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The influence of inter-bracket distance on load deflection characteristics of nickel-titanium wires: Labial versus lingual technique

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***Abstract*---**Aim: Aim of this study was to compare and evaluate load deflection characteristic of NiTi wires of different cross-section between labial and lingual straight wire system in aligned and crowded condition. Materials & Methods: The study was divided into two parts one with the aligned teeth and in other part typodont set was manipulated to simulate the crowded arch. Crowding was created in the anterior region by displacing one central incisor and one lateral incisor 2 mm palataly and canine were rotated in mesio-buccal direction. Typodont was sent to laboratory for lingual setup and CAD-CAM based Avant grade laser sintered 3D lingual brackets were and bonded using Cyanoacrylate by the laboratory. A modified three point

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bending test simulating the clinical conditions was carried out to investigate load deflection characteristics of Cu-NiTi arch-wires using Instron Universal Testing Machine. Results: Shapiro-wilk test and Kolmogorov-Smirnov test were used to check the normality of the sample and values. Intergroup comparison of LDR of wires between labial and lingual group in aligned and crowded condition showed that LDR of wires in the lingual bracket system was significantly higher as compared to labial bracket system. PostHoc–Tukey HSD test was used for the multiple comparisons between all the possible combinations of wires and the bracket system. Moreover, the result were insignificant in crowded condition on comparing LDR of 0.016 NiTi wire in labial segment in crowded condition with the 0.014 NiTi wire in lingual segment in crowded condition. Conclusion: Within the limitations of the study, authors concluded that Load deflection rate of NiTi wires significantly depend upon the inter-bracket distance and Load deflection rate increases with increasing wire dimension for both labial and lingual group in aligned and crowded condition.

***Keywords*---**load deflection, nickel-titanium, labial, lingual, orthodontics.

Introduction

Patients expectation from orthodontic treatment has evolved over the years to include smile esthetics as an important compound. Smile plays an important role in facial expression and appearance. Creating an esthetic smile requires an understanding of the principle that manages the balance between teeth and soft tissues. Although ideal occlusion should be the primary functional goal of orthodontics, the esthetic result is also critical for patient satisfaction and therefore necessary to the overall treatment objectives. The straight-wire appliance (SWA) is based on the concept that ideal bracket placement will correct tooth positions in all three planes of space during treatment. Initially it started with conventional labial bracket system but later on it showed adults have a negative reaction toward the esthetics of conventional fixed orthodontic appliances. Therefore to overcome the increase demands of esthetics during treatment lingual bracket system was developed. Lingual appliances can produce a comparable treatment outcome over similar time periods and are thus an alternative treatment modality for patients to consider.[1] Optimum orthodontic forces will produce maximum tooth movement and maximum biologic response, and do not compromise patient comfort. Excessive forces have been associated with undesirable reactions and side effects, including bone hyalinization, root resorption, pain and patient discomfort, and anchorage loss. With the rapid change in the materials used in orthodontics in recent years, there has been a change from the conventional variable cross-section orthodontics to variable-modulus orthodontics. The archwire of a fixed appliance is the major component in the alignment of irregular teeth, both vertically and radially. Wires capable of large elastic deflections are popular as they allow greater working ranges and therefore fewer archwire changes.[2] The development of beta-titanium (TMA), nickel-titanium (Nitinol), super-elastic nickel-titanium wires has revolutionized the light force application over the teeth. Nickel titanium (NiTi) wires are widely used for the initial leveling phase of orthodontic treatment due to their shape memory, super-elasticity, biocompatibility, resistance to corrosion, low elastic modulus leading to a low load- deflection ratio and wide elastic working range that delivers the desired level of force and provides good control of force magnitude.[3] The labial and lingual orthodontic approaches are quite different in their biomechanical principles. The main difference compared with traditional orthodontics is the smaller inter-bracket distance: the labial arch is significantly longer than the lingual arch.[4] One important goal during the alignment phase of orthodontic treatment is to use suitable and predictable force levels. The force of orthodontic wires is inversely proportional to the cube of the inter-bracket distance. This means that even small reductions in the arch length lead to a significant increase in the force applied to the tooth. Decreased inter-bracket distance associated with lingual appliances makes a wire seem approximately 3 times as stiff as when used with labial appliances for first- and second-order bends, and approximately 1 1/2 times as stiff for third-order bends.[5] An adequate knowledge of load-deflection characteristics of NiTi archwire is necessary to apply adequate force within the bracket system. The three-point bending test is considered a suitable method to investigate the load-deflection characteristics of NiTi archwires. Load-deflection plots of NiTi archwires, obtained by use of classic three-point bending tests. The aim of our study is to compare and evaluate load deflection characteristic of NiTi wires of different cross-section between labial and lingual straight wire system in aligned and crowded condition.

Materials and Methods

The study was carried in the Department of Orthodontics and Dentofacial Orthopaedics and Research Centre of I.T.S-Centre for Dental Studies and Research, Muradnagar, Ghaziabad, Uttar Pradesh. A single acrylic typodont (Nissin, Japan) was used in this study. The study was divided into two parts one with the aligned teeth and in other part typodont set was manipulated to simulate the crowded arch. Crowding was created in the anterior region by displacing one central incisor and one lateral incisor 2 mm palataly and canine were rotated in mesio-buccal direction**.** Typodont was sent to laboratory for lingual setup and CAD-CAM based Avant grade laser sintered 3D lingual brackets were and bonded using Cyanoacrylate by the laboratory. For labial setup conventional MBT brackets (0.018 slot size) were bonded using 17×25 SS wire as a template for proper alignment of the slots using cyanoacrylate. Total of 80 Copper-Nickel-Titanium (Cu-NiTi) round arch-wire of 2 diameters 0.014 inches and 0.016 inches (40 each) were used for the study. For labial setup 40 Cu-NiTi arch-wire (Ormco) (20 of size 0.014 inches and 20 of size 0.016 inches) were used and for lingual straight wire CAD-CAM based setup 40 customized lingual Cu-NiTi arch-wires (20 of size 0.014 inches and 20 of size 0.016 inches) were used for aligned and crowded condition. A modified three point bending test simulating the clinical conditions was carried out to investigate load deflection characteristics of Cu-NiTi arch-wires using Instron 1193, Universal Testing Machine (Instron Corp, Canton, Mass). The load frame was equipped with Instron's ±500 N static cell and a deflecting rod with chisel type end was used to deflect the wires in sagittal direction. For labial setup left central incisor was removed from the typodont 40 Cu-Niti wires were tested for the load deflection in the Aligned and crowded arch condition out of which 20 wires of each 0.014 NiTi and 0.016 NiTi were ligated sequentially using elastomeric ligatures and model was mounted in up-righted position in the lower compartment of the Instron. Chisel type deflected rod connected to ±500 N cell were used to deflect the mid portion of the wire in removed central incisor region. The wire was deflected 2mm in bucco-palatal direction at a crosshead speed of 2mm/min and readings were recorded in Newton (N). For Lingual CAD-CAM base straight wire setup, 40 customized straight Cu-NiTi wires were tested in Aligned and crowded arch condition (20 wires of each 0.014 NiTi and 0.016 NiTi). Procedure to measure load deflection was similar as done for labial setup except the typodont was placed in inverted position in lower compartment of Instron machine. The wires were deflected 2mm in palato-buccal direction at a crosshead speed of 2mm/min and readings were recorded in Newton (N). Each wire was tested three times and the mean of all the three measurement was taken to reduce the working error. Force deflection diagram for the Labial and Lingual setup in Aligned and Crowded condition were plotted on X-Y axis. (Figure 1-6)

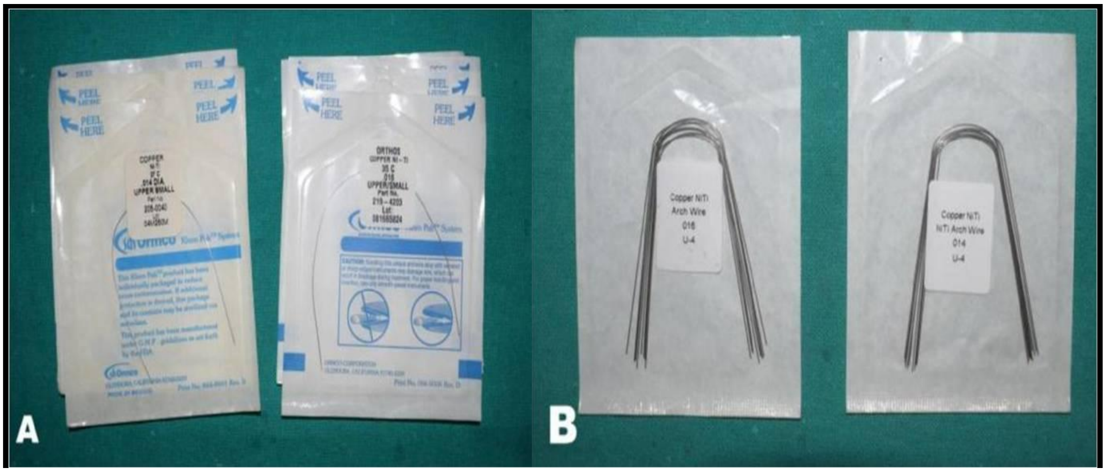


Figure 1: Cu NiTi wires (0.014 & 0.016 inch) for testing Load deflection rate. (A) Conventional Labial Straight wires, (B) Customized Lingual Straight wires

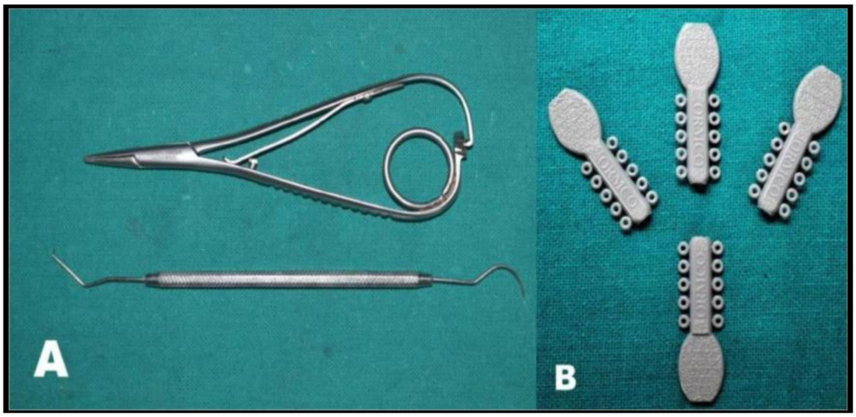


Figure 2: A. Mathews Forceps & Probe. B. Elastomeric Modules

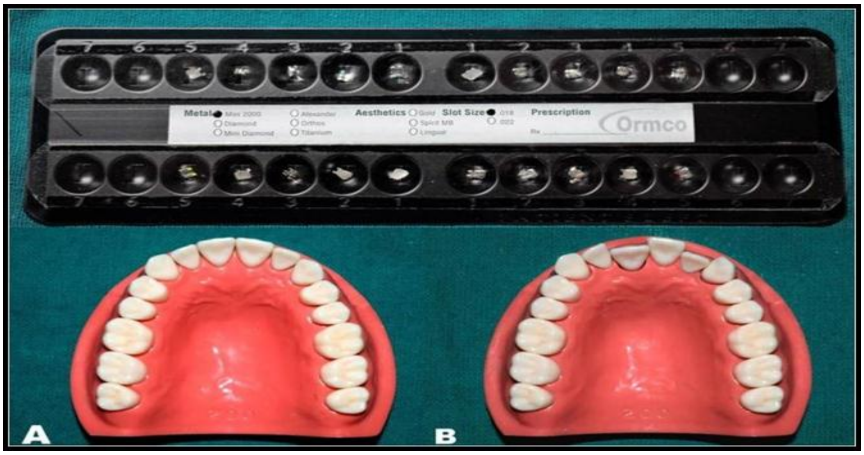


Figure 3: Acrylic typodont model [Nissin] A) Aligned arch, (B) Crowded arch

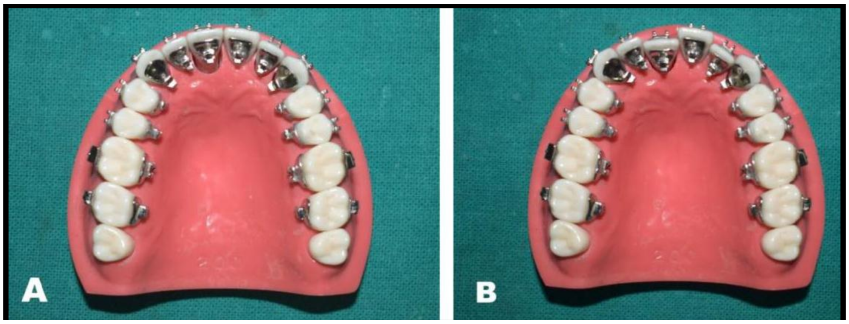


Figure 4: Acrylic typodont model (Nissin) with Labial and Lingual straight wire brackets. (A) Aligned arch, (B) Crowded arch

Figure 5: Universal Testing machine (Instron)

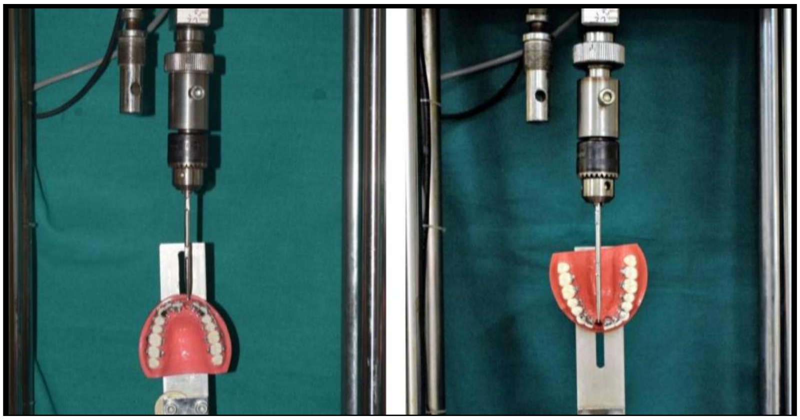


Figure 6: Modified Three point bending test using Instron Machine A. Upright Model for Labial Bracket System. B. Inverted Model for Lingual Bracket system

Statistical Analysis

All the data was collected, compiled and tabulated in MS Excel sheet and analyzed using statistical software SPSS (Statistical package for Social sciences) version 20.0 (SPSS Inc. Chicago, Illianois). The normality of data was tested using Kolmogorov-Smirnov and Shapiro-Wilk test and data was normal. The descriptive statistical mean and standard deviation of the parameter was calculated. Intergroup comparison was calculated using Student T-test to check the mean significant difference of two wires (0.014 NiTi and 0.016 NiTi) among two groups in variable condition. Intragroup and intergroup comparison was done using ANOVA to check the difference between all the available wires and bracket combination. Post-Hoc Tukey HSD test was applied for multiple comparisons between the available wire and brackets combination. The level of significance and confidence interval were 5% and 95% respectively.

Result

The deflection force was measured in newton for 0.014 and 0.016 inch wires in labial and lingual bracket system in two clinically simulated conditions i.e. aligned and crowded. Shapiro-wilk test and Kolmogorov-Smirnov test were used to check the normality of the sample and values are tabulated in Table 1 which shows data was in normal distribution and can be compared further. Distribution of mean ± standard deviation, standard error mean of load deflections are tabulated in Table 2 and shown in Graph 1. LDR of wires in the lingual bracket system was significantly higher as compared to labial bracket system and are tabulated in Table 3 and 4 and shown in Graph 2 and 3. Inter and intra group comparison of Load deflection rate measured for the wires of different cross section in aligned and crowded condition showed a significant difference between all the groups. These results conclude that the LDR of the wires significantly depends upon the cross section of the wires and the inter-bracket distance (Table 5). PostHoc–Tukey HSD test showed statistically significant difference between almost all the groups (Table 6) except two combinations: First, on comparing LDR of 0.016 NiTi wire in labial segment in aligned condition with the 0.014 NiTi wire in labial segment in crowded condition showed statistically insignificant difference

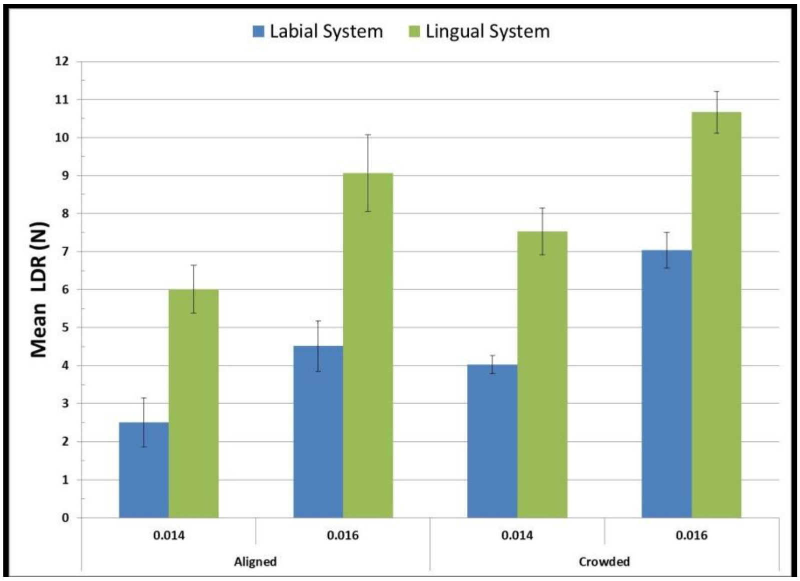
(P>0.05). Also the result were insignificant in crowded condition on comparing LDR of 0.016 NiTi wire in labial segment in crowded condition with the 0.014 NiTi wire in lingual segment in crowded condition. (P>0.05).Thus it could be seen that decreased inter-bracket distance in the lingual bracket system results in the increased LDR as compared to the labial bracket system.

Table1: Test of normality for labial and lingual group for 0.014 and 0.016 NiTi wire in aligned and crowded condition

Groups		Kolmogorov-Smirnov test[a]			Shapiro-Wilk test		
		Statistic	df	Sig.	Statistic	df	Sig.
Aligned 0.014	Labial group	.230	10	.144	.879	10	.126
	Lingual group	.126	10	.200*	.958	10	.760
Aligned 0.016	Labial group	.210	10	.200*	.870	10	.100
	Lingual group	.136	10	.200*	.961	10	.799
Crowded 0.014	Labial group	.232	10	.137	.877	10	.120
	Lingual group	.184	10	.200*	.970	10	.889
Crowded 0.016	Labial group	.135	10	.200*	.988	10	.994
	Lingual group	.143	10	.200*	.944	10	.593
a Lilliefors Significance Correction, *This is a lower bound of the true significance.							

Table 2: Distribution of Mean and standard deviation of load deflection of 0.014 and 0.016 inches NiTi wires in Labial and lingual group in aligned and crowded condition.

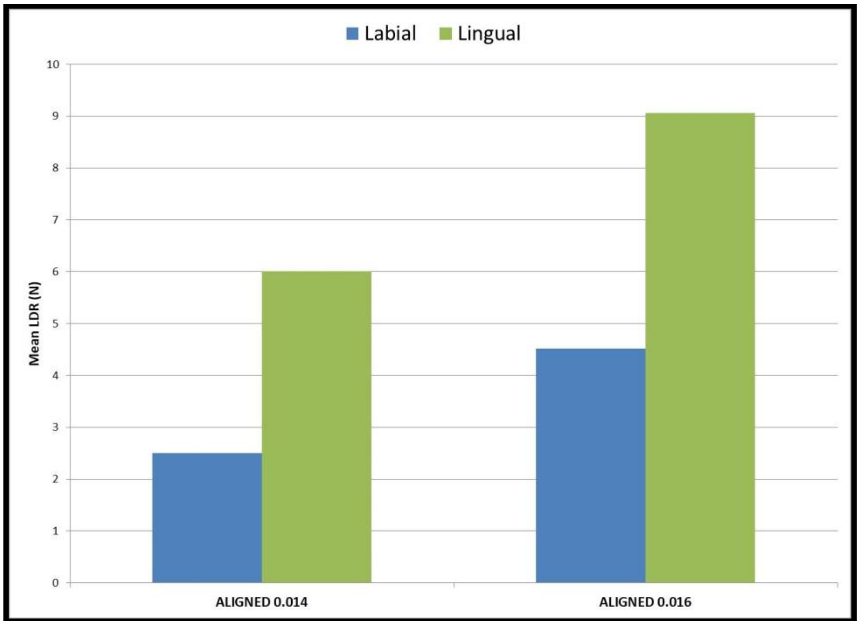
Groups		Labial System (n=40)			Lingual System (n=40)		
		Mean (Newton)	SD	Std. Error Mean	Mean (Newton)	SD	Std. Error Mean
Aligned	0.014	2.5070	.64883	.20518	6.0060	.63235	.19997
	0.016	4.5130	.66384	.20993	9.0590	1.00642	.31826
Crowded	0.014	4.0260	.24364	.07705	7.5270	.61968	.19596
	0.016	7.0390	.47075	.14887	10.6620	.55353	.17504



Graph 1: Mean and standard deviation of load deflection of 0.014 and 0.016 inches NiTi wires in Labial and lingual group in aligned and crowded condition.

Table 3: Intergroup comparison of Load deflection of NiTi wires between labial and lingual bracket system in aligned condition

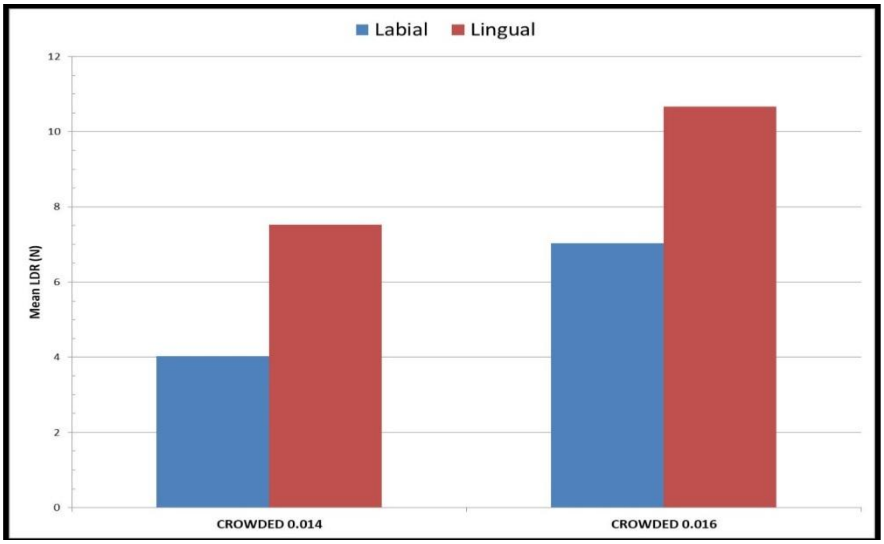
	Levene's Test for Equality of Variances		T-test for Equality of Means						
Groups	F	Sig.	T	Df	P Value	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Aligned 0.014	.037	.850	-12.213	18	<.001	-3.49900	.28650	-4.10092	-2.89708
Aligned 0.016	1.458	.243	-11.924	18	<.0001	-4.54600	.38126	-5.34699	-3.74501



Graph 2: Intergroup comparison of Load deflection of NiTi wires between labial and lingual bracket system in aligned condition.

Table 4: Intergroup comparison of Load deflection of NiTi wires between labial and lingual group in crowded condition.

Groups	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	T	Df	P value	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Crowded 0.014	8.500	.009	-16.627	18	.000	-3.50100	.21056	-3.94337	-3.05863
Crowded 0.016	.530	.476	-15.767	18	.000	-3.62300	.22978	-4.10576	-3.14024



Graph 3: Intergroup comparison of Load deflection of NiTi wires between labial and lingual group in crowded condition.

Table 5: Inter and Intra group comparison of load deflection rate between labial and lingual bracket system using ANOVA

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	514.183	7	73.455	181.046	.000
Within Groups	29.212	72	.406		
Total	543.395	79			

Table 6: p values obtained after Post Hoc comparison of load deflection rate between labial and lingual bracket system using Tukey HSD.

	Lab-Align-014	Lab-Align-016	Lab-Crowd-014	Lab-Crowd-016	Ling-Align - 014	Ling-Align-016	Ling-Crowd-014	Ling-Crowd-016
Lab-Align-014		.000	.000	.000	.000	.000	.000	.000
Lab-Align-016	.000		0.681	.000	.000	.000	.000	.000
Lab-Crowd-014	.000	.000		.000	.000	.000	.000	.000

Lab-Crowd-016	.000	.000	.000		.000	.000	.000	.000
Ling-Align-014	.000	.000	.000	.000		.000	.000	.000
Ling-Align-016	.000	.000	.000	.000	.000		.000	.000
Ling-Crowd-014	.000	.000	.000	0.679	.000	.000		.000
Ling-Crowd-016	.000	.000	.000	.000	.000	.000	.000	

Discussion

The use of NiTi arch-wires became prevalent because of their ability to exert light continuous force and consequently improve the efficacy of treatment, particularly in leveling and alignment phase. If the force is applied to wires its response can be measured as deflection produced by force. Load deflection rate (LDR) calculates the magnitude of force delivered by the appliance for a particular amount of deflection. In orthodontics, the LDR is the force generated by an orthodontic appliance causing unit deflection. The LDR of an orthodontic appliances is, therefore, dependent on bracket system labial or lingual(inter-bracket distance), bracket slot size (either 0.022 or 0.018 slot), bracket design, the wire material, the cross-sectional geometry,[6] ligation material (SS ligature or elastomeric ligature), temperature and saliva. The force applied by an orthodontic wire is inversely proportional to the cube of the inter-bracket distance which states that even small reduction in arch length lead to significant increase in force applied to the tooth. Consistent increase of force values are seen as a result of the decreased anterior inter-bracket distance associated with lingual appliances. So the study was conducted to evaluate and compare the influence of inter-bracket distance on load deflection characteristic of NiTi wires in labial and lingual bracket system in aligned and crowded condition. Several studies have been conducted to evaluate the LDR of different wires which are commonly used in the clinical practice. However these studies suffer from inherent methodological drawbacks, such as the model design as most of the studies used the brass jigs and acrylic blocks, which can affect the amount of deflection forces as these conditions does not correlate with the clinical situation which results in method errors in calculating LDR. Also almost all the studies comparing the LDR in the labial and the lingual bracket system have not standardized the bracket type, model design, technique used and not simulated the clinical situations. In our study we have used a single acrylic typodont (Nissin) model for the evaluation of LDR in the labial and lingual bracket system in aligned and crowded clinical conditions. Conventional MBT 018 slot brackets were bonded on the labial surface using a template with the help of cyanoacrylate. On the lingual side of the same model, CAD-CAM based 018 slot lingual brackets were bonded and same model was modified to simulate crowding in the anterior region. Various studies like Lombardo et al (2011)[1] measured inter-bracket distance in labial and lingual setup by bonding labial and lingual brackets on ideal cast and simulating this inter-bracket distance to calculate the LDR. Many studies in past like Wilkinson et al (2002)[7], Bartzela et al (2007)[8], Lombardo et al (2013)[9] evaluated load deflection of initial leveling and alignment wires using brass jigs and acrylic blocks, which can affect the amount of deflection forces as these condition does not correlate with the clinical situation which results in method errors in calculating LDR. None of these studies compared the LDR on a dental arch that could simulate aligned and crowding conditions similar to clinical situations. According to Schudy and Schudy[10], the deflection of orthodontic wire is directly proportional to the inter-bracket distance and inversely proportional to the wire cross-section. To reduce wire stress on teeth, orthodontist must use wires with smaller cross-section and brackets of smaller dimension. In our study we evaluated two commonly used initial alignment wires i.e., 0.014 and 0.016 NiTi , and our result shows highly significant difference between these two wires in both the labial and lingual bracket system. Our study shows that with the increase in the cross section of the wire there is an increase in the LDR. The result of our study are in concordance with the study by Montasser et al (2015)[11] in which they investigated the effect of arch-wire cross section on the level of force applied to teeth with various arch-wire-bracket combination and concluded that increasing the cross-section of the wire increased the force level invariably with all brackets. Results of our study showed a highly significant difference in the LDR of both 0.014 inches and 0.016 inches size NiTi wires when compared between the labial and lingual bracket system. All the groups showed increased LDR values in the lingual segment as compared to the labial segments. These results are in concordance with the results of studies done by Lombardo et al (2011)[1] and Alobeid et al (2017)[12] in which they compared LDR of NiTi wires in labial and lingual bracket system and found that lingual bracket system showed higher forces compared to labial bracket system. These results can be explained on the basis of difference in the inter-bracket distance in the anterior segment in labial and lingual bracket system. LDR also depends upon the slot size as the study done by Nucera et al(2014)[13] used 0.018 and 0.022 inch slot size self-ligating bracket to evaluate the effect of slot size on wire deflection and found that use of 0.018 slot compared with 0.022 inch system increases the forces exerted by NiTi wires at 2mm deflection. The 0.018-inch bracket system decreases the free play of the wire compared with the 0.022-inch bracket and causes an earlier deflection of the wire and greater LDR. Another recent study by Alobeid et al (2017)[12] compared LDR of NiTi wires in labial and lingual bracket system in which they used commonly available slot size of 0.022slot for labial brackets and 0.018 slot for lingual brackets and found that lingual bracket system showed higher forces compared to labial bracket system. But still it is not clear with result of the study that whether LDR was increased because of different slot size or difference in inter-bracket distance in labial and lingual bracket system. But with our study it is confirmed that the LDR in the lingual segment is significantly higher in comparison to the labial bracket system despite of using the same slot size i.e 0.018 inch in the labial and lingual bracket system. In our study we compared and evaluated LDR of Niti wires at 2mm as it is routinely encountered clinically.

Previous studies like Yang et al (2001)[14], Wilkinson et al (2002)[7], Parvizi et al (2003)[15] checked deflection of NiTi wires at 1mm, 2mm, 3mm and 4mm. Nucera et al (2014)[13] suggested at 2-mm deflection the stress-induced martensitic (SIM) transformation of the wire is not complete which induces the release of significantly higher forces and at 4-mm deflection, the SIM transformation of the wire is complete; consequently, a greater deflection of the wire does not cause the release of higher forces. In our study we calculated load deflection only in bucco-lingual direction because previous studies done by Rock et al (1988) and Filleul et al (1997) showed that if the wire was loaded in bucco-lingual or gingiva-occlusal direction the differences in loading direction do not alter mechanical behavior. On comparing all the available combinations of wire and bracket systems, the result showed significant difference between almost all the groups (Table 6) except two combinations. First, on comparing LDR of 0.016 NiTi wire in labial segment in aligned condition with the 0.014 NiTi wire in labial segment in crowded condition showed insignificant difference ($P>0.05$). This result can be explained as even the cross section of wire is decreased but because of crowding the binding of the wire in the slot must have increased the LDR. Second, on comparing LDR of 0.016 NiTi wire in labial segment in crowded condition with the 0.014 NiTi wire in lingual segment in crowded condition showed insignificant difference ($P>0.05$). This result showed that for the same amount of crowding in the arch if 0.016 wire is used in the labial segment, then to apply the same amount of force over the teeth in case of lingual appliance, smaller diameter wire i.e. 0.014 should be used. Most of the studies done in the past used the conventional lingual bracket system in which mushroom lingual wires were used for comparing the LDR in labial and lingual bracket system. Since the wire in the labial is in a straight form, a direct comparison with the mushroom arch form in the lingual may not be entirely valid. In order to overcome this limitation and to confirm the influence of inter-bracket distance over the LDR, in our study we have used the CAD-CAM based lingual straight wire system instead of conventional lingual system. Our results showed that despite using lingual straight wire the deflection force was more in lingual than labial in both aligned and crowded conditions. One limitation of our study is that no attempt was made to simulate the effect of oral environment such as physical and chemical effects of saliva, debris around brackets, intraoral temperature. All these factors might have impacts on the result which were not considered in this study.

Conclusion

- Load deflection rate of NiTi wires significantly depend upon the inter-bracket distance and plays an important role in wire selection in lingual orthodontics.
- Load deflection rate increases with increasing wire dimension for both labial and lingual group in aligned and crowded condition.
- To apply the same amount of force over the teeth in case of lingual appliance when compared to labial appliance, smaller diameter wire should be used.

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