CHANGES IN ARCH DIMENSION AND INCISOR POSITION IN PATIENTS TREATED NON-EXTRACTION WITH PASSIVE SELF-LIGATING BRACKETS

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Submitted to the Graduate Faculty of

School of Dental Medicine in partial fulfillment

of the requirements for the degree of

Master of Dental Science

University of Pittsburgh

2019

Committee Membership Page

UNIVERSITY OF PITTSBURGH

SCHOOL OF DENTAL MEDICINE

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June 7, 2019

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The recent paradigm shift in orthodontics towards non-extraction treatment has been facilitated with the introduction of newer appliance systems such as self-ligating brackets. OBJECTIVE: The purpose of this study was to investigate the effects of moderate to severe dental crowding on changes in incisor position and arch dimension in patients treated non-extraction using the Damon passive self-ligating system. It was hypothesized that patients do not experience a significant amount of labial movement of the incisors due to space being gained through arch expansion. MATERIALS AND METHODS: Previous orthodontic records of 15 patients with a mean pre-treatment age of 14.4 years were obtained at the University of Pittsburgh Department of Orthodontics. The inclusion criteria were: treatment with Damon Q (Ormco) passive self-ligating brackets, class I malocclusion treated non-extraction, severe maxillary dental crowding (>6 mm), and a complete permanent dentition. The initial and final cephalograms and digital dental casts were evaluated. Paired t-tests were used to perform intragroup comparisons of pretreatment and posttreatment values. RESULTS: The mean amount of crowding was 8.93 mm in the maxillary arch and 4.77 mm in the mandibular arch. Resolution of severe maxillary crowding resulted in an increase of 9.16° in incisor inclination and 3.05mm in incisor protrusion. Resolution of moderate mandibular crowding resulted in an increase of 5.87° in incisor inclination and 1.95 mm in incisor protrusion. In the maxilla, the greatest arch width increase was at the first premolar (4.39 mm) followed by second premolar (4.24 mm), canine (1.85 mm), and molar (1.65 mm). In the mandible, the order of the width increase was similar - first premolar (2.95mm), second premolar (2.23mm), canine (2.12mm) and molar (0.90mm). All changes were statistically significant ($p<.01$). CONCLUSION: The resolution of moderate to severe crowding resulted in significant proclination and protrusion of the incisors along with a significant increase in arch width.

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1.0 Introduction

1.1 History

The specialty of orthodontics has undergone many changes and refinements since its advent in the early 20th century. Changes in treatment philosophy along with the advancement of treatment mechanics and appliances has allowed for a better understanding of orthodontics today. The development of self-ligating bracket systems has been a major innovation in orthodontics and is increasing in popularity amongst orthodontists. The idea of self-ligation is not new to orthodontics. In fact, the first self-ligating bracket was devised in the 1930's but did not gain much popularity at the time possibly due to the skepticism of the orthodontic society or the lack of promotion (Chen et al 2010). Over the past few decades, there has been a resurgence in the interest of self-ligating brackets, with the introduction of various types of new self-ligating systems that are now more robust and reliable.

1.2 Properties of Self-Ligating Brackets

Self-ligating brackets are ligatureless bracket systems that have a built-in mechanism that can close off the slot of the bracket. This mechanism acts to secure the archwire within the bracket slot and replaces the need for a steel/elastomeric ligature. Self-ligating brackets are divided into 2 main categories, active and passive, according to the mechanism in which they interact with the archwire. In the active system, the labial/buccal clip that closes off the edgewise slot encroaches the slot lumen and actively presses on the archwire providing an active seating force. In the passive system, when closed, the door/latch entraps the archwire without an active seating force against the archwire (Zreaqat et al 2011). These self-ligating bracket systems were constructed on the philosophy of delivering light forces on a low friction basis, insuring tooth movement that is more physiologic by not overpowering the musculature or compromising the periodontal tissues (Zreaqat et al 2011).

1.3 **Theory of Tooth Movement**

The success of orthodontic treatment is influenced by a number of factors, including periodontal health, oral hygiene and optimal orthodontic forces (Kumar et al 2015). As the science of bone biology continues to evolve, several theories regarding orthodontic tooth movement have been proposed, with the pressure-tension theory being generally accepted as a mechanism that plays a part in the biologic control of tooth movement (Proffit 2013). The mechanical stimuli generated by orthodontic forces elicits a biological response in the tissues surrounding the teeth, resulting in remodeling of the periodontal ligament, gingiva, and alveolar bone (Meeran 2012). The concept of the pressure-tension theory was mainly evaluated using histologic studies of the periodontium. Previous studies have indicated that tooth movement occurs with the formation of a “pressure side” and “tension side” in the periodontal ligament space (Krishnan et al 2006). According to the pressure-tension theory, the applied force causes compression of the periodontal ligament and alveolar bone on one side stimulating bone resorption (pressure side) while on the opposite side the periodontal ligaments are widened stimulating bone deposition (tension side) (Dolce et al 2002). This force elicits changes in the tissue vascularity and leads to the activation of a cascade of cellular and molecular responses involving the synthesis and release of various signaling molecules and metabolites that are necessary for tissue deposition and resorption (Nayak et al 2013). This inflammatory reaction stimulates the recruitment of osteoblast and osteoclast progenitors, allowing localized bone remodeling and periodontal ligament turnover (Kumar et al 2015).

1.4 **Bone Resorption**

There are two forms of bone resorption (frontal and undermining) that are related, in part, to the magnitude of the applied force. The association between the applied force and the type of bone resorption is related to the integrity of the periodontal membrane, which is dependent on the vascularity of the membrane (Gianelly 1969). The inflammatory response involved in bone remodeling requires significant vascular activity. Therefore, patent vessels appear to be essential for resorptive activity (Gianelly 1969). Cellular elements necessary for bone remodeling are recruited locally from progenitor cells in the periodontal ligament, or from a distant location in adjacent marrow spaces (Sivarajan et al 2014).

1.4.1 **Frontal Resorption**

When a prolonged, light force is placed on a tooth, there is a decrease in blood flow through the periodontal ligament at the sites of compression. Since the microvasculature is not completely occluded, inflammatory processes occur without significant delay and leads to the activation and recruitment of osteoclasts from the progenitor cells of the periodontal ligament. With this application of light force, tooth movement is facilitated by the process of frontal resorption where osteoclasts line up in the margin of the alveolar bone adjacent to the compressed PDL, producing direct bone resorption (Krishnan et al 2006). At the opposite side where the periodontal ligament undergoes tension, osteoblasts are recruited from the progenitor cells of the periodontal ligament for bone deposition (Proffit 2013).

1.4.2 **Undermining Resorption**

When heavy forces are applied to a tooth, blood flow is completely occluded throughout the periodontal ligament at areas under pressure. As a result, osteoclast progenitor cells cannot be stimulated locally from the periodontal ligament space and the areas under pressure undergoes a sterile necrosis. Under histological observation, this area is referred to as hyalinized, and represents the loss of all cells due to occlusion of blood flow (Proffit 2013). This hyalinized tissue must be resorbed in a rearward fashion for tooth movement to resume. After a delay of several days, macrophages, osteoclasts, and foreign body giant cells infiltrate the necrotic area and resorption begins through a process called undermining resorption where the bone immediately adjacent to the hyalinized tissue must be removed, from the underside of the lamina dura. This lag phase of tooth movement can last from several days to several weeks (Proffit 2013).

1.5 **Optimal Orthodontic Force**

Previous studies have concluded that orthodontic forces should be light for physiological-like influences and that stronger forces result in injuries to the periosteum due to the disturbances in circulation (Oppenheim 2007). This concept was detailed further by correlating the response of the tissues to the magnitude of the applied force and its relation to the capillary bed blood pressure. Studies have concluded that the optimal force for tooth movement should not exceed the capillary bed blood pressure of 20-25 g/cm^2 of root surface area and that if the forces are in excess, tissue necrosis would occur through suffocation of the strangulated periodontium (Krishnan et al 2006).

1.6 **Self-Ligating Bracket Claims**

In recent years, self-ligating bracket systems have increased in popularity with a host of purported advantages over conventional appliance systems. These include enhanced treatment efficiency, less chair time, reduced patient discomfort, better maintenance of periodontal health, superior torque expression, and a more favorable arch-dimensional change (Zreaqat et al 2011; Harradine 2008). In addition, others have claimed advantages such as greater amounts of arch expansion, possible anchorage conservation, less proclination of anterior teeth, and less need for extractions in orthodontics (Chen et al 2010). It was reported that treatment with the Damon passive self-ligating system with low force, superelastic nickel-titanium wires does not overpower the forces of the perioral musculature, facilitating a "lip-bumper" effect through the action of the orbicularis and mentalis muscles (Damon 1998). The key factor associated with many of these claims is based on the reduced resistance to sliding between the bracket and archwire, allowing orthodontic tooth movement to be achieved using light forces.

1.6.1 **Reduced Friction**

The claim of reduced friction with self-ligating brackets is often cited as a primary advantage over conventional bracket systems (Shivapuja et al 1994; Damon 1998; Khambay et al 2004; Henao et al 2005; Monteiro et al 2014). This occurs because the standard ligation methods of steel and elastomeric ligatures are not necessary as self-ligating brackets possess an in-built feature to close off the bracket slot. Frictional forces that are produced by the method of ligation must be overcome and may prevent the attainment of ideal force levels necessary to generate an optimal biologic response. It was reported that 50% of the applied force is used to overcome friction and binding (Ehsani et al 2009). Since the force magnitude must overcome the frictional resistance, minimizing friction will allow tooth movement to occur with lower forces. By reducing the amount of friction with passive self-ligating brackets, low force archwires can work to peak expression and tooth movement can occur more physiologically and at a balanced oral interplay by not overpowering the musculature and interrupting the vascularity of the periodontal ligament (Chen et al 2010). Besides the method of ligation, other factors that affect frictional resistance include archwire size and material, saliva, and the angulation of the wire to the bracket (Ehsani et al 2009). Many studies investigating frictional resistance between the bracket and archwire were performed in-vitro and while many have shown that less friction is generated with self-ligating brackets compared to conventional brackets, the suitability of applying these findings to in-vivo situations remains unclear (Chen et al 2010).

The advantages of the Damon passive self-ligating system include the expansion of the dental arches partly attributable to the use of broad, light archwires while alignment occurs. It is claimed that the low friction and freedom of the wire in the bracket slots allows the wire to slide posteriorly as crowding is being resolved and this freedom coupled with lateral dentoalveolar expansion was proposed to reduce the effect of incisor flaring (Damon 1998; Maltagliati et al 2011).

In contrast to these claims, studies have reported no significant difference in arch width, incisor proclination, and protrusion between conventional brackets and Damon passive-self ligating brackets (Atik et al 2016; Nogueira et al 2018). Furthermore, a systematic review found that efficiency of treatment was not greater with self-ligating brackets, as it reported no significant difference in terms of efficiency of arch alignment, rate of canine retraction, space closure, and overall treatment duration (Fleming et al 2013).

1.7 **Archwire Properties**

The use of light and continuous forces is accepted as ideal in orthodontic tooth movement (Higa et al 2016). Archwires composed of nickel-titanium (NiTi) are extremely useful in the leveling and alignment stages of orthodontic treatment due its low modulus of elasticity, high springback, its ability to deliver light, continuous force over a large range of activation, and its "shape memory" and "superelastic" qualities (Higa et al 2016). The introduction of copper to NiTi (CuNiTi) in the mid-90's has given the wires the property of thermoelasticity, further contributing to the shape memory effect of these archwires (Kusy 1997). Furthermore, it was reported that the unloading force produced by CuNiTi wires were lower than NiTi wires, demonstrating an advantage in terms of delivering lighter forces to the dentition (Wilkinson et al 2002). The Damon system utilizes these wires and advocates the use of broader arch forms composed of Cu-NiTi such as the "Damon broad arch" in the early stages of treatment due to the reported advantages of arch expansion especially in situations where the resolution of crowding is beneficial without use of distalizing appliances, tooth stripping or extraction (Atik et al 2018).

1.8 **Non-Extraction Paradigm Shift**

Cases treated non-extraction with significant dental crowding demand flaring of the teeth with the greatest change typically occurring in the incisor region (Maltagliati et al 2011). In a prospective trial utilizing conventional brackets, it was reported that there was a positive correlation between the degree of crowding and incisor proclination while an inverse relationship existed between intercanine expansion and incisor proclination (AlQabandi et al 1999). The recent paradigm shift in orthodontics towards non-extraction treatment has been facilitated with the introduction of newer appliance systems such as self-ligating brackets (Dahiya et al 2018). These appliance systems may be used to produce orthodontic expansion and this property is often exploited to treat patients non-extraction (Fleming et al 2013).

2.0 Objective of Study

While the effects of non-extraction treatment with self-ligating brackets on arch dimensions have been reviewed, most studies have evaluated situations with mild to moderate crowding. The current literature is limited with regards to the effect of non-extraction treatment in cases with severe dental crowding. With claims of posterior expansion without the prominent labial movement of incisors, this study was set to investigate the effects of moderate to severe dental crowding on changes in incisor position and arch dimension with the Damon passive self-ligating system. It was hypothesized that patients with moderate to severe crowding treated non-extraction with the Damon system do not experience a significant amount of labial movement of the incisors due to space being gained through arch expansion.

Therefore, the objectives of this study are: 1) to evaluate the degree of change in incisor position and 2) to evaluate the degree of change in arch dimension in cases with moderate to severe dental crowding treated non-extraction with the Damon passive self-ligating system.

3.0 Materials and Methods

Ethical approval was obtained from the University of Pittsburgh institutional review board. Patients from Department of Orthodontics and Dentofacial Orthopedics at the University of Pittsburgh were included in this retrospective study. The patients were selected according to the following inclusion criteria: treatment with .022" Damon Q (Ormco) passive self-ligating brackets, class I malocclusion treated non-extraction, severe maxillary dental crowding (>6mm), complete permanent dentition, no previous orthodontic treatment, and no presence of syndromes or systemic disease. Following the complete review of available records, a sample of 15 patients was obtained.

All cases were treated by orthodontic residents under the supervision of one orthodontic faculty familiar with the Damon philosophy. The initial and final cephalograms and digital dental casts were evaluated for each patient. The main outcome measures were changes in incisor position represented by U1-NA(° and mm), U1-constructed FH(°) measured as U1-SN(°) minus 7° (Burstone et al 1980), L1-NB(° and mm), and IMPA(°). Changes in arch dimensions were represented by intercanine width (ICW), interpremolar widths (1PW, 2PW), intermolar width (IMW), and arch depth (AD) displayed in Table 2 and Table 3.

OrthoCAD digital software version 5.6.0.222 was utilized to determine the amount of crowding, arch width, and arch depth. A digital caliper was used to measure the following transverse arch dimensions on pretreatment (T0) and posttreatment (T1) models: intercanine width (ICW), the distance between the canine cusp tips; interpremolar widths (1PW, 2PW), the distance between the central pits of both first and second premolars; and intermolar width (IMW), the distance between the central fossae of the first molars as seen in Figure 1. Arch depth (AD) was measured from the midpoint contact between the central incisors perpendicular to a line connecting the mesial contact point of the first molars (Figure 1). The amount of crowding was determined by the difference in arch perimeter between T0 and T1 (FIGURE 2, FIGURE 3) (Vajaria et al 2011). Arch perimeter was measured from the distal contact point of first premolar to the distal contact point of the contralateral first premolar. All measurements were performed by the primary investigator.

The pretreatment and posttreatment lateral cephalometric radiographs of each subject were digitally traced using Dolphin Imaging Software V11.95.8. The cephalometric tracings were performed by the primary investigator. The following sequence of broad arch Ormco archwires were used throughout treatment: .013/.014-in CuNiti, .018 CuNiti, .014x.025 CuNiti, .018x.025 CuNiti, followed by .019x.025-in stainless steel archwire. No distalizing appliances were utilized. All patients were finished in class I occlusion with ideal overbite and overjet.

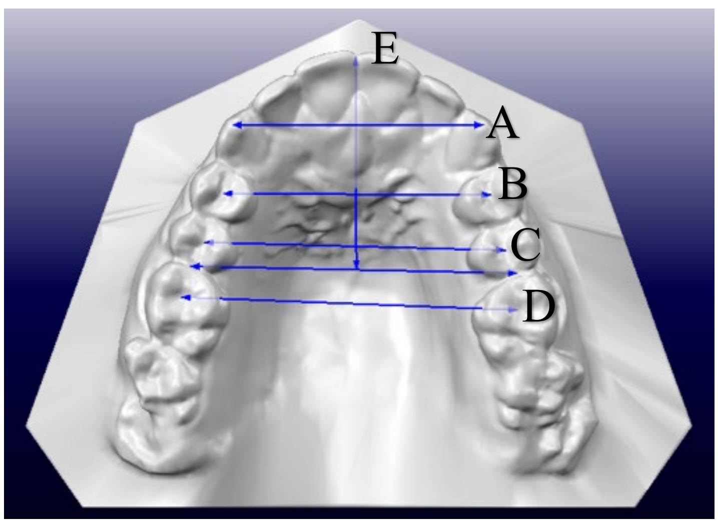

Figure 1: Arch Dimensional Variables.

(A) Intercanine width. (B) Inter-first premolar width. (C) Inter-second premolar width. (D) Intermolar width. (E) Arch Depth.

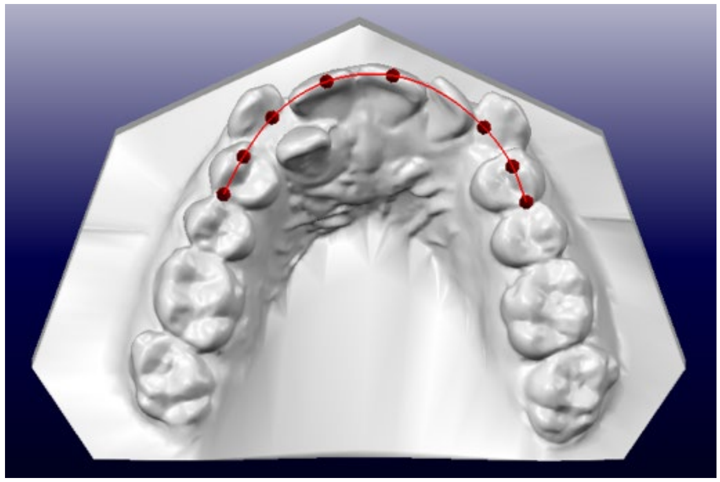

Figure 2: Measurement of Arch Perimeter at T0.

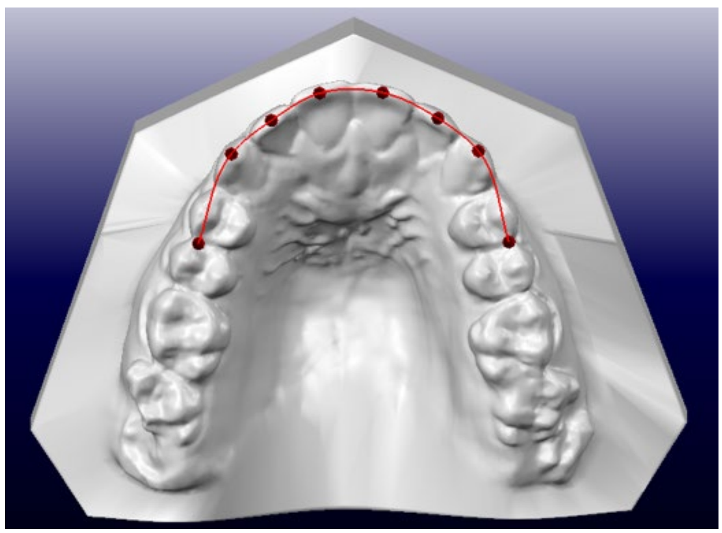

Figure 3: Measurement of Arch Perimeter at T1.

3.1 **Method Error**

To assess intra-rater reliability, 5 digital casts and 5 cephalometric radiographs were randomly selected 1 month after initial measurement. The cephalometric radiographs were digitally retraced and the cephalometric variables were remeasured. Crowding and arch dimensional variables were also remeasured on digital casts. Correlation coefficients were calculated to determine the strength of the relationship between repeated measurements using a 95% confidence interval. High reliability was confirmed with intra-rater reliability ranging from .906 to .989.

3.2 **Statistical Analysis**

The mean pre-treatment age was 14.4 ± 3.6 years. The mean and standard deviation for each variable were determined. The Shapiro-Wilk test was performed on all outcome variables to ensure that they were normally distributed. Paired t-tests were used to perform intragroup comparisons of pretreatment and posttreatment values. All statistical analyses were conducted using Stata statistical software with a statistical significance of 5%.

4.0 Results

Demographic and clinical characteristics of the sample are displayed in Table 1. The mean amount of crowding was found to be 8.93 ± 3.00 mm in the maxillary arch and 4.77 ± 2.67 mm in the mandibular arch (Figure 4). The pretreatment, posttreatment and difference of incisor positional variables and arch dimensional variables are displayed in Table 2 and Table 3, respectively. The results of this study revealed that all arch dimensional variables and cephalometric variables were significantly increased following treatment ($p<.01$). At T1, all maxillary and mandibular incisor variables (U1-NA (° and mm), U1-cFH (°), L1-NB (° and mm), and IMPA (°)) increased. Maxillary and mandibular arch depths (Mx AD and Md AD) as well as arch widths (ICW, 1PW, 2PW, and IMW) increased following treatment.

Table 1: Demographic and Clinical Characteristics of Sample (n=15).

Variables	**N (%) or mean ± s.d.**
Age (yrs)	14.4 ± 3.60
Gender	6 Male (40%) 9 Female (60%)
Crowding (mm)	Maxillary 8.93 ± 3.00 Mandibular 4.77 ± 2.67
Overjet (mm)	2.63 ± 0.96
Overbite (mm)	2.49 ± 1.46
ANB (°)	2.27 ± 1.06
FMA (°)	24.45 ± 4.94

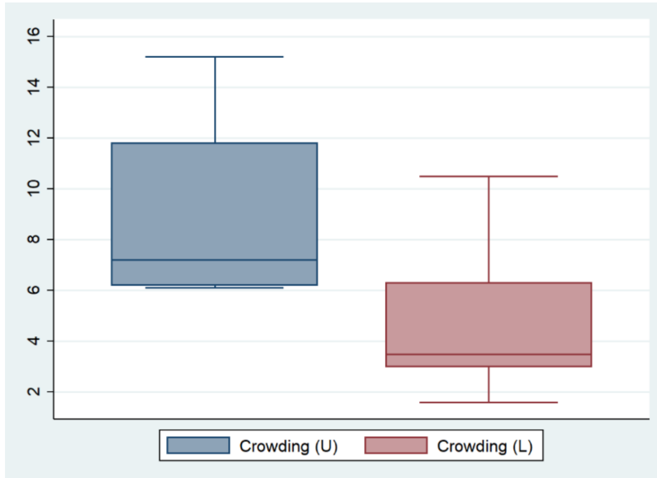

Figure 4: Distribution of Crowding (mm).

4.1.1 **Incisor Position**

Maxillary incisors displayed significant proclination with mean increases in U1-NA (°) of 8.75 ± 3.80° and U1-cFH of 9.16 ± 3.71° (p<.001). Maxillary incisors also displayed significant protrusion indicated by U1-NA (mm) with a mean increase of 2.10 ± 1.25 mm (p<.001). Mandibular incisors displayed significant proclination with mean increases in L1-NB (°) of 5.87 ± 5.68° and IMPA of 5.62 ± 6.26° (p<.01). Mandibular incisors also showed significant protrusion indicated by L1-NB (mm) with a mean increase of 1.57 ± 1.67 mm (p<.01).

4.1.2 **Arch Dimension**

In the maxilla, the increase in arch width was the greatest at the first premolar (4.39 ± 1.60 mm, p<.001), followed by the second premolar (4.24 ± 2.56 mm, p<.001), canine (1.85 ± 1.49 mm, p<.001), and molar (1.65 ± 1.49 mm, p<.001). In the mandible, the increase in arch width was greatest at the first premolar (2.95 ± 1.85 mm, p<.001) , followed by the second premolar (2.23 ± 1.49, p<.001), canine (2.12 ± 2.01 mm, p<.01), and molar (0.90 ± 0.26 mm, p<.01).

Arch depth was increased in both maxillary and mandibular arches with a mean increase of 3.05 ± 2.03 mm in the maxilla (p<.001) and 1.95 ± 1.89 (p<.01) in the mandible.

Table 2: Changes in Incisor Position (n=15).

	T0	**T1**	**T1-T0**	
Variables	**Mean ± s.d.**	**Mean ± s.d.**	**Mean ± s.d.**	**p**
U1-NA (°)	20.34 ± 5.97	29.09 ± 4.50	8.75 ± 3.80	<.001
U1-NA (mm)	3.05 ± 1.76	5.15 ± 1.67	2.10 ± 1.25	<.001
U1-cFH (°) *	100.03 ± 7.14	109.19 ± 6.98	9.16 ± 3.71	<.001
L1-NB (°)	21.82 ± 5.71	27.69 ± 5.34	5.87 ± 5.68	<.01
L1-NB (mm)	3.21 ± 2.00	4.79 ± 1.90	1.57 ± 1.67	<.01
IMPA (°)	89.75 ± 5.48	95.37 ± 6.59	5.62 ± 6.26	<.01

*U1-cFH: constructed Frankfort horizontal, measured as U1-SN minus 7°.

Initial = T0, Final = T1

P values according to paired t-test.

Table 3: Changes in Arch Dimension (n=15).

	T0	T1	T1-T0	
Variables	**Mean ± s.d.**	**Mean ± s.d.**	**Mean ± s.d.**	**p**
Mx ICW (mm)	33.24 ± 2.43	35.09 ± 2.09	1.85 ± 1.49	<.001
Mx 1PW (mm)	32.85 ± 1.59	37.24 ± 1.68	4.39 ± 1.60	<.001
Mx 2PW (mm)	37.62 ± 2.48	41.86 ± 2.03	4.24 ± 2.56	<.001
Mx IMW (mm)	44.62 ± 1.90	46.27 ± 2.26	1.65 ± 1.49	<.001
Md ICW (mm)	24.69 ± 2.22	26.80 ± 2.04	2.12 ± 2.01	<.01
Md 1PW (mm)	28.47 ± 2.03	31.41 ± 2.17	2.95 ± 1.85	<.001
Md 2PW (mm)	34.37 ± 2.55	36.60 ± 2.06	2.23 ± 1.49	<.001
Md IMW (mm)	40.70 ± 2.55	41.60 ± 2.89	0.90 ± 0.26	<.01
Mx AD (mm)	26.24 ± 1.92	29.29 ± 2.00	3.05 ± 2.03	<.001
Md AD (mm)	22.04 ± 2.06	23.99 ± 2.09	1.95 ± 1.89	<.01

Mx = Maxillary; Md = Mandibular; ICW = Intercanine width; 1PW = Inter-first premolar width; 2PW = Inter-second premolar width; IMW = Intermolar width

Initial = T0, Final = T1

P values according to paired t-test.

5.0 Discussion

The Damon passive self-ligating system introduced the use of broad arch form wires with the claim of minimizing anterior movement of incisors through space gained by posterior expansion. This is also facilitated by the claim of reduced friction within the system, resulting in freedom of the wires in the bracket slots allowing the wire to slide posteriorly as crowding is being resolved (Damon 1998). Our hypothesis that patients with severe dental crowding treated non-extraction with the Damon appliance system do not experience a clinically significant amount of labial incisor movement was rejected.

Studies comparing the changes in incisor position and arch dimension using the Damon system versus conventional systems are lacking regarding the effects of treatment with severe dental crowding. Atik et al (2016) reported significant increases in these variables, however, the mean amount of crowding in the Damon group was found to be 3.8 mm and 3.9 mm in the mandibular and maxillary arch, respectively. Similarly, another study investigating these parameters had a mean maxillary crowding of 2.3mm in the Damon group (Fleming et al 2013) while another study included cases of moderate to severe crowding indicated by the Little's Irregularity Index (Pandis et al 2010). In our study, the records of 15 patients with greater than 6mm of crowding in the maxillary arch were obtained and the data shows that the mean crowding was significant, with 8.93 ± 3.00 mm in the maxilla and 4.77 ± 2.67 mm in the mandible.

The results of our study indicated that the relief of dental crowding with the Damon passive self-ligating system was accomplished through labial incisor advancement and arch width expansion which agreed with previous studies (Vajaria et al 2011; Atik et al 2016; Nogueira et al 2018). In our study, incisor inclination increased about 9° in the maxilla and 6° in the mandible.

In the treatment of moderate crowding with the Damon system, Vajaria et al (2011) reported an increase in incisor inclination of 3.13° in the maxilla and 6.09° in the mandible while Nogueira et al (2018) reported an increase of 4.73° and 3.80°, respectively. Pandis et al (2010) found that with moderate to severe mandibular crowding, the mandibular incisors proclined about 3.5°. Regarding incisor protrusion, our sample showed an increase in U1-NA and L1-NB measures of 2.10 mm and 1.57 mm, respectively. Nogueira et al (2018) found smaller increases in these variables of 0.95 mm and 1.0 mm, respectively. The differences in maxillary incisor proclination and protrusion values between previous studies and this study is likely attributable to the amount of initial crowding in the maxilla that was higher in our sample. In the mandible, changes in incisor position were generally in agreement with the previously mentioned studies.

There was a significant increase in arch dimensions following treatment. In this study, the intercanine, interfirst premolar, intersecond premolar, as well as the intermolar widths were significantly increased following treatment. The pattern of arch width change was identical in both arches. In the maxilla, the greatest increase was observed at the first premolar (4.39 mm), followed by the second premolar (4.24 mm), canine (1.85 mm), and then molar (1.65mm). Fleming et al (2013) found changes in the maxilla that were identical in order and similar in magnitude to our results. Atik et al (2016) also reported the same sequence of arch width increase, but the increases in intercanine and intermolar width were greater, with values of 2.53 mm and 3.43 mm, respectively.

A study by Pandis et al (2010) found that when using the same broad form archwires in both conventional and self-ligating bracket groups, there was no difference in transverse arch width increases between the groups. Therefore, the dental arch expansion with the Damon passive self-ligating system is due to the use of broad archwires and not the bracket type. Our findings indicate that the greatest amount of expansion happens at the premolar region and corroborates the results of other studies (Vajaria et al 2011; Fleming et al 2013; Atik et al 2016). A previous study showed that rapid palatal expansion with the Hyrax appliance produced increases in maxillary arch perimeter at a rate of 0.7 times the change in first premolar width (Adkins et al 1990). Using this formula, an increase of 4.39 mm at the maxillary first premolars in our sample would result in a gain of 3.07 mm in maxillary arch perimeter. It is likely that the remainder of crowding was resolved through the advancement of incisors. Regarding changes in arch depth, our sample showed an average increase of 3.05 mm in the maxilla and 1.95 mm in the mandible, while Vajaria et al (2011) reported a 0.13 mm and 1.37 mm increase, respectively. This difference is likely due to the amount of initial crowding which was higher in our sample.

This study revealed that there was a significant amount of incisor proclination and protrusion following treatment and therefore refutes the claim that the resolution of crowding occurs without significant labial movement of the incisors. In patients with moderate to severe crowding starting with normal to elevated incisor inclination, the degree of changes noted in our sample would likely produce undesirable results in terms of esthetics.

Stability of orthodontic treatment has been widely reviewed in the literature and it is generally accepted that there is a tendency of teeth to relapse towards the original malocclusion many years post treatment (Al Yami et al 1999). Stability of treatment is variable across individuals and may be due to differences in severity and type of malocclusion, growth pattern, treatment approach, patient cooperation, and also the type, duration, and timing of the retention appliance (Al Yami et al 1999). Numerous reports show that expansion across the canines is almost never maintained, especially in the lower arch and as patients mature, the intercanine width typically decreases possibly due to the lip pressures at the corners of the mouth (Proffit 2013).

Expansion at the molar and premolar areas were found to be more stable than at the canines, possibly because of the relatively low pressures of the cheek. Regarding the labial movement of incisors, a limitation of 2 mm was reported because lip pressure increases considerably when incisors are moved forward by 2mm into the space occupied by the lip, and this was subject to considerable individual variation. Labial movement exceeding this amount was considered to carry a great risk of instability (Proffit 2013). Increasing arch perimeter through incisor advancement and transverse expansion not only carries risk on stability, but also periodontal health. Dehiscence and fenestration of the alveolar bone as well as gingival recession become increasingly likely the more the incisors are advanced. Similar issues occur with increasing risk of periodontal breakdown following expansion across the premolars and molars beyond 3mm (Proffit 2013). Proponents of self-ligating bracket systems claim that the low forces produced within the system allows more physiologic tooth movement and therefore more stable treatment results (Chen et al 2010). In contrast to this claim, a previous study comparing the stability of conventional brackets to self-ligation found that although there was an increase in incisor irregularity in both groups 5 years post retention, there were no statistical differences in long-term stability between self-ligating brackets and conventional brackets (Yu et al 2014).

Certain limitations existed in this study. Due to treatment performed at a university setting, all patients were previously treated by different residents under the supervision of one faculty member that solely practices with Damon appliances. In addition, the curve of spee was not considered which would contribute to the amount of pretreatment crowding. These factors were considered as potential limitations of the study. The results of this study can be used to design larger confirmatory studies in the future. Further research comparing the Damon system to conventional bracket systems would aid in identifying the strengths and weaknesses of the Damon system and this information would be useful for patient selection and treatment planning.

6.0 Conclusion

This study reveals that the relief of moderate to severe dental crowding with non-extraction treatment using the Damon passive self-ligating system was accomplished through statistically significant increases in incisor proclination, incisor protrusion, arch width, and arch depth. The greatest increase in arch width occurred at the first premolar, followed by the second premolar, canine, and molar. The findings of this study can aid in patient selection as the degree of these reported changes may or may not be desirable according to the patient's dental and facial characteristics.

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