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Maxillary and Mandibular Expansion Treatment with Invisalign First: A Retrospective Study of Virtual Prediction Versus Clinical Outcomes

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MAXILLARY AND MANDIBULAR EXPANSION TREATMENT WITH INVISALIGN FIRST: A RETROSPECTIVE STUDY OF VIRTUAL PREDICTION VERSUS CLINICAL OUTCOMES.

by

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ORTHODONTICS

ABSTRACT

Introduction: The purpose of this retrospective study is to evaluate the maxillary and mandibular expansion achieved with Invisalign First (Align Technology, San Jose, CA) in growing children. **Methods:** Clinical stereolithography (STL) models of 32 patients in the mixed dentition stage, treated with the Invisalign First, were extracted from the ClinCheck software and analyzed in Dolphin imaging (version 11.95 Premium, Chatsworth, Calif) at three timepoints: T1 (initial records), T2 (virtual outcome prediction), and T3 (achieved outcome). The recorded measurements included: upper and lower primary intercanine and permanent intermolar width, upper and lower primary intercanine and permanent intermolar gingival width, upper arch perimeter, and upper arch depth. **Results:** Out of the 10 measurements evaluated, 8 showed a mean increase from T1-T3 (Initial-Final) and a decrease from T2-T3 (Prediction-Final). The upper deciduous intercanine gingival width (UICGW) showed the largest increase (+2.92 mm with 56.24% of planning accuracy). The least amount of expansion was found at the upper permanent intermolar gingival width (UIMGW) which showed the lowest percentage of accuracy. **Conclusions:** Clinically, the upper and lower transverse dimensions increased. The upper and lower primary intercanine distances showed the largest changes while the movement of the maxillary permanent molars was not significant. Clear aligners seem to be a good option for arch expansion in cases of mild to moderate transverse discrepancies in growing individuals. They appear to modify arch form to a broader shape, mostly in the anterior segments, thus providing space to alleviate crowding and help with malocclusion correction.

Key words: Invisalign, clear aligners, Invisalign first, maxillary expansion, mandibular expansion, Invisalign first phase I.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Invisalign (Align Technology, San Jose, CA) was first introduced in 1999 as an esthetic alternative to traditional fixed appliances to deliver orthodontic treatment using a series of clear aligners. Invisalign utilizes information technology through their proprietary software (Clincheck Pro) to prescribe three-dimensional tooth movement that is engineered into the clear aligners. The progression of dental movements from start to finish is rendered as a video depicting the prescribed movements stage by stage, each stage corresponding to one set of aligners. Since its introduction, Align technology has worked to improve the accuracy of the movements by modifying the quality of the aligner material, the digital scan and the accessibility to new tools in the software to achieve more predictability.[1] Invisalign First, launched in 2018, is the new product of Align company that addresses the early phase I treatment. It provides an interceptive option to young patients with different malocclusions such as crowding, constriction of the maxilla and mandible, and open bites, thus expanding the scope of treatment with clear aligners.[2] While heavily promoted by key opinion leaders, there are currently no published articles that quantify the effectiveness and predictability of Invisalign First treatment in mixed dentition patients.

Transverse discrepancies are a common problem in the early mixed dentition due to lack coordination between the upper and lower jaws. The variation in width between the maxillary and mandibular arches often results is a unilateral or bilateral crossbite.

Maxillary expansion is the treatment of choice to correct transverse discrepancies. Predictability in arch expansion is higher in younger patients before the end of the growth spurt.[3] Different modalities to deliver maxillary expansion have been described, and include the use of tongue blades, inclined planes, spring appliances, removable and fixed expanders, and expanders with skeletal anchorage.[4] Increasing the intercanine and intermolar distance increases arch perimeter and helps in accommodating the dentition.[5,6] Additionally, the plasticity of the bones during the early to mid-mixed dentition allows slow maxillary expansion to provide significant changes in arch form.[1,2] Expanding the transverse dimension benefits arch configuration, crowding, smile and facial esthetics.[7] When transverse discrepancies are not corrected at an early stage, studies have shown that they are usually transferred to the permanent dentition and malocclusions become more severe.[8] Currently, there is a lack of evidence on how Invisalign First works in the mixed dentition leading to a need to clarify the relationship between the initial clinical presentation, the virtual prediction and the achieved clinical outcomes after the first phase of treatment.[2]

Virtual predictions of Invisalign First in the treatment of young children show significant changes in arch width. Moreover, maxillary expansion achieved clinically is expected to match the virtual treatment prediction (ClinCheck).[9] Treatment with clear aligners is becoming increasingly popular in the young population due to the state-of-the-art technology, esthetics, periodontal health, comfort, remote control, less visits and patient self-time arrangements.[3] It is therefore imperative to understand the biology and biomechanical principles of clear aligner therapy that lead to successful and predictable clinical results.[4] This study will be one of the first to evaluate the maxillary expansion movement achieved with Invisalign First and compare initial records (T1), virtual prediction (T2) and final results (T3) using digital models.

CHAPTER 1

DENTAL ARCH DIMENSIONS

The configuration of the dental arches has been carefully studied in the orthodontic literature over the years to identify the physiologic changes from deciduous teeth to permanent dentition. A 1969 study by Coenraad Moorrees et al. stated that, during normal growth and in the transition from mixed to permanent dentition, arch width increases, especially in the intermolar area. They also showed that arch length usually decreases with the eruption of the first permanent molars since existing spaces between the deciduous teeth start to close. Furthermore, there is an expected decrease in arch length with the exfoliation of the primary molars, especially the second primary molars in both the maxilla and the mandible, but more so in the mandible. On the other hand, when the permanent incisors erupt, there is an increase in arch length in the maxilla, but arch length is not significantly changed in the mandible. With respect to arch circumference, the authors stated that between the ages of 5 to 18, there will be a minor increase in the maxillary arch circumference more for the average male (1.3 mm) than for the average female (0.5 mm). In the mandible, the opposite happens with a decrease of 3.4 mm in male) and 4.5 mm in females.[10]

A longitudinal study done by Sillman[11] brought detailed description of the changes in natural dentitions from birth up to 25 years old. Forty subjects were analyzed and each of them had dental casts made every year until adulthood (20-25 years old). Since males and females have different patterns of growth, the results were divided by gender. In males, it was found that the length of the maxilla increases between 6 and 10 years. After the appearance of at least 3 premolars in the arch, there was a decrease in length from ages 12 to 17 years and this does not change significantly until the appearance of a third molar (around 19 years old). For the female group there is not significant increase of the total length after age 13 years for the maxilla and after 14 years old for the mandible.[11]

Sillman also stated that, in males, the intercanine width increases from birth through 2 years of age by about 5 mm in the maxilla and 3.5 mm in the mandible. This dimension increases from between ages 2 through 13 in the maxilla and up to 12 years of age in the mandible. Females do not show significant growth from ages 16 to 25. The intermolar width in males shows a gradual increase in the maxilla (0.5 mm) and in the mandible (0.2 mm) from the deciduous stage up to the appearance of the second molars on the arch. After age 14, the changes are not significant. In the female group the intermolar width decreases in both jaws and changes are not significant after age 16.[11]

Knott found in her study that the maxillary deciduous intercanine distance tends to increase 2.8 mm with the eruption of the permanent central incisors, lateral incisors and permanent first molars. In the mandible, the intercanine increase ranges between 1.3 and 3.8 mm while in the maxilla the range was wider and varied between 1.2 and 4.9 mm. The intercanine width remains stable and little change is seen after the eruption of the permanent dentition according to the author results. [12]

Bishara provided concepts that are important to consider when planning modifications in the dimension of the arches in the early stages of growth. At the end of his research, it was understood that the crowding of the dentitions is mainly the result of a decrease in arch length in both jaws. This finding could be related to facial configuration, overjet, arch dimensions, incisor position, and mesiodistal tooth diameters. The reduction in arch length was the most consistent parameter studied with a greater reduction in patients who had more severe tooth size arch-length discrepancies during early adulthood. [13]

In 1998, Bishara reported that the main incremental changes in arch length occur during the first 2 years of age. This dimension continues to increase in the maxilla up until 13 years of age, and in the mandible up to 8 years old. After this period, there is a considerable reduction in arch length of about 5mm between 13 and 45 years of life.[7,14] Some studies of untreated upper and lower jaws have reported interesting findings including that the mandibular intercanine distance does not increase after the 12-year mark and little change is seen in the premolar region. Likewise, the best time to take advantage of the increase of the intermolar width is between 7-18 years of age specially in males. [7,15]

Sinclair's study aim was to evaluate the changes in untreated natural occlusions from early childhood to adulthood, in order to assess the development of normal occlusion without orthodontic treatment. Sixty-five dental casts were evaluated. The intercanine width and arch length were shown to be reduced overtime. The decrease in the intercanine width was more evident in females and the arch length reduction was more evident between mixed dentition and early adulthood. The intermolar width showed to be stable on average, however females showed little but significant reduction between 13 and 20 years old compared to males. The authors concluded that the development changes found in untreated arches were similar when these were compared with treated individuals. However, less changes were noticed in the untreated group. [16]

Meanwhile in a study conducted by Knott, the author analyzed the changes in width of the laterals, canines and second molars at 4 different stages: deciduous, mixed, permanent, and young adult dentitions. Six dental arches were evaluated (3 maxillary and 3 mandibular). Males had larger values for the arches increasing anteroposteriorly in both genders. The mean dimensions in the maxillary arch in the male group exceeded that of the female group by 1 mm for lateral incisor width, 2.5 mm for intercanine distance and 3 mm for deciduous second molars. It could be observed that during the transition of the full deciduous dentition (5.4 years) to the mixed dentition (9.4 years), the interincisal deciduous width increased in a mean of 5.5 to 6 mm, while in the mandible the mean increase was 3.5 mm for the same measure. The average for intercanine deciduous maxillary and mandibular width was an increase of 2.8 mm and finally for the second deciduous molars, the intermolar width was between 1.5 and 2 mm.[12]

During the transition from mixed dentition to full permanent dentition (mean age 13.6 years), minor changes were noticed for interincisal and intercanine distances. The intermolar width was the same than the measurement observed 4 years earlier before the completion of permanent dentition. In the maxillary arch, the interincisal width decreased by a mean of 0.9 mm, while the intercanine increased approximately 2 mm with the eruption of the permanent teeth. Between the second deciduous and the permanent molars there was an increase of 1.4 mm. The least change found along the 20 years in these patients was the intermolar width between the second deciduous molars and the second permanent premolars.[12]

DeKock studied dental arches from 12 years old to adulthood after patients finished their orthodontic treatment. He evaluated arch depth and width annually in casts of 26 subjects aged between 12 and 17 years until early adulthood. Arch depth decreased in both males and females with a less extent after 15 years old. The mean decrease for males was 3.2 mm (10%) and for females 2.6 mm (9%). Arch width in the female group did not change significantly in the span between 12 to 26 years, however in the males it had a relevant increase from 12 to 15 years. After reaching age 15, every subject analyzed showed a decrease in arch depth.[17]

Another study that evaluates the changes in arch configuration with time is by Harris, who in 1997, studied dental casts of subjects at 20 years old and later at age 55. These patients did not receive orthodontic treatment. Results demonstrate that arch configurations vary in a similar fashion in males and females: over time, dental arches became shorter (decreased arch length) and wider (increased arch width). Arch width increase was more significant in the posterior area and very limited in the canine region. For the maxilla, the arch width ratio changed from 0.702 to 0.682, intermolar width was greater than intercanine width. The mean in arch length change was very subtle (0.25 mm). The author concludes that changes in the arches between the second and third decade of life occur at a greater rate. However, they saw that dimensional changes of the arches keep happening in older patients.[18]

The configuration of the dental arch form is a unique and individualized feature resulting from the combination of each tooth position. For decades, the expansion of dental arches has been used as an orthodontic treatment to help with the malalignment of teeth and transverse intra-arch and inter-arch discrepancies.[7]

CHAPTER 2

EXPANSION OF THE DENTAL ARCHES

Maxillary expansion is an orthodontic treatment modality commonly used in patients with deficient arch dimensions. It usually provides more space for the accommodation of the dentition. In this regards, Adkins stated that each 1 mm of interpremolar distance increase resulted in 0.7 increase in arch perimeter.[3,19]

In the very early studies of Edward Angle, expansion was considered the treatment of choice to alleviate crowding. The extraction philosophy came into place when Charles Tweed redirected the orthodontic profession, demonstrating that extraction of teeth provided a more stable position of the teeth into the basal bone thus minimizing the dentoalveolar tipping provided by expansion.[7] Additionally, esthetics of the arches, facial esthetics and stability were improved in some of the cases presented by Tweed. Today, orthodontists frequently try to avoid extractions by relying on dental arch expansion to meet treatment plan goals. Dental expansion, done with the appropriate protocol, in the correctly diagnosed clinical situation and at the right growth stage, remains a proper treatment option to create space and coordinate arches in orthodontics.

At early ages (9-10 years old), the mid-palatal suture is not fused. For this reason, any expansion appliance design can produce the desired expansion since heavy forces that cause the bone split are not needed. Maxillary expansion at these ages seems to be an easier treatment. There are different orthodontic appliances design for this function: removable jackscrew type appliance, transpalatal arch like W-arch or quadhelix, fixed jackscrew appliance that may be attached with bands (Haas appliance with acrylic palatal coverage or Hyrax appliance), which could be combined with skeletal anchorage.[3] The latest option in expansion is the one achieved with clear aligners, as proposed by Invisalign First.

Rapid Maxillary Expansion

The theory behind Rapid Palatal Expansion is that if a fast activation of the appliance's jackscrew takes place (0.5 mm daily/2 quarter turns), the transverse movement will mostly be skeletal, as teeth will not have enough time to move at this rate. At this pace, 10 mm of expansion are predicted to be expressed in about 2 to 3 weeks, and the pressure in the suture will be between 10 to 20 pounds. Most of the times, patients show a maxillary midline diastema between the upper central incisors since the suture opens faster and wider anteriorly rather than posteriorly, where it starts to close physiologically. After the expansion is completed, it is recommended to retain the appliance for 3-4 months for stability purposes. The newly created diastema starts to fill with fluids and blood, thus this retention time is appropriate for the closure of the space with a combination of tooth movement and stretched fibers.[3]

The net effects of rapid maxillary expansion are divided among skeletal and dental results. In a patient where 10 mm of expansion were completed, 8 mm are allocated to skeletal movement and 2 mm to dental movement. After the retention phase is completed, the literature shows that 5 mm of expansion are attributed to dental movement and 5 mm to skeletal expansion. Proffit states than RME does not favor skeletal movement over dental movement as anchor teeth still move even with the rapid rate of screw opening.[3]

Slow Maxillary Expansion

Slow maxillary expansion occurs when the activation of the appliance is around 2 mm per week over a period of 10 to 12 weeks. It produces approximately 2 pounds of force that is shown to be enough to produce the same dental and skeletal changes seen with rapid maxillary expansion at the end of the activation period. A diastema between the upper incisors usually does not occur but opening of the suture is evident on radiographs. The major difference found between rapid and slow maxillary expansion is that with the rapid expansion the intercanine distance and the arch perimeter were greater than with slow expansion, however the posterior expansion was similar. [3]

Few studies evaluate the behavior of slow maxillary expansion in early mixed dentition and rapid maxillary expansion in later stages of life. Geran studied subjects between 8 and 10 years of age with bonded maxillary expanders and an activation of 0.25 mm per day. McNamara evaluated patients at later ages (mean of 12.2 years) with an acrylic bonded maxillary expander and an activation of 0.5 mm per day. In both studies, patients completed expansion and retention followed by orthodontic treatment without further expansion. Patients were then evaluated long-term between 19 and 20 years of age and the expansion at the levels of the canines and molars were similar, showing that the results of both approaches were equivalent. [3,6,20]

Expansion of the maxillary arch has been a popular and effective procedure during the early phases of orthodontic treatment. Children with malocclusions that include crowding benefit from maxillary expansion to accommodate the permanent dentition. On average, 8.2 mm of space is needed while transitioning from the deciduous to the permanent dentition.[21]

Other Expansion Modalities

Heavier forces to are required to split the palatal suture in patient in late adolescence. Moderate forces have not been shown to be successful in opening the suture.[3] Heavy forces delivered to anchor teeth will probably only move the teeth without producing skeletal movement, for this reason, in mature patients, implant supported appliances are recommended. Palatal implants are used to anchor the appliance and transmit the expansion forces to the bone. Slow maxillary expansion is indicated for this type of expanders (less than 2 mm per week). Dental movement will still happen, and it is advised to leave the screw in place for 2 to 3 months.[3]

In more complex transverse discrepancies, surgical expansion is an available option. Usually, it can be achieved with a down-fracture Lefort I osteotomy where the maxilla is segmented. When not sufficient, segmental osteotomies can be performed lateral to the nasal septum. Some authors recommend grafting and appropriate rigid fixation if the expansion performed is greater than 3 mm.[22]

O'Higgins et al. reported that slow maxillary expansion could create 1 mm of space for every 2 mm of expansion. Using rapid maxillary expansion, greater spacing can be achieved with similar amounts of expansion.[23] Nonetheless, besides the rate and the range of achieved expansion, orthodontists should be aware that expansion and configuration of the arches are not set parameters. Expansion outcomes should be individualized to each patient taking into account patient's ethnicity and face geometry. For instance, there is a tendency for broader arches in races such as Afro-Caribbean as opposed to Caucasian individuals, therefore expansion has to be planned according to face and soft tissues limitations.[7]

The configuration of the arch is a key feature when planning treatment for crowding and other discrepancies such as posterior crossbites. Howe et al. studied the relationship between dental crowding, arch configuration, tooth sizes in groups of patients with and without dental crowding in the permanent dentition. Interestingly, their results indicate that in the non-crowded dentition group, arch width and arch perimeter were larger than in the crowded group. In this study, arch width was measured from the molars to the canines at the lingual gingival margin of these teeth, in the center of the cervical are of each tooth. Arch perimeter was measured tracing a line connecting the occlusal centers of the teeth. The authors did not find relevant differences between tooth size and crowding in both groups. Nonetheless, significant differences were found in the configuration of the arches among the two groups. [24]

Howe at al.'s study revealed that buccal and lingual arch widths were larger in the noncrowded group. In males, the mean lingual arch width in the non-crowded group was 37.4 mm. The crowded group had, on average, 6.1 mm less lingual arch width. In females, lingual widths measurements were similar with 36.2 mm for the noncrowded group and 30.8 mm for the crowded group. Arch perimeter was larger in the non-crowded group. In the female group, the arch appeared to be broader and wider in the noncrowded patients. The results of this study have important clinical implications: Since crowded arches are more constricted and narrower than non-crowded arches, the authors suggest an association of narrow arches with dental crowding. Authors concluded that modifying the arch transverse dimensions at earlier growth stages using expansion appliances could result in more jaw space needed for better alignment of the dentition. [24]

When evaluating dental crowding, Ranzic stated that it is appropriate to study arch dimensions, i.e., width and perimeter, instead of only concentrating on tooth-size discrepancies. The study concluded that even though crowded arches increase in arch width throughout the years in a greater amount compared to the non-crowded patients, the end result is still a very narrow maxilla (average of 32.7 mm). Usually, children who have a predisposition for narrow dental arches will not change their configuration considerably during normal growth. [25]

In his arch form studies, Lee concludes that transverse expansion of the arches is considered a valid treatment at young ages. However, it is still uncertain if this type of treatment can stimulate growth and, if so, to which degree it would vary from natural growth. The presence of crossbites alters the space available to accommodate the dentition, therefore a combination of expansion, occlusion management and tongue control could be beneficial for malocclusion correction. The author states than expansion outcomes are more stable in the absence of extractions, and the amount achieved is greater in the posterior regions. Additionally, performing expansion along with anteroposterior movement allows the posterior dentition to fit better into the arch. Expansion must be planned on an individual basis knowing that the amount of planned expansion usually is less than what is achieved. Expansion usually allows an increase in arch width and a decrease in arch depth of about 1/3 of the achieved expansion (wider and broader arches).[15]

CHAPTER 3

CLEAR ALIGNER THERAPY

In 1944, Harol D. Kesling was the first orthodontist to use clear aligners. These appliances were used by patients that were close to treatment completion. A diagnostic setup using the patient's models was made and used to fabricate rubber trays called "the tooth positioner". These were worn by patients for a certain number of hours during the day. [26]

Nowadays, there are many clear aligner companies on the market around the globe. Most of the initial companies such as Raintree Essix (New Orleans, LA, USA) fabricated clear trays for minor tooth discrepancies, usually no greater than 2 to 3 mm movements before another impression had to be done to repeat the setup process.[27]

Invisalign

Patients continued seeking clear aligners for esthetics and the evolving technology led to the creation of Invisalign (Align Technology, San Jose, CA), first introduced in America in 1997 as a series of removable clear trays made from polyurethane with a thickness of 0.75 mm. The aligners are made using stereolithography with computer-aided design and manufacturing (CAD-CAM). The average movement with each set of trays ranges between 0.15 and 0.25 mm.[28,29] Patients can change their set of aligners every 5 to 14 days depending on the velocity of the planned movements and their compliance with treatment. Patients are advised to wear the aligners for 22 hours a day.

The process of moving teeth with aligners starts with a digital scan or polyvinyl siloxane (PVS) impression taken from the patient's mouth. Most of the clinicians are currently using optical digital scans for convenience, time saving purposes and to minimize distortions due to impressions. The scan is available in few minutes and must be uploaded in the Invisalign software to begin the electronic prescription. This prescription consists of a group of clinical preferences made by the practitioner, relayed to the company. The available software tools are used to achieve the desired movements. After the initial prescription is created and sent, Invisalign develops a "ClinCheck" for each case. This tridimensional video, made by a software shows the steps of treatment from initial to final position of each tooth, aligner by aligner. It is considered a force system more than an actual depiction of tooth movement. It expresses in detail how the system's biomechanics will tip, rotate or translate each tooth into the position planned by the doctor to correct the malocclusion. The ClinCheck represents a digital simulation of the treatment plan that will take place. [3]

Treatment with Invisalign follows a staging sequence with meticulously calculated forces in each set of trays. One of the important features of Invisalign is that the treatment includes the bonding of "attachments", tooth-colored composite knobs with specific geometric shapes strategically bonded on select teeth and needed for tray retention and increased effectiveness of the system. Invisalign is considered as a push system, and these attachments enhance the pushing surfaces according to the needed movements. The advantages of clear aligner therapy are esthetics, a smaller number of doctor's visits, the removable nature of the appliances, oral hygiene convenience, and digital and incremental tooth movement. The disadvantages include compliance, showing of the attachments and staining, intervals of time when the aligners are not in the mouth (removal of the aligners before eating, post-meals cleaning), and accurate predictability of complex movements such as skeletal and root movements.[3]

Proffit et al. state that there are plenty of limitations to consider with Invisalign treatment. They recommend a combination treatment involving clear aligners and adjunctive appliances such as expanders, power arms, and even a short phase of fixed appliances in combination with the aligners. In their view, the most difficult movements with clear aligners include anteroposterior molar correction, deep and open bites, and treatment plans that include dental extraction. Cases that do not respond well to aligners include extended treatment in children where the dentition transition generate loss of aligner tracking (i.e. lack of snuggle fit of the aligner), high canines and major rotations. [3]

In 2009, Kravitz et al. evaluated anterior teeth of 37 subjects treated with Invisalign. They used the virtual superimpositions to compare predicted versus achieved movements. The found that the overall accuracy of Invisalign was 41%. The most accurate movement was lingual crown movement (47.1%) and the least accurate was extrusion (29.6%). Recently, Kravitz et al. identified the improvement of Invisalign through the years after technology improvements were incorporated to the product. They concluded that the overall accuracy is 50%, the buccolingual crown tip movement being the most predictable (56%). The least accurate movements remain complex rotations (canines, premolars and molars) and incisor intrusion.[30,31]

Dental Arch Changes with Invisalign

A 2020 article by Zhou and Guo confirmed that there is scarce literature on expansion efficiency and accuracy of the predicted movements with Invisalign. The range of expansion has been reported to be between 2 and 4 mm to avoid periodontal injury, particularly at the maxillary molars level. The authors set the amount of expansion for each aligner at 0.15 ± 0.05 mm. The results of the study showed that the efficiency of the expansion done with Invisalign can be expressed as the following percentages: at the intercanine cusp tip 79.75 ±15.23%, at the first premolar cusp tip 76.1 ± 18.32%, at the second premolar cusp tip 73.27 ± 19.91%, and at the first molar cusp tip 68.31 ± 24.41%. The predictability for maxillary expansion with Invisalign in this study was slightly lower than the results found in the study published by Houle et al. who reported the following values: at the intercanine distance 88.7%, first premolars 84.7%, second premolars 81.7% and first molars 76.6%. [28,29]

The studies by Zhou and Guo also showed that expansion efficiency was reduced from the canine to the molars. Different causes may be considered: root configuration, anatomy of the cortical bone, occlusal load, and musculature function. Similar findings were reported in the Houle's study. [28,29] Bodily expansion of the upper first molar was 36.35 ± 29.32% and the root/crown ratio of movement was 2:5. The maxillary first molar tipped buccally 2.07 ± 3.27° after expansion was completed. This summarizes that expansion produced by Invisalign is mainly dentoalveolar due to a tipping movement. The authors suggest that it is important to evaluate the initial torque of the upper molars to avoid excessive tipping that can lead to gingival recessions and harming of the periodontal tissues. Another way to avoid complications is to add lingual crown tip in the aligners while planning the expansion to achieve less tipping. The interdental width and buccolingual alveolar crest widths increased with clear aligner expansion (P < .05) which indicates that the expansion was mainly due to buccal tipping.[29]

In their study of arch form changes in adult Class II patients treated with aligners, Deregibus et al. inferred that the configuration of the arch varies among patients and is the result of a multifactorial etiologies including musculature and soft tissues pressure. In this study, the authors stated that arch form changes happen according to the malocclusion pattern. They found that Class II patients presented an increase in arch width in the upper premolar and molar regions. The upper and lower intercanine widths changes were not clinically significant.[32] Moreover, the authors discussed the biomechanical differences between the movements planned digitally and what was achieved at the end of treatment. Changes in the arch form can have similarities to that achieved with fixed appliances, as the posterior segments of the arch tend to get less forces due to the increase in interbracket distance and wire flexibility. This interesting phenomenon is similar to the expansion observed when expansion with clear aligners is attempted, as the aligners have more flexibility in the distal segments, thus decreasing the amount of force delivered to achieve the desired movements.[32]

The expansion achieved with Invisalign is mainly due to dental tipping. It is proper to consider the study done by Grünheid in 2016 where Invisalign-treated patients were compared with patients treated with fixed appliances treatments for Class I malocclusions. The conclusions were that Invisalign treatment increases the intercanine width but does not show a change of buccolingual inclination of the lower canines. Meanwhile, in the fixed appliance group the intercanine width was not altered, but the lower canines were more upright.[33]

CHAPTER 4

INVISALIGN FIRST

In April of 2018, align company (San Jose, CA) expanded their scope of treatment to cover Phase I in growing children. The treatment with Invisalign First includes expansion, anteroposterior correction, crowding, open bites among other malocclusions. It is designed for children between 8 and 12 years old that have at least the first molars erupted, two incisors (2/3 erupted), two of these primary teeth C, D, or E or unerupted 3, 4 or 5 permanent teeth per quadrant. Three quadrants must fulfill the requirements.[2]

This treatment approach has been on the market for three years. There are few studies that show its efficiency and predictability. As one of the earliest investigators in Invisalign First, Blevins (2019) concluded in her review that advantages include excellent oral hygiene of the treated children since they can remove the aligner for brushing, high compliance. Appliance loss was not reported as an issue since patients had the next set of trays ready to be use. Blevins states that it is ideal to start the treatment when the first and second molar are still in the mouth for at least one more year. Even when aligners have eruption compensations built in the prescription, tracking can be an issue if deciduous teeth start to exfoliate during treatment. The most predictable movements were distalization in Class II malocclusions and up to 5 mm of expansion of constricted jaws.[2]

The objective of this work is to evaluate the accuracy of the digital treatment plan (ClinCheck) and the actual clinical results after expansion of the maxilla and mandible with Invisalign First. The central hypothesis is that predicted and achieved outcomes are closely related, which provides an accurate vision of the expansion to be achieved. The goal of this study is to provide clinicians with the precise information that must be built into the Invisalign First system according to each malocclusion to correct transverse discrepancies through maxillary expansion with a minimum margin of error.

SPECIFIC AIMS

Specific Aim 1: Quantify the clinical expansion achieved with Invisalign First treatment after completion of the first set of aligners. T1 (initial records) and T3 (outcomes) ClinChecks will be compared and superimposed to assess the clinical results. Measurements will be collected for both timepoints.

Specific Aim 2: Compare the clinical maxillary expansion outcomes against the virtual prediction. T2 (virtual prediction) and T3 (outcomes) will be compared, measured and superimposed to assess any variation of the clinical outcomes with the initial virtual planning.

MATERIALS AND METHODS

This study was approved by the University of Alabama at Birmingham Institutional Review Board (300005519).

In this retrospective study, orthodontic records of 32 patients in mixed dentition treated exclusively with Invisalign First between July 2018 and January 2020 were identified and reviewed. These patients received orthodontic treatment under the same company umbrella distributed among different offices. The final sample consisted in 32 growing patients (19 males and 13 females) in the mixed dentition stage, with an average age of 9.1 years at T1 (initial records). Average aligner staging was 31 stages during 7.2 months of treatment for the first set of trays.

The inclusion criteria were: (1) mixed dentition; (2) presence of upper deciduous canines and first molars; (3) erupted first permanent molars; (3) 90% of completion of first set of aligners; (4) good compliance in aligner wear (18-20 hours per day). The exclusion criteria were: (1) use of adjunctive appliances such as mandibular advancement device or expanders; (2) patients with cranio-facial syndromes.

Clinical stereolithography (STL) models were extracted from the ClinCheck software and uploaded into Dolphin imaging software (version 11.95 Premium, Chatsworth, Calif).

The variables of the study were measured at each of the three following timepoints:

1. T1 (Initial Records): digital models of each patient at their initial stage extracted from the iTero scan.
2. T2 (Virtual Prediction): digital models of each patient at the conclusion of their first set of aligners calculates by the Invisalign software and extracted from the iTero scan.
3. T3 (Clinical Outcomes): digital models of each patient at the second scan after the conclusion of their first set of aligners extracted from the iTero scan.

Variables measured:

- Upper Intercanine width (UICW): distance between the cusp tips of the maxillary deciduous canines.

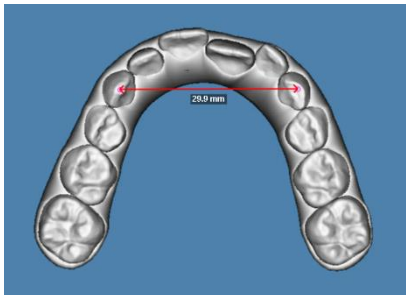

Fig. 1 Upper intercanine width

- Upper Intermolar width (UIMW): distance between the mesiolingual cusp tips of the upper first permanent molars.

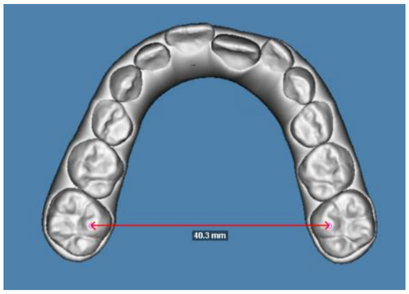

Fig. 2 Upper intermolar width

- Upper arch perimeter (UAP): imaginary line drawn in the middle of de upper basal bone.

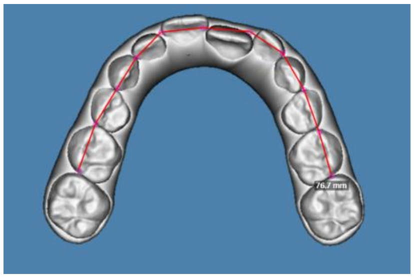

Fig. 3 Upper arch perimeter

- Upper arch depth (UAD): perpendicular traced to a horizontal line that passes between the mesial surface of the upper first permanent molars. The anterior end of the perpendicular is the contact point between the upper permanent incisors.

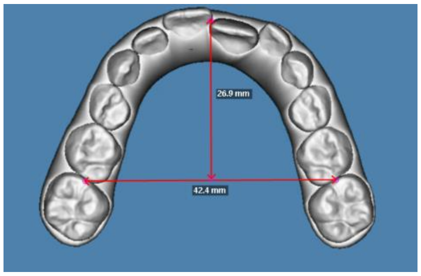

Fig. 4 Upper arch depth

- Lower Intermolar width (LIMW): distance between the mesiobuccal cusp tips of the lower first permanent molars.

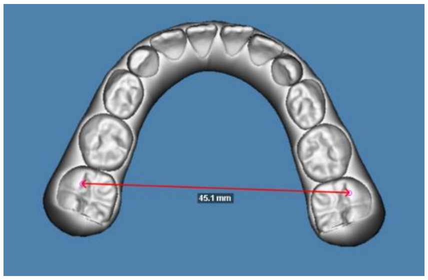

Fig. 5 Lower intermolar width

- Lower Intercanine width (LICW): distance between the cusp tips of the mandibular deciduous canines.

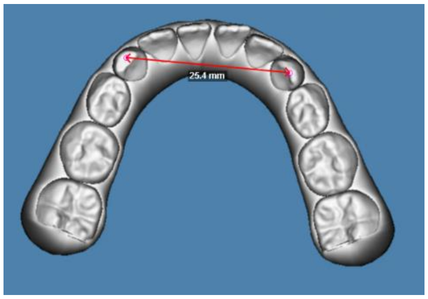

Fig. 6 Lower intercanine width

- Upper Intercanine gingival width (UICGW): distance between the middle point of the lingual gingival margin of the upper permanent canines.

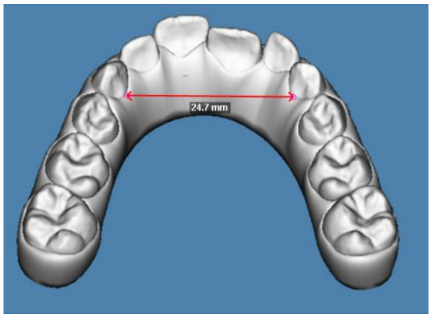

Fig. 7 Upper intercanine gingival width

- Upper Intermolar gingival width (UIMGW): distance between two points that connects the lingual gingival margin and the palatal groove of the two upper first permanent molars.

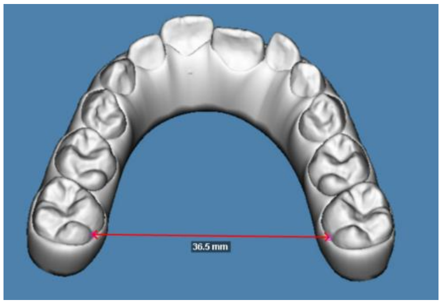

Fig. 8 Upper intermolar gingival width

- Lower Intercanine gingival width (LICGW): distance between the middle point of the lingual gingival margin of the lower permanent canines.

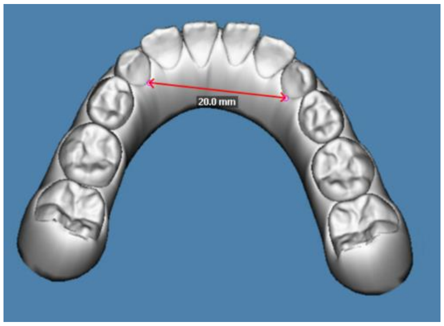

Fig. 9 Lower intercanine gingival width

- Lower Intermolar gingival width (LIMGW): distance between two points that connects the lingual gingival margin and the lingual groove of the two lower first permanent molars.

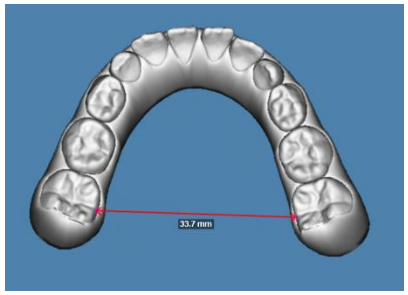

Fig. 10 Lower intermolar

Statistical Analysis

Summary statistics (mean, standard deviation, minimum, maximum, median, lower quartile, and upper quartile) were calculated for all measurement for the observed baseline measurement (T1), predicted outcome measurement (T2), and achieved measurement (T3). Baseline, predicted, and achieved measurements were compared with each other using the Wilcoxon signed rank test. The test accounts for repeated measures within subjects, was two-sided, and alpha was set at <0.05. Percent accuracy was determined using the same methods as Kravitz et al. (2009). The equation is:

Percent accuracy = 100% – ((|predicted measurement – achieved measurement|)/|predicted|) X 100%.[30]

To determine intra-rater agreement, baseline measurements were taken twice for 5 patients. The intraclass correlation coefficient was calculated using the Shrout-Fleiss reliability random set method. All statistical tests were completed in SAS version 9.4 (SAS Institute, Cary, N.C.). The intra-rater coefficient was in average 0.98 which indicates a highly consistent pattern when measuring the variables.

Table 1. Intraclass correlation coefficient

	Intraclass correlation coefficient (Intra-rater agreement)
LICGW	0.94
LICW	0.98
LIMGW	0.97
LIMW	0.99
UAD	0.99
UAP	0.99
UICGW	0.99
UICW	0.99
UIMGW	0.99
UIMW	0.97

RESULTS

1. Findings indicate that, for 8 out of the studied 10 variables, the means significantly increased from T1 (initial) to T3 (final) and decreased from T2 (prediction) to T3 (final). The only 2 measurements that did not follow the same pattern were UAD and UIMGW. UAD increased slightly from T2 to T3 (27.33 mm and 28.09 mm respectively).

2. Expansion at the maxillary and mandibular first permanent molar crowns level showed statistically significant changes from T1 to T3 and from T2 to T3 ($P<0.0001$). Upper intermolar width increased from T1=40.75±2.48 mm to T3=42.44±2.78 mm. From T2 to T3 there was a difference between predicted values 44.94±2.76 mm to final outcomes 42.44±2.78 mm. Lower intermolar width changed in a very similar fashion. The percentages of accuracy were similar for UIMW (40.33%) and LIMW (38.14%). Predicted values were greater than final outcomes.

3. Changes in the deciduous intercanine distance were statistically significant between T1-T2 and T2-T3. From predicted values to final outcomes, the lower intercanine width at the level of the crowns (LICW) showed a statistically significant variation ($p=0.0002$). Overall, there was an increase in intercanine width from T1 to T3 in a greater amount than in the molar area and the accuracy was 70.88% for the LICW. Expansion outcome was lower than the predicted values for these variables. The greatest increase was

found at the upper intercanine gingival width (UICGW) (2.92 mm of achieved expansion and 51.91% of planning accuracy).

4. The least amount of expansion was found at the upper intermolar gingival width (UIMGW). It changed from 35.17±2.46 mm at T1 to 35.13±3.24 mm at T3. This change was not statistically significant ($p=0.28$). From T2 to T3, there was a statistically significant change ($P<0.0001$) showing a difference between expected expansion (T2=38.5 ±3.30 mm) and outcomes (T3=35.13±3.24 mm). UIMGW also showed the lowest percentage of accuracy (0).

5. Expansion achieved from T1 to T3 was greater at the level of the deciduous canines and decreased posteriorly in the arches. Transverse changes at the canine crowns went from 31.29±2.37 mm to 34.14±2.37 mm in the maxillary arch and 26.22±1.97 mm to 28.23±1.9 mm in the mandible. Planning accuracy was greater at the crowns of lower canines (70.88%) than in the upper canines (51.91%).

6. UAP showed significant changes from T1 to T3. Values of arch perimeter increased from baseline to final (mean=1.55 mm) and decreased from predicted to final (mean=1.7 mm). UAP showed a relevant value of percentage of accuracy (47.85%).

7. UAD was the variable that had less variation from baseline to final (increased 0.14 mm). Baseline to predicted value variation was not significant statistically ($p=0.31$). However, UAD increase was statistically significant when evaluating predicted versus outcome values where the depth of the arch increased in a mean of 0.76 mm. Prediction percentage was not accurate.

Table 2. Means Procedure. Descriptive statistics for the studied variables

Variable	N. Obs	Variable	Label	Mean	Std Dev	Minimum	Maximum	Median	Lower Quartile	Upper Quartile
LICGW	32	T1	T1	20.93	1.90	16.40	23.90	21.10	19.75	22.60
		T2	T2	23.66	1.99	18.10	26.90	24.00	22.45	24.80
		T3	T3	22.44	1.76	18.90	25.30	22.50	21.15	23.95
LICW	32	T1	T1	26.22	1.97	22.00	30.60	26.30	24.80	27.45
		T2	T2	29.07	2.04	24.50	32.60	29.35	27.50	30.15
		T3	T3	28.23	1.92	25.00	31.50	28.80	26.60	29.90
LIMGW	32	T1	T1	33.11	1.84	29.30	36.00	33.55	31.70	34.40
		T2	T2	35.92	2.84	29.60	39.70	36.35	34.30	38.45
		T3	T3	33.93	2.40	28.70	38.30	34.25	32.10	35.65
LIMW	32	T1	T1	44.92	2.25	41.10	48.50	45.45	42.75	46.65
		T2	T2	49.00	3.26	41.40	53.80	49.05	46.60	52.05
		T3	T3	46.47	2.84	42.20	51.90	46.20	44.40	49.00
UAD	32	T1	T1	27.95	2.46	23.60	33.30	28.35	26.05	29.65
		T2	T2	27.33	1.96	23.60	31.80	27.30	26.30	28.45
		T3	T3	28.09	1.86	24.30	32.20	28.30	26.60	29.55

UAP	32	T1	T1	83.62	5.84	70.70	93.60	82.30	78.85	88.20
		T2	T2	86.87	4.82	78.00	96.90	87.00	83.50	90.40
		T3	T3	85.17	4.84	74.80	95.10	85.35	81.75	88.85
UICGW	32	T1	T1	26.29	3.01	23.10	37.60	25.20	24.10	27.80
		T2	T2	31.50	2.10	28.30	36.20	31.10	30.05	33.30
		T3	T3	29.21	3.53	24.30	40.10	28.40	26.60	30.80
UICW	32	T1	T1	31.29	2.37	27.40	37.00	30.90	29.40	32.90
		T2	T2	36.77	2.06	31.90	40.40	36.70	35.30	38.55
		T3	T3	34.14	2.37	27.50	38.60	34.40	33.05	35.40
UIMGW	32	T1	T1	35.17	2.46	28.20	39.30	35.30	33.50	36.85
		T2	T2	38.52	3.30	25.90	42.60	38.80	36.45	41.00
		T3	T3	35.13	3.24	26.40	40.80	35.50	33.35	37.70
UIMW	32	T1	T1	40.75	2.48	35.90	46.40	40.05	39.00	42.85
		T2	T2	44.94	2.76	38.00	49.60	45.05	43.30	47.00
		T3	T3	42.44	2.78	37.30	47.30	42.45	40.25	44.25

Table 3. Variation of the means

Variable	T1-T3: Initial- Final	T2-T3: Predicted-Final
LICGW	Increased 1.51	Decreased 1.22
LICW	Increased 2.01	Decreased 0.84
LIMGW	Increased 0.82	Decreased 1.99
LIMW	Increased 1.55	Decreased 2.53
UAD	Increased 0.14	Increased 0.76
UAP	Increased 1.55	Decreased 1.7
UICGW	Increased 2.92	Decreased 2.29
UICW	Increased 2.85	Decreased 2.67
UIMGW	Decreased 0.04	Decreased 3.39
UIMW	Increased 1.69	Decreased 2.5

Table 4. p-values between timepoints

	T1 vs. T3	T2 vs. T3	T2 vs. T1
LICGW	<0.0001	<0.0001	<0.0001
LICW	<0.0001	<0.0002	<0.0001
LIMGW	<0.0001	<0.0001	<0.0001
LIMW	<0.0001	<0.0001	<0.0001
UAD	0.7089	0.0006	0.3117
UAP	0.0249	0.0031	0.0001
UICGW	<0.0001	<0.0001	<0.0001
UICW	<0.0001	<0.0001	<0.0001
UIMGW	0.2872	<0.0001	<0.0001
UIMW	<0.0001	<0.0001	<0.0001

Table 5. Accuracy of changes in percentage

VARIABLE	T1	T2	T3	Predicted	Achieved	Accuracy %
LICGW	20.93	23.66	22.44	2.73	1.51	55.31
LICW	26.22	29.07	28.24	2.85	2.02	70.88
LIMGW	33.11	35.92	33.94	2.81	0.83	29.54
LIMW	44.92	49.01	46.48	4.09	1.56	38.14
UAD	27.95	27.34	28.09	-0.61	0.14	0%
UAP	83.62	86.88	85.18	3.26	1.56	47.85
UICGW	26.29	31.5	29.22	5.21	2.93	56.24
UICW	31.29	36.78	34.14	5.49	2.85	51.91
UIMGW	35.17	38.52	35.13	3.35	-0.04	0%
UIMW	40.75	44.94	42.44	4.19	1.69	40.33
Average of changes				3.34	1.51	39.02%

DISCUSSION

As of April 2021, three years after Invisalign First was launched, clinical studies about efficiency and accuracy of the predicted movements by this product are scarce. To our knowledge, there aren't any articles published in an orthodontic journal on Invisalign First evaluating arch expansion. The information available to clinicians are the studies done using Invisalign that evaluate dental expansion in adults and the studies on normal growth and development of the arches that will be taken as reference. There is also a preliminary study posted in the European Journal of Pediatric Dentistry about Invisalign first and arch expansion in the mixed dentition that will serve as one of our references for discussion on this topic.[34] The main objective of our work was to evaluate the accuracy of the digital treatment plan and the outcomes after expansion of the upper and lower jaws with aligners in growing patients. Our aim is to provide clinicians with information on the accuracy of Invisalign First for maxillary and mandibular expansion, in order to standardize and reduce the margin of error of treatment plans using Invisalign First.

After applying all inclusion/exclusion criteria, this study evaluated 32 growing patients (19 males and 13 females) that were treated with Invisalign First between he ages of 6 to 11 years, with a mean age of 9.11 years. The average number of aligners used between T1 and T3 was 31 aligners, with a mean treatment duration of 31 weeks. Ten variables were evaluated for the maxillary and mandibular arches, 8 of which (4 for the upper arch and 4 for the lower arch) evaluated the position of the upper and lower primary canines and upper and lower permanent first molars before and after expansion. Upper arch depth and arch perimeter were included as well completing the total of 10 variables.

Our assumption is that expansion done with Invisalign First in growing patients follows the slow maxillary expansion philosophy since patients are changing trays every 7 to 10 days and the predicted movement is 0.25 mm per tray. Proffit states that the concept of slow maxillary expansion (SME) is done at a rate of approximately 2 mm of expansion per week with 2 pounds of force, which corresponds to the maximum rate for bone formation. Usually with this type of expansion, and in contrast with rapid maxillary expansion (RME/RPE) where the suture is being opened, a midline diastema does not appear. Studies have shown that, 10 to 12 weeks after treatment of patients who underwent either rapid or slow maxillary expansion, almost the same amount of dental and skeletal expansion was achieved.[3]

A 2020 systematic review of maxillary expansion long-term stability compiled 20 years of research and concluded that treatment with rapid and slow maxillary expansion seems very stable after a 2 to 15 years follow-up. [35] Lima also concluded in their study of Class II patients treated with rapid and slow palatal expansion that long-term stability (10 years) is shown in both groups. In this study, a Haas-type appliance along with headgear was used for rapid maxillary expansions and only headgear with inner bow was used for the slow maxillary expansion group.[36]

Haas studied the stability after palatal expansion at 1 and 5-year follow-up. He concluded that this treatment maintained a long-term stability of clinical significance at the apical base of the maxilla and the width of the nasal cavity levels as evaluated on head films.[37,38] Opposite to Haas findings, it is relevant to consider Timms studies, where most of the expansion achieved with the non-rigid appliance used had a relapse of 41% with a range from 31% to 82%. The molars basically tipped buccally during the use of the appliance and relapsed after the appliance was removed. This finding could be attributed to non-compliant patients or what he called "few bad cases". The design of the appliance is a major contributor for the big differences reported. This factor must be taken into consideration when evaluating expansion with Invisalign First and its long-term stability since aligners are a flexible tooth-borne appliance with no support in the palatal/basal bone. [39]

Our results demonstrated that all the measurements increased for arch perimeter and intercanine/intermolar distances between initial (T1) and clinical outcomes (T3). All the changes showed from T1 to T3 were statistically significant except for arch depth ($p < 0.70$) and upper intermolar gingival width ($p < 0.28$). Upper intermolar gingival width was the only measurement that did not vary since a small decrease from initial to final was not significant (decreased 0.04 mm). On the other hand, the virtual prediction for most of the variables was greater than the achieved outcome, similar to the results showed by Houle in 2017. In this study, the accuracy of the transverse changes in adult populations ranged between 72.8% and 87.7% in the maxilla and mandible respectively[28]. Our percentage of accuracy predicting the changes during expansion ranged between 0% (UIMGW) and 70.88% (LICW).

Measurements between ClinCheck (T2) and clinical outcomes showed a decrease from the prediction calculation in all the variables. Upper arch depth (UAD) was the only variable that showed an increase of 0.76 mm compared with the prediction. We believe this result may be associated with growth since the mean age of the studied population is 9 years old. According to the Iowa longitudinal study done in North American children, in boys the arch depth usually increases between ages 9 to 11 (0.4 mm) and starts to decrease between 11 and 15 years old (1.9 mm). In the mandible, the decrease between 11 to 15 years old is greater (2.4 mm) and the early increase in arch depth (0.3 mm) is also seen.[40]

Previous studies evaluated the effect of growth on the size and form of dental arches with good occlusion. In females aged 9 through 11, arch depth increases by 0.4 mm, The same increase is seen in males in the same study. Arch depth decreases between ages 10 to 15 by 1.9 mm. The timing of the biggest changes in arch depth are observed in growing patients between ages 9 and 14 years. The transition from mixed to permanent dentition explains arch depth increases, which amount to 1 mm yearly.[40] In this study, planned movements in the software projected a small decrease in arch depth after the first set of aligners. However, an increase of 0.76 mm was noted. This increase was explained by the presence of the first permanent molars were already on the arch and some of the children lost primary molars during treatment. For our results, growth and slight proclination of upper incisors are possible contributors with the clinical outcome in arch depth.

Regarding the inclination of the upper and lower molars after expansion with Invisalign First, the difference between the virtual planning (ClinCheck) and the outcomes were significant. No movement was observed clinically at the lingual gingival margin of the crowns of the first permanent molars, in contrast with the predicted movement (predicted movement is 1.99 mm for the lower molars and 3.39 mm for the upper molars, ($p<0.0001$). This finding indicates that the permanent lower and upper first molars stayed in a similar position and did not move during treatment. Changes in the intermolar width were greater at the gingival level of the lower molar compared to the upper molars (0.82 mm lower intermolar gingival width increase and 0.04 upper intermolar gingival width decrease). However, expansion at the level of the dental crowns (UIMW and LIMW) was similar in the upper and lower jaws. The mean increase for expansion at the level of the crowns from initial to final (T1-T3) was 1.6 mm. Difference between prediction accuracy seen in the ClinCheck and outcomes was smaller at the level of the crowns than at the gingival level (UIMGW and LIMGW).

In a study done by Solano-Mendoza using Ex30' aligners in adult patients by superimpositions in the rugae area, they found that the major differences between ClinCheck and outcomes after expansion were in arch depth and first molar width. While the methods of this study and target population differed from our sample, the decreased predictability observed in the posterior segments, specifically regarding intermolar width, is similar to our study's results. Authors explained that possible causes could be the severity of the expansion, growth or even the rate of change in the aligners. Changing aligners frequently may interfere with the stabilization of achieved expansion in adult patients, and this factor should probably be considered in growing children as well.[41]

Our study shows that teeth that followed the prediction in the closest fashion were the mandibular canines (LICW and LICGW). The difference between clinical outcomes and predicted canine crown measurements was a decrease of 0.84 mm from the prediction. Clinically, lower intercanine distance increased from initial to final between 1.5 mm and 2 mm. Lower canines moved very similar at the crown and lingual gingival levels suggesting a more bodily movement of these teeth (Fig. 4 and 5). We would expect more tipping of the crowns with Invisalign as found in the study done by Kravitz in adult patients where the most accurate movement with aligners was the crown buccolingual tipping showing 56% of accuracy.[31] This was not the case at least for the lower canines in our study population where we are suggesting that a more bodily movement occurred.

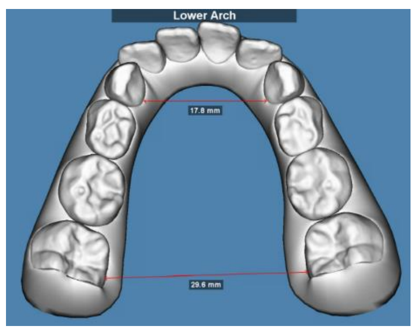

Fig. 11 Initial model before treatment showing the lower intercanine distance

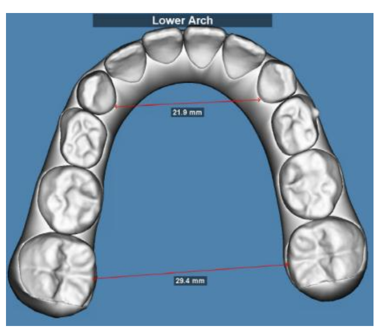

Fig. 12 Final model after treatment showing the intercanine distance

Similar to our study findings at the level of the mandibular deciduous canines, Vidal-Bernardez et al. (2021) showed that mandibular expansion is more predictable in the lower arch at the gingival level. Their sample however consisted of adult patients with permanent teeth and they used the same SmarTrack material from the company. [42] They also stated that their results mainly resulted from crown movements.

Grünheid et al. (2017) evaluated the buccolingual inclination and intercanine distance of mandibular canines in fixed appliances therapy compared to a clear aligner therapy group. They found that treatment with aligners demonstrated an increase in intercanine distance. Their findings mirror our intercanine distance results, but not necessarily with a buccolingual movement of the roots, suggesting a tipping movement of the crowns. When compared with the fixed appliance group, the latter experienced very little change in intercanine distance and the canines were more upright. [43]

The intercanine distance in our research evaluated primary intercanine distance. For the upper canines, even when there was a considerable difference between the prediction and the clinical outcome, the achieved movement was 3 mm after expansion at the crown and gingival levels, showing a clinically significant increase in the intercanine width. Overall, upper and lower canines showed increased intercanine distances with a tendency for the canines to move bodily. Expansion was greater in the anterior segments of the arch. Posterior movement of the upper and lower first permanent molars was around 1.5 mm, mainly produced by buccal tipping of the crowns. When comparing the expansion at the level of the canines and permanent molars, the deciduous canines have a single and smaller root and have smaller crowns, which could contribute to the greater anterior expansion observed in our results.

A very recent study by Levrini et al. (2021) is probably the first article published about maxillary expansion using clear aligners, specifically Invisalign First. It relates closely with our study. Sample groups are very similar: they studied subjects between the ages of 6 and 11 (same as our sample), mean age of 8.9 years while our mean age was 9yrs old and they used 33 aligners on average while our mean of aligners number was 31. They measured the intercanine width using the methods proposed by Solano-Mendoza as in our study and they found an average increase of 2.8 mm at the cusp tips level and 2.01 mm at the gingival level.[41] We observed almost the same increase of 2.8 mm at the cusp tips and 2.9 mm at the gingival level of the deciduous canines. Regarding the upper first permanent molars, the increase found in the study by Levrini was greater than what we found in our sample. Expansion achieved at the cuspid level was 3.05 mm and 2 mm at the gingival level. We found an increase of 1.69 mm at the cusp tips and a decrease from T1 to T3 of 0.04 mm at the gingival level. Regarding the arch perimeter, we found a mean increase of 1.55 mm while their study showed a 0.85 mm increase from baseline to outcomes. Arch depth was decreased in their sample by 1.24 mm while our results show a slight increase of 0.14 mm. The increase in arch depth in our study does not have clinical significance, while the decrease observed in their study could be attributed to the exfoliation of deciduous molars and the broadening of the arch. That decrease was only 1.24 mm on average after the expansion was achieved. According to the Iowa growth studies, upper arch depth starts to decrease after the age of 11 in males and females. Our sample finished their first set of aligners around 10 years old and some of our patients had not exfoliated their deciduous molars and probably did not have much proclination of anterior teeth since the aligners hold these teeth into position. It is important to consider that upper arch depth is one of the most complex variables to measure due to the arbitrary lines used by different clinicians to measure the outcomes after expansion. Therefore some measuring error is probably another variable to consider.[34]

In addition, our study shows that the expansion had greater results in the anterior segment mesial to the premolars and this led to a change of the arch configuration. This happened even when the bone at the premaxilla is more dense compared with the less dense trabecular alveolar bone and thin cortices in the posterior maxilla.[44] Arch forms were broader and developed a more square form from initial to final, as observed on the digital models . (Figs, 5-8). Our findings in arch form match the study by Levrini (2021) where they used 3D digital superimpositions at the palatal ruggae level. They clearly show a broadening the maxillary arch form, providing more space for the dentition, lingual movement of upper central incisors, decrease in arch depth and perhaps only a small increase in the arch perimeter.[34]

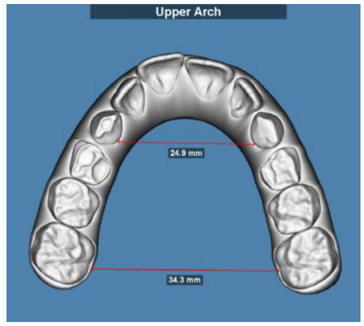

Fig. 13 Initial model before treatment showing the arch shape

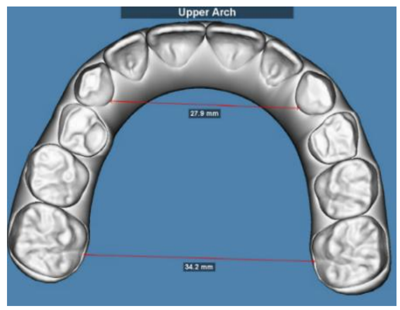

Fig. 14 Final model after treatment showing change in the arch

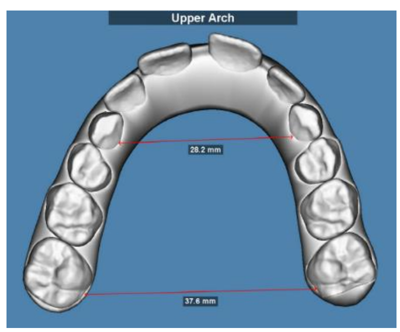

Fig. 15 Initial model before treatment showing the arch shape

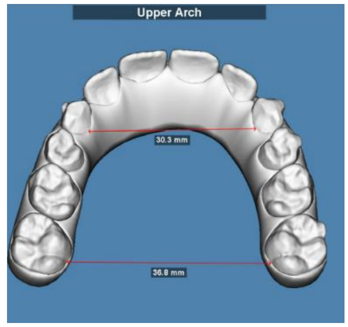

Fig. 16 Final model after treatment showing change in the arch

LIMITATIONS

The limitations to consider in this study are:

1. Compliance is not an absolute measurement: it is hard to measure patient commitment to treatment and patient behavior is very variable between individuals.
2. The use of a skeletal landmarks for superimposition purposes would yield a more accurate evaluation of the achieved dental expansion.
3. The degree of expansion needed for each patient is variable and could affect the recorded results.
4. A larger sample group divided by sex would account for better growth evaluation.
5. Limited number of published studies for comparison purposes.

CONCLUSIONS

1. Overall, expansion planning with ClinCheck is greater than the achieved clinical expansion. The teeth that showed the highest variability from the expected results was the upper first molar, specifically at the lingual gingival margin (UIMGW), where almost no movement occurred from T1(initial) to T3 (outcome) (0.04 mm intermolar decrease). This finding is related to the limited buccolingual bodily movement of the upper molars. The net deficit between T2 (prediction) and T3 (outcome) is 3.3 mm.

2. Clinically, upper and lower transverse dimensions demonstrated dental expansion. Upper and lower primary intercanine distances had the greatest changes. In particular, the upper intercanine gingival distance (UICGW) increased by 2.92 mm from T1 to T3. The lower intercanine distance (LICW) expanded 2 mm between T1 and T3, with more tipping of the crown compared with the upper movement of the primary canines. LICW had the greatest percentage of prediction accuracy (70.88%).

3. The measurement that did not change significantly was upper arch depth (UAD). Clinically, UAD only increased by 0.14 mm from T1 to T3 and comparing the outcome with the ClinCheck (T2-T3) it varied by 0.74 mm from what was expected.

4. Upper arch perimeter (UAP) increased with a mean of 1.55 mm between T1 and T3. The planned change was 1.7 mm from T2 to T3. UAP showed a percentage of prediction accuracy of 47.85%.

5. This study showed that dental expansion with aligners in growing patients is a good alternative in cases with transverse discrepancies and lack of eruption space in children. Compliance remains an important factor to take into consideration. All the measurements pertaining to intercanine and intermolar dimensions were increased from T1 to T3. Upper and lower first permanent molars demonstrated buccolingual crown tipping whereas the upper and lower primary canines showed more bodily movement. Expansion was expressed more anteriorly than posteriorly and change in the shape of the arches was evident. Anteriorly, the arches became broader and wider.

6. Clear aligners seem to be a good alternative to traditional expansion appliances in cases of mild to moderate transverse discrepancies. Careful expansion planning with Invisalign First serves to increase the intercanine width, slightly increase the intermolar width as well as the arch perimeter. This translates in a broader arch shape that provides more room to help with crowding and arch expansion. The slow rate and small movements programmed in the aligners are thought to help with slow bone remodeling to solve mild malocclusions in growing children where the bone is still immature.

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APPENDIX A

IRB APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

NHSR DETERMINATION

TO: Souccar, Nada M

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance Number FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)

DATE: 10-Jun-2020

RE: IRB-300005519
Dental arch dimensions changes with clear aligner therapy

The Office of the IRB has reviewed your Application for Not Human Subjects Research Designation for the above referenced project.

The reviewer has determined this project is not subject to FDA regulations and is not Human Subjects Research. Note that any changes to the project should be resubmitted to the Office of the IRB for determination.

if you have questions or concerns, please contact the Office of the IRB at 205-934-3789.

Additional Comments:

De-identified data from a non-research source (Thesis/Dissertation).