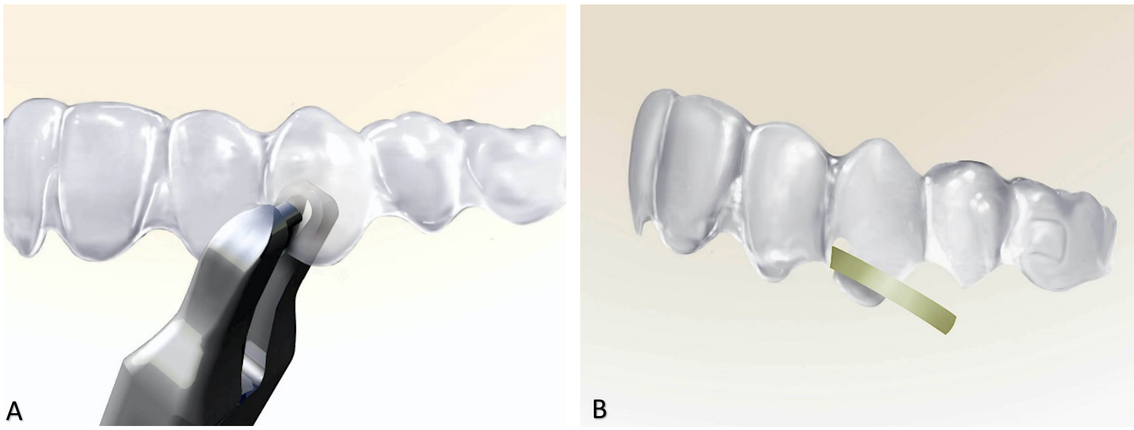


Figure 18 A,B. The Tear Drop instrument (Hu-Friedy, Chicago) is used to cut a tear-drop shaped reservoir at the gingival margin on an aligner to hold an orthodontic elastic in place prior to seating the tray.

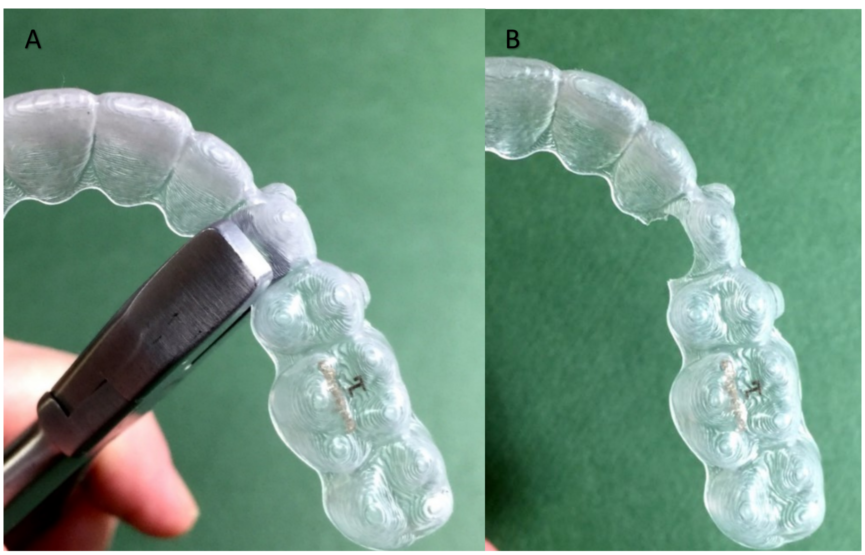


Figure 19 A,B. The Hole Punch instrument is used to cut plastic clearance for a bonded button on the lingual of the tooth to be "erupted."

After the tray/elastic combination is inserted in the mouth, the elastic is pulled around-and-over the aligner tray to the button (Figure 14,20,21). Another option is to place an esthetic bonded button on the facial of the lateral with plastic clearance for a button-to-button elastic stretched over the tray (Figure 22). The elastic then provides the extrusive force to the stubborn tooth, seating it into the tray; analogous to using the small straps on boots to seat footwear; hence, the name "bootstrapping." Also keep in mind that the counteracting force on the adjacent teeth may also be used to direct their intrusion if desired.

Figure 20. To enhance the movement of a “lagging” tooth, an elastic is applied to “tear-drop shaped notches” at the aligner margin and draped over the plastic to a button on the lingual of the affected tooth.

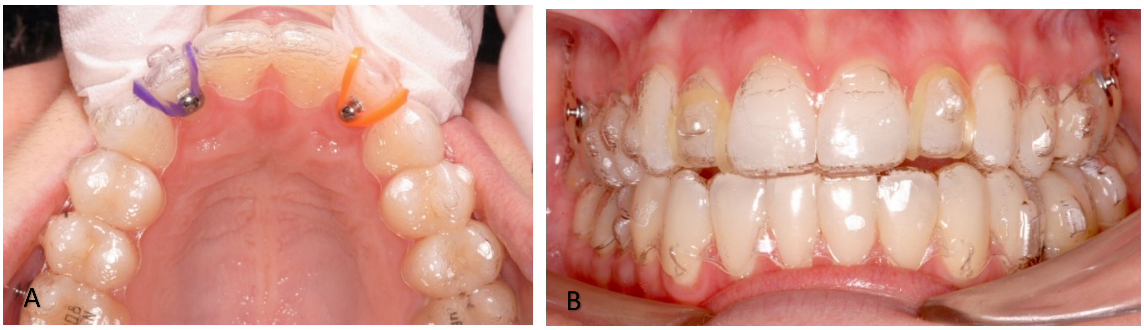


Figure 21 A,B. Lagging maxillary lateral incisors were forcibly erupted using “bootstrap” elastics. Tear drop cuts were made at the mesial and distal gingival embrasures of the labial of both incisors and an elastic is retained in the notches. After the aligner is seated, then the elastic is stretched over the tray to connect to buttons bonded on the lingual of the teeth.

Taking this concept one step beyond, more than just as a rescue mission when a tooth isn’t tracking, consider that the direction of eruption and/or rotation of a specific tooth might be more predictable if bootstrapping were initiated from the beginning. In this situation, the final position of the tooth in question (e.g., rotation, eruption, and torque) needs to be incorporated into the digital set-up to appear potentially with the first few aligners in a series. In other words, written direction to the technician (or manipulating the software) will result in a tooth or teeth that appear out of position in the set-up. The first aligner in the series will look odd and suspect in fit for the tooth in question. Bootstrapping begins immediately during the aligner series and the elastics facilitate a more predictable response (Figure 23).

Figure 22. “Button-to-button.” An alternative to the “tear-drop cuts to button” bootstrap is to stretch an elastic over the aligner from an esthetic button, bonded near the facial gingiva, to another button at the gingival margin on the lingual.

Figure 23 A-E. A,B. An adult female with chief complaint of the position of the lateral incisors. C. Esthetic buttons were bonded on the facial, near the gingival margin, of each tooth. Buttons were also placed on the lingual of the incisors as well. The digital set-up prescribed that the incisors be erupted by 0.25 mm past the incisal edges of the central incisors starting at Stage 1. In other words, the “air gap” was purposefully created as space to direct the eruption the laterals using “button-to-button” bootstrap elastics. D,E. Final results.

A most important concept when creating a software 3D set-up is that of incorporating “overcorrection.” Considering the errors involved in creating aligners, the levels of manufacturing tolerances, and flexibility of the plastic, it may be contended that no correction can occur without built-in overcorrection [25]. For instance, to achieve corrected rotation of any tooth, asking for at least 2-3° of over-rotation may be necessary. Resolving a midline deviation may necessitate over-correction by a millimeter, and so forth. The Horizontal and The Vertical are also instruments* (Hu-Friedy) to individualize each aligner by placing indents to accent desired movements (Figure 24) [30, 31, 38, 39].

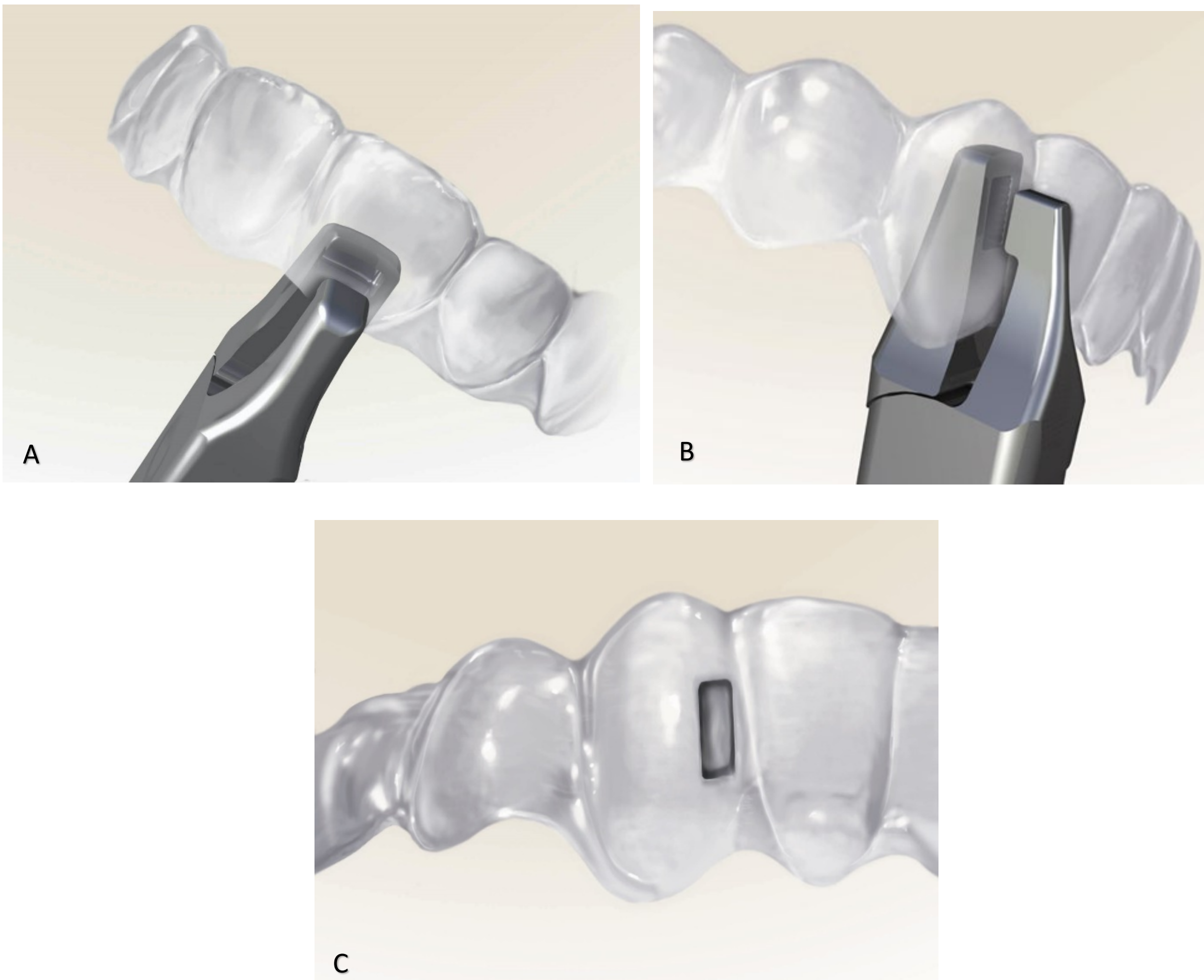


Figure 24 A-C. A. The Horizontal instrument is designed to add indents to the aligner plastic to produce root rotation (i.e., torque) or increase retention of an aligner or clear retainer if used in the posterior. B. The Vertical pliers may be employed to add accent indents in the plastic to generate rotational couples.

SLINGING THE OPENBITE

It has been advocated that anterior openbites might be better resolved with aligners [72-74]. Historically, caution has been advised for closing anterior openbites by extrusion of anterior teeth as possibly an invitation to relapse. Often, it would be more desirable to produce intrusion of posterior teeth to affect a clockwise rotation of the mandibular plane instead. Considering Newton's 3rd law, is it reasonable to expect that plastic on the back teeth will intrude them in deference to the anteriors? If we're looking for a predictable result, that doesn't simply depend upon incisor extrusion, it seems that miniscrew-supported "elastic slings" look to be indispensable (Figure 25).

A "sling" elastic is draped around the maxillary aligner from a miniscrew, inserted in the palatal alveolus, over to one in the buccal alveolus [31, 34].[31,34] The posterior teeth are directed for intrusion in the digital set-up and the sling elastic produces the intrusive force. If a mandibular sling is needed, then miniscrews are placed in the buccal alveolus. A button is bonded on the lingual of the 1st molars and the elastic is stretched from the button over the aligner to the buccal miniscrew (Figure 25). The digital set-up must reflect the desired intrusion, but the sling elastics force the issue.

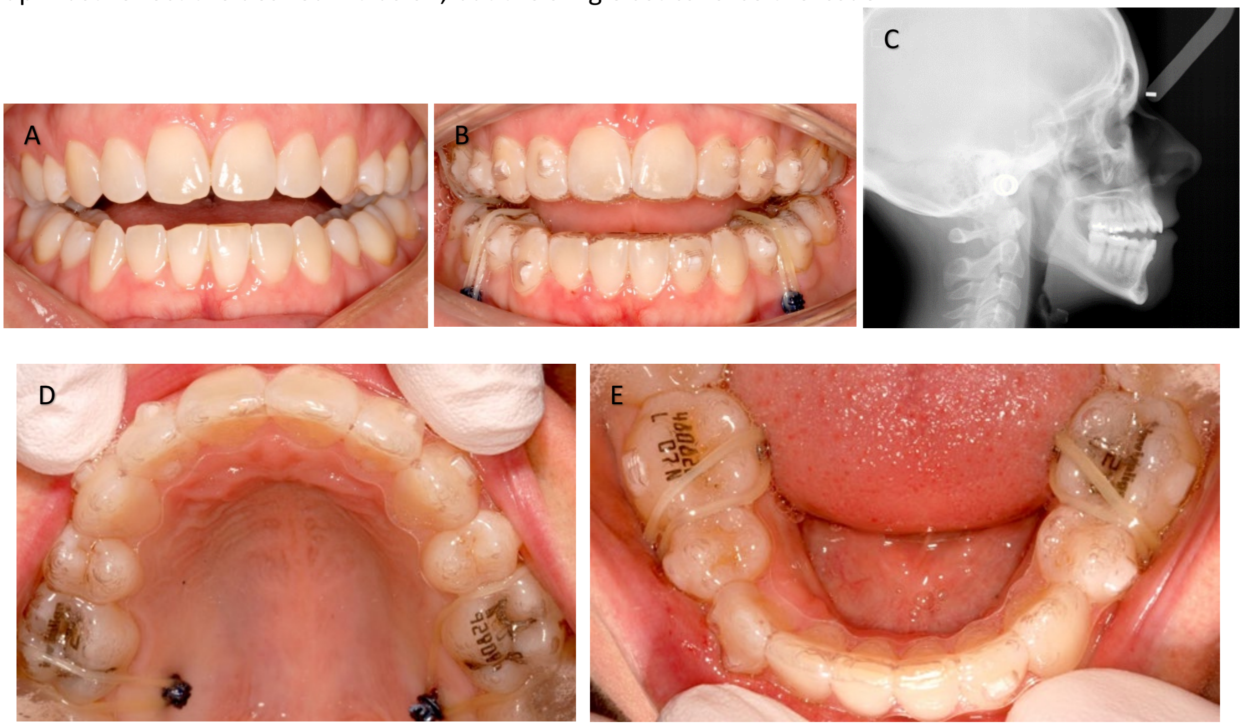


Figure 25. A-E. Adult female with anterior open treated with clear aligners enhanced with miniscrews and elastics in a "sling" arrangement. Miniscrews were placed into the maxillary dentoalveolus on both the buccal and palatal and elastics were worn across the aligners from one anchor to the other to *generate posterior intrusion. Miniscrews were also placed in the buccal alveolus in mandible and buttons were bonded on the lingual of the 1st molars. Elastics were "slung" from the buttons to the miniscrews to assist with aligner-directed intrusion.*

Figure 25. F-J. *Programmed posterior intrusion was accompanied by counterclockwise mandibular rotation to aid in closure of the anterior openbite.*

Recall, however, that there are circumstances where some anterior extrusion is still appropriate, especially in situations of reverse smile lines (Figure 26).

Figure 26 A-J. A-D. Teen patient with mild anterior openbite and reverse smile line. Class III elastics maintained a positive overjet. E-J. Intermaxillary "rectangular" seating elastics to finalize the result.

BACK BITE, BITES BACK

If one is more resolved to create results with aligners equivalent to those with braces, then just aligning the social six is insufficient. Self-examination can be difficult and time consuming such as when preparing case presentations for the American Board of Orthodontics, Angle Society, a study club, or for an audience of your peers. However, there is nothing more instructive than reviewing your own work as you may likely be much more critical and will improve your diagnostic acumen and treatment results. When evaluating aligner results, esthetics are obvious. More revealing than considering the fit of the posterior teeth in a buccal view is also taking a peek from the "tongue side."

Posterior openbites occasionally appear when there were none. Is it simply the effect of having two thin pieces of plastics sandwiched between the molars for months on end? Is it a kind of "Gelb" splint effect that intrudes the back teeth while the others might be erupting? Or is it incomplete leveling of the Curve of Spee when anterior teeth actually need substantially more intrusion to permit posteriors to touch? If any of these are determined to be the cause, what is to be done to correct this issue or, better yet, prevent it for future patients.

When leveling with braces, not only are anterior teeth intruded, but posterior teeth are often extruded at the same time to maintain occlusion. The same can be designed for aligners. Certainly, incomplete incisor intrusion when leveling the Curve of Spee may be a factor; however, if some positive overjet has not been simultaneously produced for adequate clearance of incisors, then inappropriate contact on anterior teeth will still be present.

Incisor root “torque” is difficult to produce with aligners with reliability due to the flexibility of the plastic in creating a consistent rotational couple. For one thing, the forces involved have a tendency to push the aligner incisally (Figure 27) [75]. A secondary issue was also discovered during the Invisalign Teen Study when examining the effects of “torque ridges” [40, 41]. As more torque was added into the diagnostic set-ups, posterior openbites were observed clinically, especially at the maxillary first molars (Figure 28 A). When considering the forces involved, a distolingual rotational force is applied to the incisor roots, resulting in a resisting force at the distal of the first molars; pushing them anteriorly. In this manner, the molar is squeezed mesially and it tends to tip and intrude mesially; tipping and lifting out of the aligner. The effect mimics additional Stolerization (mesial crown tip and more prominence for the distal of the tooth)(Figure 28 B). Applying a large attachment on the first molars may assist in limiting this type of disconcerting “openbite”; however, if anterior torque is treatment planned, then it may be more predictable to add mesial root tip and/or extrusion of the mesio-buccal cusps of the first molars from the start.

Figure 27. The application of significant maxillary anterior root rotation (i.e., torque) with “torque ridges” may produce the unintended side effect of pushing the aligner incisally; thereby, mimicking “lag.”

Figure 28 A-C. Maxillary anterior torque application may cause an untoward intrusion and tipping of the first molars in reaction.

When critically evaluating posterior openbites, it is important to note the Curve of Wilson, especially if any maxillary expansion has been produced [76-78]. Often the palatal cusps of the molars and perhaps premolars may be more prominent (or “hanging”), causing the appearance of an openbite

(Figure 29, 30). Adding buccal root torque for posterior teeth during treatment may reduce this common error that is also found with braces as well. Marshall et al. stated, "For proper occlusion, there should be no significant difference between the heights of the buccal and lingual cusps of molars and premolars" [76]. Adding some mild intrusion for second molars may also be necessary to close midarch openbites (Figure 28 C). Finally, aligners can be sectioned distal to cuspids to allow for some settling as well to close posterior openbites.

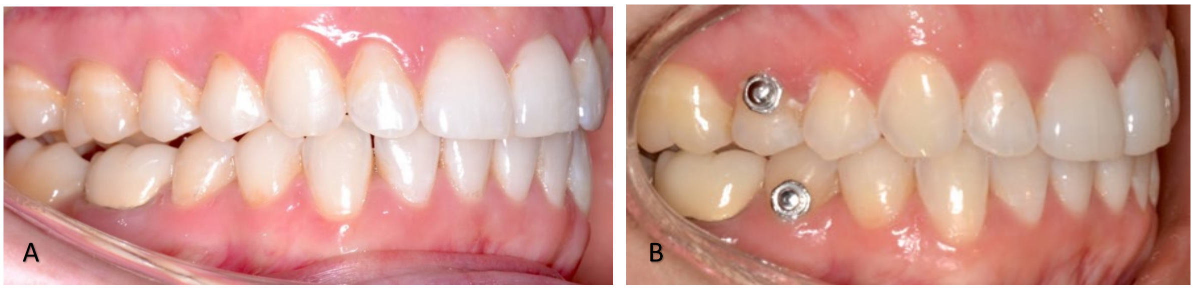


Figure 29 A,B. A. Appearance of a posterior "openbite" marring clear aligner finishing. Inattention to maxillary posterior buccal root torque is the culprit. B. Added posterior torque in refinement with intermaxillary elastics resolved an issue that could have been easily avoided by prior planning.

Figure 30 A,B,C,D. A troublesome openbite developed during clear aligner treatment. Adding significant buccal root torque and intermaxillary elastics ultimately resolved the situation.

Another extremely useful solution is the use of "seating" intermaxillary elastics, arrayed in a variety of configurations—just like with braces—in combination with the set-up changes noted above (Figure 27-30). Finally, the intensive use of a custom tooth positioner may be employed as a finishing device [79, 80].

LIMITED TREATMENT & RETENTION ALTERNATIVE

Innumerable strategies and appliances for retention of orthodontic results have populated our literature throughout our history. Recently, Littlewood et al. completed a Cochran Collaboration summarizing much of the information and then offering some best-practices advice [81]. Popular options today include removable (Hawley-type or clear aligner style) and fixed (bonded wires on the lingual of the anterior teeth) retainers.

Although the concept of having "permanent" retention appears to be most appealing, there are many concerns with long-term responsibility and liability, difficulty in maintenance and cleaning, diet restrictions to reduce breakage (there have been reports of swallowing fractured retainers), and also some risks for iatrogenic tooth movement and gingival loss. Survival of bonded retainers has been a primary concern with perhaps 20% failure in the mandible and 50% for the maxilla [82, 83].

A recent modification of the "spring retainer" concept has been recently introduced. The Revolution Spring (Apex Ortho Innovations, Fuquay-Varina, NC)(Figure 31-33,35) features labial and lingual bows that are fabricated from Beta Titanium wire that is flat along the surfaces of the anterior teeth [84, 85]. As there is no acrylic applied over those bows, they are smoother, less bulky (lower profile), and less likely to affect speech than the typical spring retainer. More importantly, these bows can be easily adjusted to accent 1st Order movements using a Quadra-Z pliers (Apex Ortho Innovations)(Figure 34,35). This instrument was designed specifically to avoid fracturing the brittle Beta Titanium.

Figure 31. The Revolution Spring appliance was designed as both a retainer and for minor tooth movement issues. "Flat" Beta Titanium bows can be adjusted and yet has better resiliency than stainless steel. There is no acrylic over the wires found in most spring retainers, so there is less bulk or speech concerns.

Figure 32 A-C. Correction of mandibular crowding and rotations wearing the Revolution Spring full-time for 4 months.

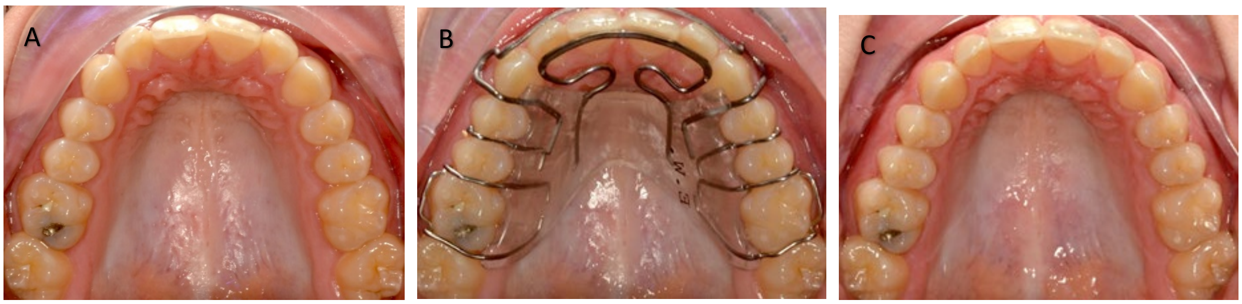


Figure 33 A-C. Correction of maxillary crowding and rotations treated with the Revolution Spring in 1 month.

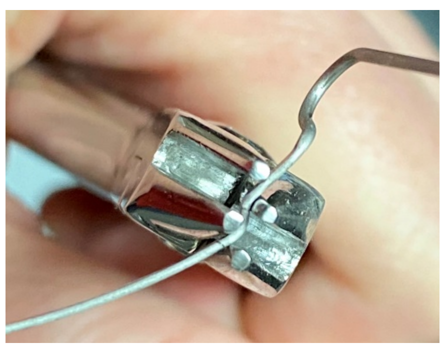


Figure 34. The Quadra-Z pliers (Apex Ortho Innovations) were designed to produce 1st Order bends into the brittle Beta-Titanium bows of the Revolution Spring to accent and individualize minor tooth movement without wire fracture.

The Revolution Spring appliance serves multiple purposes. First, it may be a more reliable alternative to traditional Hawley or spring retainers as the forces from activated Beta Titanium are less prone to dissipate or fatigue over time. Second, if any minor tooth movement is detected, the patient can often correct it themselves by simply wearing the device full-time again. Third, if minor tooth movement is treatment planned, even for new patients, this appliance may serve as a more predictable, rapid, and economical alternative. If a fixed retainer fractures or is dislodged, the patient may not be aware until adverse tooth movement has already occurred. Then a Revolution Spring treatment may be required to recover from the relapse. Using this device from the start of retention, it serves as a kind of insurance policy as the patient is responsible for maintaining their result and if anything changes, they may be able to reverse it with the same aligner.

Figure 35 A-C. A. Mandibular "relapse" of rotations and crowding. B. Revolution Spring aligner constructed from digital set-up that included mild labial overcorrection of the lower right central incisor. Mild accent 1st Order bends made in the labial bow with Quadra-Z pliers. C. Final results in 1 month.

THAT'S A WRAP

The basis for clear aligners may be quite old, but their actual clinical use has sprung forth exponentially in only the past 20 years. During the growing pains, it became obvious that just a series of aligners alone cannot resolve the majority of malocclusion issues facing our specialty—no matter the quality of the software design, modeling, nor type of plastic developed. Certainly, the experience of the clinician plays a significant role in diagnosis and treatment planning; however, it is interesting that with millions of patients treated there is simply still a dearth of data gathered from successful final results. If only that information had been archived, even more substantial improvements may have been possible by now.

Instead, it has been innovations brought forward by orthodontists that have moved the needle. Yet, little credit is afforded those individuals as the companies take the credit. Early adopters stood by the aligner concept through the frustrating times, effecting improvements, such as the addition of elastic forces, one-week changes, interesting attachment designs, adjunctive appliances, individualization of aligners, and so on. It was these inventive practitioners that expanded the scope of aligners from mild Class I situations to complex malocclusions and even surgical treatments.

It will be those same forward-thinking individuals who will continue to ever improve the efficiency, effectiveness, and ultimately, the predictability of aligners with or without the limitation of the commercial ventures. These creative innovators may eventually further splinter the already increasing number of companies that are producing aligners by simply just going it alone; fabricating aligners in their own office labs and alliances, unobstructed by the limitations and constraints of corporate governance beholden to "shareholders" instead of to patients and practitioners. In the meantime, the encroachment of direct-to-consumer products have also seemed to stymie and interrupt the evolution of clear plastic treatments. Sadly, profits before patients. Products over practitioners.

Drastic Plastic was the title of the last album (on actual vinyl) by art rock band, Be-Bop Deluxe, released in 1978.

*The author has a financial interest for Aligner Chewies and the Hu-Friedy Clear Collection.

REFERENCES

1. Kesling HD. The philosophy of tooth positioning appliance. Am J Orthod 1945;31:297-304.
2. Kravitz ND, Kusnoto B, Begole E, Obrez A, Agran B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. Am J Orthod Dentofac Orthop 2009;135:27-35.
3. Chisari JR, McGorray SP, Nair M, Wheeler TT. Variables affecting orthodontic tooth movement with clear aligners. Am J Orthod Dentofacial Orthop 2014;145(Suppl 4):S82-91.
4. Lombardo L, Arreghini A, Ramina F, Huanca Ghislanzoni LT, Siciliani G. Predictability of orthodontic movement with orthodontic aligners: a retrospective study. Prog Orthod 2017;18:35.
5. Houle JP, Piedade L, Todescan Jr R, Pinheiro FHSL. The predictability of transverse changes with Invisalign. Angle Orthod 2017;87:19-24.
6. Solano-Mendoza B, Sonnemberg B, Solano-Reina E, Iglesias-Linares A. How effective is the Invisalign system in expansion movement with Ex30' aligners? Clin Oral Investig 2017;21(5):1475-1484.
7. Glassick A, Gluck AJ, Kotteman W, Messersmith M. Evaluating the efficacy of lower incisor intrusion with clear aligners. J Clin Orthod 2017;51:233-239.
8. Charalampakis O, Iliadi A, Ueno H, Oliver DR, Kim KB. Accuracy of clear aligners: a retrospective study of patients who needed refinement. Am J Orthod Dentofacial Orthop 2018;154:47-54.
9. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod 2015;85:881-889.
10. Buschang PH, Ross M, Shaw SG, Crosby D, Campbell PM. Predicted and actual end-of-treatment occlusion produced with aligner therapy. Angle Orthod. 2015;85:723-727.
11. Zheng M, Liu R, Ni Z, Yu Z. Efficiency, effectiveness and treatment stability of clear aligners: a systematic review and meta-analysis. Orthod Craniofac Res 2017;20(3):127-133.
12. Leake J. Does Invisalign line up with evidence? Master's Thesis 2018. Toronto: University of Toronto.
13. Wiboonsirikul S, Manopatanakul S, Dechkunakorn S. Invisalign update: a review of articles. M Dent J 2014;34:174-180.
14. Kim AS. Treatment effectiveness of the Invisalign system: a systematic review. Master's Thesis 2013. Philadelphia: Temple University.
15. Robertson L, Kaur H, Fagundes NCF, Romanyk D, Major P, Flores-Mir, C. Effectiveness of clear aligner therapy for orthodontic treatment: a systematic review. Orthod Craniofac Res 2020;23(2):133-142.
16. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Treatment outcome and efficacy of an aligner technique—regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health 2014;14;68.
17. Ke Y, Zhu Y, Zhu M. A comparision of treatment effectiveness between clear aligner and fixed appliance therapies. BMC Oral Health 2019;19:24.
18. Kuncio D, Maganzini A, Shelton C, Freeman K. Invisalign and traditional orthodontic treatment postretention outcomes compared using the American Board of Orthodontics Objective Grading System. Angle Orthod 2007;77(5):864-869.
19. Gu J, Tang JS, Skulski B, Fields HW Jr, Beck FM, Firestone AR, et al. Evaluation of Invisalign treatment effectiveness and efficiency compared with conventional fixed appliances using the Peer Assessment Rating Index. Am J Orthod Dentofac Orthop 2017;151(2):259-266.
20. Galan-Lopez L, Barcia-Gonzalez J, Plascencia E. A systematic review of the accuracy and efficiency of dental movements with Invisalign. Korean J Orthod 2019;49(3):140-149.

21. Djeu G, Shelton C, Maganzini A. Outcome assessment of Invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system. Am J Orthod Dentofacial Orthop 2005;128:292-8.
22. Papageorgiou SN, Koletsi D, Iliadi A, Peltomaki T, Eliades T. Treatment outcome with orthodontic aligners and fixed appliances: a systematic review with meta-analyses. Eur J Orthod 2019;23.
23. Azar JD. Do-it-yourself orthodontics: an objective assessment of dental impression outcomes between an orthodontic resident and patients. Master's Thesis 2016. St. Louis: Saint Louis University – Center for Advanced Dental Education.
24. Buschang PH, Shaw SG, Ross M, Crosby D, Campbell PM. Comparative time efficiency of aligner therapy and conventional edgewise braces. Angle Orthod 2014;84(3):391-396.
25. Izhar A, Singh G, Goyal V, Singh R, Gupta N, Pahuja P. A prospective comparative study between the software models and clinical models of clear aligner treatment. Orthod J of Nepal, 2019;9(1):28-34.
26. Bowman SJ. They still shoot horses, don't they? Angle Orthod 2018;88(3):370-372.
27. Haouili, N, Kravitz, ND, Vaid, NR, Ferguson DJ, Makki L. Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign. Am J Orthod Dentofacial Orthop 2020 158(3):420-425.
28. Gomez JP, Peña FM, Martínez V, Giraldo DC, Cardona CI. Initial force systems during bodily tooth movement with plastic aligners and composite attachments: A three-dimensional finite element analysis. Angle Orthod 2015;85:454-460.
29. Glaser B. *The insider's guide to Invisalign treatment*. Sacramento: 3L Publishing, 2017.
30. Bowman SJ, Celenza F, Sparaga J, Papadopoulos MA, Ojima K, Lin JC. Creative adjuncts for clear aligners: part 1: Class II treatments. J Clin Orthod. 2015;49:83-94.
31. Bowman SJ, Celenza F, Sparaga J, Papadopoulos MA, Ojima K, Lin JC. Creative adjuncts for clear aligners: part 2: Intrusion, rotation, and extrusion. J Clin Orthod. 2015;49:162-174.
32. Bowman SJ, Celenza F, Sparaga J, Papadopoulos MA, Ojima K, Lin JC. Creative adjuncts for clear aligners: part 3: Extraction and interdisciplinary treatment. J Clin Orthod. 2015;49:249-262.
33. Bowman SJ. Improving the predictability of clear aligners. Sem Orthod 2017;23:65-75.
34. Mompell R, Bowman SJ. Microimplant-assisted aligner therapy. In: Park JH, ed. *Temporary Anchorage Devices (TADs) in Contemporary Orthodontics.* Hoboken: Wiley. 2020;53:567-580.
35. Schupp W, Haubrich J, Ojima K, Boisserele W, Morton J. *Aligner orthodontics: diagnosis, treatment planning, orthodontic and orthopedic treatment.* London: Quintessence Publishing, 2015.
36. Tai S. *Clear aligner technique*. Batavia: Quintessence Publishing, 2018.
37. Tuncay, O. Clinical Reports & Techniques. 2005;6(2):1.
38. Bowman SJ. Clear Collection instruments for clear aligner treatments Part I. Orthod Prac US 2015;6:74-78.
39. Bowman SJ. Clear Collection instruments for clear aligner treatments Part 2. Orthod Prac US 2015;6:48-52.
40. Tuncay O, Bowman SJ, Nicozsis J, Amy B. Effectiveness of clear aligner compliance indicator. J Clin Orthod 2009;43(4)263-268.
41. Tuncay O, Bowman SJ, Nicozsis J, Amy B. Aligner treatment in the teenage patient. J Clin Orthod 2013;47(2):115-119.
42. Arreghini A, Trigila S, Lombardo L, Siciliani G. Objective assessment of compliance for intra- and extraoral removable appliances. Angle Orthod 2017;87:88-95.
43. Schupp W, Haubrich J, Neumann I. Class II correction with the Invisalign system. J Clin Orthod 2010;44:28-35.
44. Daher, S. Dr. Sam Daher's techniques for Class II correction with Invisalign and elastics: Align Technology, Inc.; 2011. https://s3.amazonaws.com/learn-invisalign/docs/06840000000GHgmAAG.pdf Accessed 6/11/20.

45. Bowman SJ. Upper-molar distalization and the distal jet. J Clin Orthod 2016;50(3):153-163.
46. Bowman SJ. The evolution of the horseshoe jet. In: Papadopoulos MS, ed. *Skeletal Anchorage in Orthodontic Treatment of Class II Malocclusion: Contemporary Applications of Orthodontic Implants, Miniscrew Implants and Miniplates*. St. Louis: Mosby Elsevier, 2015.
47. Sung SJ, Jang GW, Chun YS, Moon YS. Effective en-masse retraction design with orthodontic mini-implant anchorage: a finite element analysis. Am J Orthod Dentofacial Orthop 2010;137:648-657.
48. Case CS. *A Practical Treatise on the Technics and Principles of Dental Orthopedia and Prosthetic Correction of the Cleft Palate*. Chicago: C.S. Case, 1921.
49. Klein BM. A cephalometric study of adult mild Class II nonextraction treatment with the Invisalign System. Master's Thesis. 2013. St. Louis: Saint Louis University – Center for Advanced Dental Education.
50. Ravera S, Castroflorio T, Garino F, Daher S, Cugliari G, Deregibus A. Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study. Prog Orthod 2016;17:12.
51. Bowman SJ. The horseshoe jet for miniscrew-supported molar distalization, J Clin Orthod 2018;51:196-218.
52. Bowman SJ. The effect of vibration on molar distalization. J Clin Orthod 2016;50(11):683-693.
53. Tsourakis AK, Johnston LE, Jr. Class II malocclusion: the aftermath of a "perfect storm." Sem Orthod. 2014;20:59-73.
54. Lin JC, Chen S, Liou EJ, Ojima K, Bowman SJ. Interdisciplinary aligner treatment of short-face patients. J of Clin Orthod 2017;51(7):382-405.
55. Lin JC, Tsai S, Liou EJW, Bowman SJ. Treatment of challenging malocclusions with Invisalign and miniscrews. J Clin Orthod 2014;48(1):23-26.
56. Lin JCY, Yeh CL, Liou EJW, Bowman SJ. Treatment of skeletal–origin gummy smiles with miniscrew anchorage. J Clin Orthod 2008;42:285-96.
57. Giancotti A, Germano F, Muzzi F, Greco M. A miniscrew-supported intrusion auxiliary for open-bite treatment with Invisalign. J Clin Orthod 2014;48(6):348-358.
58. Choi N-C, Park Y-C, Jo Y-M, Lee K-J. Combined use of miniscrews and clear appliances for the treatment of bialveolar protrusion without conventional brackets. Am J Orthod Dentofacial Orthop 2009;135(5):671-81.
59. Ojima K, Dan C, Nishiyama R, Ohtsuka S, Schupp W. Accelerated extraction treatment with Invisalign. J Clin Orthod 2014;48(8):487-499.
60. Park YC, Chu JH, Choi YJ, Choi NC. Extraction space closure with vacuum-formed splints and miniscrew anchorage. J Clin Orthod 2005;39:76-79.
61. Ludwig B, Baumgaertel S, Bowman SJ. *Mini-Implants in Orthodontics: Innovative Anchorage Concepts.* Chicago: Quintessence 2008.
62. Bowman SJ. Thinking outside the box with miniscrews. In: McNamara JA Jr, Ribbens KA, eds. *Microimplants as Temporary Anchorage in Orthodontics*. Craniofacial Growth Series, Center for Human Growth and Development, The University of Michigan, Ann Arbor, 2008;45:327-390.
63. Bowman SJ. Uno, dos, tres: one concept for three Angle classes. Sem Orthod 2018;24:3-16.
64. Bowman SJ. The horseshoe jet for miniscrew-supported molar distalization. J Clin Orthod 2018;51(4):196-218.
65. Bowman SJ. Class II combination therapy: molar distalization and fixed Functionals, In: Nanda R, Kapilla S, eds. *Current Therapy in Orthodontics*. St. Louis: Mosby Elsevier 2009:115-136.
66. Bowman SJ. Settling the score with Class IIs using miniscrews. In: Kim KB, ed. *Temporary Skeletal Anchorage Devices—A Guide to Design and Evidence-Based Solutions*. New York City: Springer 2014.
67. Carano A, Bowman SJ. Noncompliance Class II treatment with the distal jet. In: Papadopoulos, MA, ed. *Orthodontic Treatment for the Class II Noncompliant Patient: Current Principles and Techniques,* Edinburgh: Elsevier 2006;249-271.

68. Grunheid T, Loh C, Larson BE. How accurate is Invisalign in nonextraction cases? Are predicted tooth positions achieved. Angle Orthod 2017;87:809-815.
69. Papadimitious A, Mousoulea S, Gkantidis N, Kloukos D. Clinical effectiveness of Invisalign orthodontic treatment: a systematic review. Prog Ortho 2018;19(1):37.
70. Nicozisis JL. Tripping the plastic fantastic. Orthod Prod 2013;Nov:28-34.
71. Savignano R, Valentino R, Razionale AV, Michelotti A, Barone S, D'Anto V. Biomechanical effects of different auxiliary-aligner designs for the extrusion of an upper central incisor: A finite element analysis. J Heathcare Engineering 2019;Article ID 9687127:1-9.
72. Guarneri MP, Oliverio T, Silvestre I, Lombardo L, Siciliani G. Open bite treatment using clear aligners, Angle Orthod 2013;83:913-919.
73. Schupp,W.; Haubrich, J. and Neumann, I.: Treatment of anterior open bite with the Invisalign system, J. Clin. Orthod. 44:501-7, 2010.
74. Boyd R. How successful is Invisalign for treatment of anterior open bite and deep overbite? American Association of Orthodontists Annual Session May 5, 2013 Philadelphia PA. https://www.aaoinfo.org/system/files/media/documents/Boyd,%20Robert%20--%20Treatment%20of%20Deep%20and%20Open%20bite%20with%20Clear%20Aligners.pdf Accessed 2/16/21.
75. Glaser B. Dr Glaser's 10 commandments of attachment design. Orthod Prod Mar 29, 2016. https://www.orthodonticproductsonline.com/treatment-products/aligners/dr-glasers-10-commandments-attachment-design/?fbclid=IwAR2QUVq4H6yO5FNRJAL0E5TtkA4oemEZU8E4itfVP3TSo1aYZv3OChLPGBo. Accessed 6/10/20.
76. Marshall S, Dawson D, Southard KA, Lee AN, Casko JS, Southard TE. Transverse molar movements during growth. Am J Orthod Dentofacial Orthop 2013;124:615-624.
77. American Board of Orthodontics. Why case reports do not pass the ABO Phase III clinical examination. Am J Orthod 1996;110:559-560.
78. Yang-Powers LC, Sadowsky C, Rosenstein S, BeGole EA. Treatment outcome in a graduate orthodontic clinic using the American Board of Orthodontics grading system. Am J Orthod Dentofacial Orthop 2002;122:451-455.
79. Bowman SJ, Carano A. Short-term, intensive use of the tooth positioner in case finishing. J Clin Orthod 2002;36:216-219.
80. Park Y, Hartsfield JK, Katona TF, Roberts WE. Tooth positioner effects on occlusal contacts and treatment outcomes. Angle Orthod 2008;78(6):1050-1056.
81. Littlewood SJ, Millett DT, Doubleday B, Bearn DR, Worthington HV. Retention procedures for stabilising tooth position after treatment with orthodontic braces. Cochrane Database Syst Rev 2016;Jan 29(1):CD002283.
82. Kocher KE, Gebistorf MC, Pandis N, Fudalej PS, Katsaros C. Survival of maxillary and mandibular bonded retainers 10 to 15 years after orthodontic treatment: a retrospective observational study. Prog Orthod 2019;20:28.
83. Kravitz ND, Grauer D, Schumacher P, Jo Y. Memotain: a CAD/CAM nickel-titanium lingual retainer. Case reports. Am J Orthod Dentofac Orthop 2017;151(4):812-815.
84. Goldberg AJ, Burstone CJ. An evaluation of beta titanium alloys for use in orthodontic appliances. J Dent Res 1979;58:593–600.
85. Burstone CJ, Goldberg AJ. Beta titanium: a new orthodontic alloy. Am J Orthod 1980;77:121–132.