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Original Research Article

Evaluation of dimensional accuracy and surface roughness of lingual bracket slot –An in vitro study

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ABSTRACT

Background: The paradigm shift with the increasing number of adults and teens seeking aesthetic options for orthodontic treatment led to the increased demand for lingual orthodontics. When it comes to size and slot dimensions, lingual brackets are very different from labial brackets.With the rise of lingual orthodontics in our everyday practice, it's more critical than ever for practitioners to understand these potential bracket size variations. The resistance to sliding mechanics can occur if the contact angle between the archwire and bracket increases, this creates the need for precise bracket slot dimension. The amount of friction varies proportionally to the accuracy of the dimensions and the roughness of the bracket slot.
Objectives: To evaluate the precision of commercially available orthodontic lingual bracket slots in inch dimensions with manufacturers' published dimensions using a stereomicroscope and to compare the surface roughness of commercially available orthodontic lingual bracket slots using an atomic force microscope.
Materials and Methods: Lingual brackets from four different manufacturers were taken for evaluation of slot dimensions. Twenty brackets of each manufacturer were randomly selected.
Equipment: Trinocular Stemi 2000 Stereo Zoom Microscope with Digital Camera (Carl Zeiss, Germany) was used for measurement of bracket slot dimensions. An atomic Force Microscope (AFM) (Nanoscope® IV Di digital instrument, California, USA) was used to evaluate the surface roughness of lingual bracket slots.
Results: Comparison of dimensions between mesial processes and comparison of dimensions between distal processes showed that the difference was only marginal with no significant statistic value. Statistically significant results proved that slot dimensions were not precise as per the manufacturer's standards for given lingual brackets and were oversized for all bracket systems. Statistically insignificant results showed that the bracket systems were similar concerning the surface roughness of the bracket.
Conclusions: The analyzed series of lingual bracket systems exhibited significant differences with manufacturers' standards in slot dimension, which will clinically result in torque play. Lack of standardization of slot dimensions during the manufacturing process may be clinically associated with undesirable tooth positioning and movement; inferring that the bracket systems were similar concerning the surface roughness of the bracket slot.

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1. Introduction

Today orthodontists are facing increasing demand by adults for esthetic treatment alternative.[1] Currently, practicing orthodontists have the choice between numerous esthetic multibracket appliances for fixed therapy. Regarding esthetics, important factors includes appliance display, size, and color stability.[2,3] Patients' wish for almost invisible orthodontic appliances has led to the development of Lingual bracket system. The paradigm shift with the increasing number of adults and teens seeking aesthetic options for orthodontic treatment led to the increased demand for lingual orthodontics. The lingual technique has continually evolved by offering both prefabricated brackets and custom-made brackets. The various techniques have been improved over time, and the results are better than ever.[4] Even though manufacturers of the bracket system take utmost care during fabrication,[5] Badawi HM et al reported that the significant amount of variation in measurements resulted from structural variation in the brackets, specifically the slot size.[6] Manufacturing processes of the bracket, results in some variance in sizes and characteristics, including dimensional accuracy and torque prescription consistency.

One of the most important parameters in deciding the contact angle value during sliding mechanotherapy is the slot dimension.[7] The resistance to sliding mechanics can occur if the contact angle between the archwire and bracket increases, this creates the need for precise bracket slot dimension. Slot precision is a key factor that influences tooth position not only in the labiolingual but also in the vertical dimension.[8] Brown P et alreported that about one-third of the brackets would not accommodate a full-size wire, and 15% to 20% were 0.001 inches or larger than the nominal advertised size.[9] Failure to reproduce the bracket system's accuracy and prescribed dimensions will result in undersized or oversized wires in the bracket slot, compromising treatment results.

On the other hand, standardized international guidelines are lacking; the measurements of angles and distances, therefore, have to be unified with a view to future investigations.[10] When it comes to size and slot dimensions, lingual brackets are very different from labial brackets.[11] With the rise of lingual orthodontics in our everyday practice, it's more critical than ever for practitioners to understand these potential bracket size variations.

Another important factor with bracket system is surface roughness that affect tooth movement. Frictional forces, corrosion activity, the efficacy of arch-guided tooth movement, and the aesthetics of orthodontic components are all affected by the surface roughness of orthodontic archwire and brackets.[12] The amount of friction varies proportionally to the dimensions' accuracy and the bracket slot's roughness.[13]

The study aims to evaluate the precision of commercially available orthodontic lingual brackets slot size in inch dimensions using a stereomicroscope and to compare the measured dimension to the manufacturer's reported dimension. It also aims to measure and compare the surface roughness of commercially available orthodontic lingual bracket slots using an atomic force microscope.

2. Materials and Methods

Orthodontic Lingual brackets from three different manufacturers (frequently used) were taken for evaluation of slot dimensions. Twenty brackets of each manufacturer were selected randomly. They were divided into groups as follows:

1. Group 1- STB (Ormco, Glendora, CA, USA)
2. Group 2- LMX Brackets(Lingual Matrix, India)
3. Group 3- i-Lingual (JLO, India)

Equipment Used

1. Trinocular Stemi 2000 Stereo Zoom Microscope with Digital Camera (Carl Zeiss, Germany) was used for the measurement of bracket slot dimensions.
2. Atomic Force Microscope (AFM) (Nanoscope® IV Di digital instrument, California, USA) was used to evaluate the surface roughness of lingual brackets slots.

2.1. *Methods of measurement*

2.1.1. *Analysis of brackets slot dimension*

Trinocular Stemi 2000 Stereo Zoom Microscope (Carl Zeiss, Germany) was used for viewing the bracket slot at 40X magnification. The brackets were stabilized using putty as the base to provide a clear view of the slot walls (Figure 1). Each bracket was scanned and captured individually in the stereomicroscope on both the mesial and distal sides to produce a digital image. The images were exported and calibrated with software. The software used was accurate up to a least count of 1 micron or up to 5 decimals in inches. (Figure 2)

Thus, the measurements (in inches) were obtained for the following:

1. Mesial face of slot
2. Mesial base of the slot
3. Distal face of slot
4. Distal base of the slot
5. Mesial slot depth
6. Distal slot depth

The values obtained were compared to the dimensions published by each manufacturer. Comparisons were also made between brackets of different manufacturers.

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2.2. Evaluation of surface roughness of the lingual brackets slots

The three-dimensional surface roughness of the slots of the lingual brackets was evaluated using an Atomic Force Microscope (AFM) which is considered a promising technique for the evaluation of surface qualities.[14] (Figure 3)

2.2.1. Surface roughness analysis procedure

Five lingual brackets of each manufacturer were randomly selected and observed with an atomic force microscope. The samples were attached to a metal holder and then each specimen was observed under Atomic Force Microscope with probes mounted on cantilevers with a spring. The slot floors of the orthodontic brackets were scanned in an air condition chamber. All of the scanned images were 50 μm×50μm (Figure 4). Three-dimensional images were processed using Gwyddion software 2.9 and average roughness (Ra) and mean square roughness (Rms) were recorded. (Figure 5)

Average roughness (Ra): The Average Roughness (Ra) is the arithmetic average of the absolute values of the roughness profile ordinates. Ra is one of the most effective surface roughness measures and gives a good general description of the height variations in the surface.

Mean square roughness (Rms): It is defined as the square root of the sum of the squares of the individual heights and depths from the mean line. This method measures a sample for peaks and valleys. Lower numbers indicate a smoother finish.

2.3. Statistical analysis

Statistical analysis was performed using SPSS software (Version 22) with an analysis of means and standard deviations for each parameter. Statistical analysis for surface roughness was performed using by Kruskal-Wallis Test for intergroup comparison.

3. Results

3.1. Results can be divided into

1. Analysis of slot dimensions of Individual bracket systems and
2. Comparative Analysis of surface roughness of bracket systems.

3.2. Analysis of individual bracket systems

3.2.1. STB system (Table 1)

In a comparison of slot dimension with the manufacturer standard of 0.018 inches the mesial face, mesial base, distal face, and distal base, there were statistically significant differences in the entire dimension recorded as compared to the manufacturer's standards. Mesial and distal face recordings were found to be 4% more than the manufacturer's standards and the values at mesial and distal bases were more than the manufacturer's standards. The mesial base was larger by 3.5%.

In a comparison of slot dimension with the manufacturer standard of 0.022 inches the discrepancy of mesial, distal depth was larger approximately by 4% and showed a statistically significant result

3.2.2. Bracket (Table 2)

In a comparison of slot dimensions with the manufactures standard of 0.018 inches the mesial face, mesial base, distal face, and distal base, there were statistically significant differences in the entire dimension recorded as compared to the manufacturer's standard. Mesial face and distal base recordings were found to be 3.3 % more than the manufacturer's standard and the value at the mesial base was more than 3.1% of the manufacturer's standard. The mesial base was larger by 3.7%.

In a comparison of slot dimensions with the manufactures standard of 0.022 inches the discrepancies at mesial, and distal depth were larger by 2.2 and 2.8% respectively, showing statistically significant results.

3.2.3. i-Lingual system (Table 3)

In a comparison of slot dimension with the manufacturer standard of 0.016 inches the mesial face, mesial base, distal face, and distal base, there were statistically significant differences in the entire dimension recorded as compared to the manufacturer's standard. Mesial and distal face recordings were found to be more than 5 and 4.2% respectively of the manufacturer's standard and the value at the mesial and distal base was more than the manufacturer's standard by 6.3 and 6% respectively.

In a comparison of slot dimension with the manufacturer standard of 0.022 inches the discrepancy of mesial, and distal depth were larger approximately by 4% and 2.2% respectively also showing statistically significant results.

3.2.4. Comparative analysis of surface roughness of bracket systems (Table 4)

Descriptive statistics showed that the least value for average roughness (Ra) recorded was of LMX Bracket and also maximum dimension was of i- Lingual.

Descriptive statistics showed that the least value for mean surface roughness recorded was of i-Lingual and also maximum dimension was of STB.

In a comparison of surface roughness among three manufacturers, it was evaluated that the difference in average roughness (Ra) and the difference in mean square roughness (Rms) were of no significant value. Statically insignificant results showed that the bracket systems were similar concerning the surface roughness of the brackets.

Table 1: Comparison of slot dimension with manufactures standard of 0.018 x 0.022 inches. (STB system)

Dimensions	Test Value = 0.018				
	t	df	Sig.	Mean Difference	Mean Change in %
Mesial face	8.320	19	.000	.000735	+4.0
Mesial base	3.695	19	.002	.000610	+3.3
Distal face	7.807	19	.000	.000725	+4.0
Distal base	9.413	19	.000	.000660	+3.6
	Test Value = 0.022				
Dimensions	**t**	**df**	**Sig.**	**Mean Difference**	**Mean Change in %**
Mesial depth	5.908	19	.000	.0007600	+3.4
Distal depth	6.543	19	.000	.0007700	+3.5

Table 2: Comparison of slot dimension with manufactures standard of 0.018 x 0.022 inches. (Lingual Matrix System)

Dimensions	Test Value = 0.018				
	t	Df	Sig.	Mean Difference	Mean Change in %
Mesial face	7.886	19	.000	.0006000	+3.3
Mesial base	6.439	19	.000	.0005650	+3.1
Distal face	7.174	19	.000	.0006650	+3.7
Distal base	5.474	19	.000	.0005950	+3.3
	Test Value = 0.022				
Dimensions	**t**	**df**	**Sig.**	**Mean Difference**	**Mean Change in %**
Mesial depth	6.839	19	.000	.0004800	+2.2
Distal depth	6.078	19	.000	.0006250	+2.8

Table 3: Comparison of slot dimension with manufactures standard of 0.016 x 0.022 inches. (i-Lingual system)

Dimensions	Test Value = 0.016				
	t	df	Sig.	Mean Difference	Mean Change in %
Mesial face	7.007	19	.000	.0008100	+5
Mesial base	10.518	19	.000	.0010050	+6.3
Distal face	6.186	19	.000	.0006800	+4.2
Distal base	8.641	19	.000	.0009750	+6
	Test Value = 0.022				
Dimensions	**t**	**df**	**Sig.**	**Mean Difference**	**Mean Change in %**
Mesial depth	6.515	19	.000	.0008800	+4
Distal depth	6.601	19	.000	.0005000	+2.2

Table 4: Comparison of surface roughness by Kruskal Wallis Test.(Surface roughness)

Unit	Name of Brackets	N	Mean Rank	Chi-Square	df	Sig.
Ra	STB	5	7.80	1.140	2	.566
	Lingual Matrix	5	6.60			
	i-Lingual	5	9.60			
	Total	15				
Rm	STB	5	8.60	.180	2	.914
	Lingual Matrix	5	8.00			
	i-Lingual	5	7.40			
	Total	15				

Figure 1: Bracketon mounting

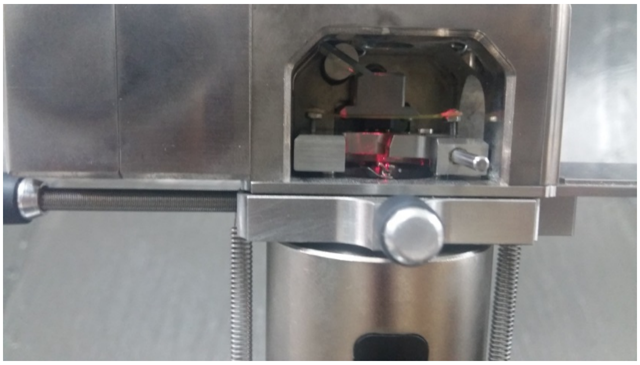

Figure 2: Bracket been scanned under atomic force microscope

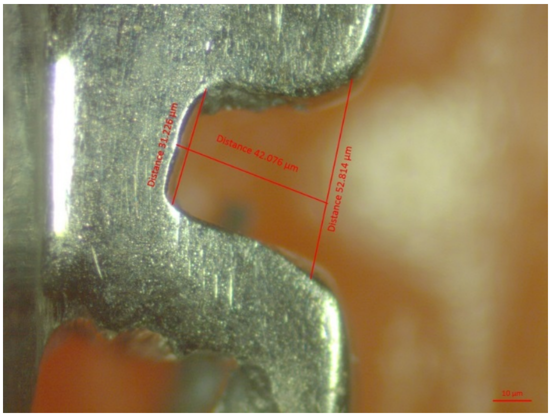

Figure 3: Slot dimention of lingual bracket

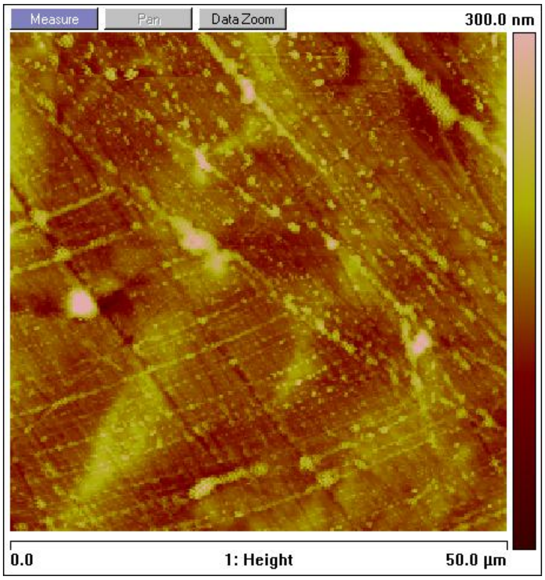

Figure 4: Surface roughness of lingual bracket slot 2d image

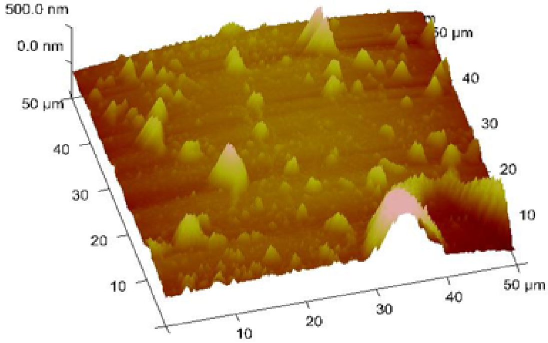

Figure 5: Surface roughness of lingual bracket slot 3D image

4. Discussion

Despite the growing number of adults interested in improving their smiles through orthodontic treatment, the visual impact and the duration of the treatment itself are frequent obstacles to patient acceptance. Fast and less visible treatment is a desirable option that adult patients often request from their orthodontists.[15]

4.1. The precision of bracket slot dimensions

Lingual brackets are different in regard to configuration and clinical aspects. Specifically, conventional lingual brackets are smaller sized to increase patient's comfort and improve oral hygiene.[14]

Orthodontic brackets are essential components of modern fixed appliances. They should have a specific archwire slot to deliver the exact force and minimize frictional resistance. The degree of play is entirely determined by geometric parameters, such as the actual slot height, archwire dimensions, and edge beveling. However, on the market, these do not necessarily correspond to the manufacturer's specifications.[16] Kusy R et al (1999) reported that 15% of the brackets were smaller than documented, and slot sizes were up to 16% and 8% larger than the nominal value.[17]

Cash AC et al. reported that .022-inch brackets from 11 different bracket series representing six different manufacturers' bracket systems were oversized by 5 to 24%, and that imprecise machining of bracket slot dimensions and play of undersized archwires can have a direct and negative impact on tooth three-dimensionality.[18] According to Joch A et al.,[19] if the slot dimensions are larger, the fraction of the specified torque in the bracket is lost due to archwire play within the slot and this torque loss in maxillary and mandibular anterior due to oversized bracket slots and undersized archwire dimensions is illustrated by Siatkowski.[20]

In contrast, if the slot dimensions are smaller than those specified by the manufacturer, there will be less clearance during sliding mechanics, creating more friction and strain on the anchor teeth. According to Demling A, the analyzed bracket systems for lingual treatment had substantial differences in slot dimension, which will clinically result in torque play, and the findings of this study back up this statement.[21] As a result, most orthodontic brackets should be precisely manufactured using a three-dimensional prescription for each tooth.[22,23]

Assad Loss et al reported that the dimensions of the slots were larger than disclosed by the manufacturer, with a range of 1.8 percent to 10.9 percent in height and from 8.2 percent to 49 percent in depth.[24] According to K.J. Kabbur et al., the slot dimensions of Ormco STb; Leone; Dentaurum; Dentos Org. Lingual Brackets were not as specified by the manufacturers, the slots were either too small or too large.[25] Slot dimensions were not precise as per manufacturer's standard and bracket dimensions were oversized or undersized for all bracket systems. The results of the study were statistically significant, indicating that slot measurements for particular lingual brackets were not as precise as the manufacturer's norms. Clinicians should be aware that the inadvertent use of orthodontic brackets can result in a three-dimensional loss of tooth positioning.

Furthermore, potential driving factors of this alarming lack of standardization of orthodontic brackets, such as their alloy properties and/or manufacturing processes, should be considered. The orthodontist should anticipate such shortcomings and be able to modify treatment mechanics through additional wire bending in three spatial planes.[26]

4.2. Surface roughness

Factors influencing surface roughness are related to the material composing brackets and wires, surface conditions of arches and bracket slot, archwire cross-section, torque at the wire-bracket interface, bonding strength, use of self-ligating brackets, interbracket distance, presence of saliva and influence of oral functions.[27] In the present study the three-dimensional surface roughness of the lingual brackets slots was evaluated using Atomic Force Microscope (AFM) for that, 2 parameters, i.e. average roughness (Ra) and mean square roughness (Rms).

Surface roughness of STb (Ormco, Glendora, CA, USA), LMX Bracket (Lingual Matrix, India), and i-Lingual (JLO, India) were compared.

The atomic force microscope is considered to be a promising technique for evaluating quantitative analysis of nanoscale irregularities on surfaces. The surface roughness of various ceramic brackets was measured using atomic force microscopy (AFM) by Lee GJ (2010) and Park KH et al.[28]

Values for average roughness (Ra) can be arranged in ascending order as follows LMX Bracket < STB < i-Lingual. Values for mean square roughness (Rms) can be arranged in ascending order as follows i-Lingual < LMX Brackets < STB. (Table 4)

5. Limitations of the Study

Further study is needed to check changes in sot dimension, surface roughness before and after use.

6. Conclusions

1. In the present study, slot dimensions and surface roughness of lingual bracket slots of three different manufacturers were evaluated. These values were compared with the manufacturer's stated dimensions. There was a significant difference in the readings recorded on the mesial and distal points of brackets in all the bracket systems. The slot evaluated showed, in STb (Ormco, Glendora, CA, USA), LMX Brackets (Lingual Matrix, India), and i-lingual brackets (JLO, India) the slots were significantly oversized.
2. Thus it was summarised that all the bracket systems were not precise; they were either undersized or oversized. On comparing the surface roughness of these bracket systems, the result was statistically insignificant; thus inferring that the bracket systems were similar concerning the surface roughness of the bracket slot.
3. The orthodontist should anticipate such shortcomings and be able to modify treatment mechanics through additional wire bending in three spatial planes.

7. Source of Funding

None.

8. Conflict of Interest

None.

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