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Evaluation and Comparison of Slot Characteristics and Mechanical Properties of Various Orthodontic Metallic Brackets Available in the Indian Market – An *In-Vitro* Study

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Abstract

Introduction: Different brands of orthodontic brackets are available in the Indian market with a wide variation in the prices. There are not any quality control criteria for orthodontic appliances in general and brackets in particular which have to be complied with for patient use during orthodontic treatment, in the Indian scenario.

Aim: To Evaluate and compare slot characterstics and mechanical properties of various commercially available metal brackets in India

Objectives: To evaluate physical dimensions, slot design, various mechanical properties including- strength characteristics, surface morphologies, microhardness.

Method: 15 different commercially available metal brackets were divided into three groups Group 1 (Low cost Rs 400-Rs 800) Group 2 (Medium cost Rs 801-Rs 1200) Group 3 (High cost Rs 1201-Rs 2000) Slot characteristics, mechanical properties were derived using Stereo Microscope image analysis, Dimensional accuracy test, Archwire torque test.

Results: 3M- Gemini brackets had least difference in torque values. 3M –Victory and Abzil brackets had the least difference in their angulation values. Orthosystem-II brackets required highest force to deform. AO-low profile brackets showed the most dense mesh-work followed by Abzil and 3M Gemini.

Conclusions: Orthodontic bracket slots were larger in all brackets Orthosystem-II showed high difference in torque value and Fine series showed high difference in angulation values. Significant difference in morphology of retentive pads in all brackets was found. Dimensional accuracy, torque, angulation and surface texture were better in Group III than other two groups.

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Introduction

One of the most important passive components of fixed appliances are brackets. Brackets can affect the directions of the force vectors when torque, angulations, and in/out are built into the brackets. Orthodontic treatment is based upon specific force applications to the dentition, the maxilla and the mandible. In order to obtain these forces, orthodontic brackets are attached to the teeth. Raymond C. Thurow has defined bracket as an orthodontic attachment secured to a tooth for the purpose of engaging an arch wire. [1] Different brands of orthodontic brackets are available in the Indian market with a wide variation in prices. However, there are no quality control criteria for orthodontic appliances in general and brackets in particular which have to be complied with for patient use during orthodontic treatment, in the Indian scenario. One of the important criteria for selection is slot characteristics and mechanical properties of brackets. There have been very few studies which have tested the slot characteristics and mechanical properties of various orthodontic bracket brands available in the Indian market. [5] Therefore, in this study slot characteristics, mechanical properties of as-received commercial stainless steel brackets produced by different manufacturers available in the Indian market, grouped into three different price ranges, and were compared. The objective was to evaluate physical dimensions and slot design using stereomicroscope image analysis system in various orthodontic metallic and compare various mechanical properties including strength characteristics, surface morphologies, and micro-hardness.

Material and Methods

Fifteen Orthodontic metallic brackets from different commercially available brands in the Indian market were selected. Based on the price range, the brackets was grouped into the following three groups-Group 1 (Low cost ranging from Rs 400 to Rs 800)

- Group 2 (Medium cost ranging from Rs 801 to Rs 1200)
- Group 3 (High cost ranging from Rs 1201 to Rs 2000)

Each group consisted of five brackets of different brands. Upper premolar brackets were used in the study. Stereo Microscope, Vicker's Micro hardness Tester, Instron Universal testing machine (computerized, software based) were used to evaluate mechanical properties, physical dimensions and slot design. Dimensional accuracy test: Dimensional accuracy was tested to determine whether the brackets meet the criteria stated by the manufacturers. To evaluate angulation and torque, the faces of the brackets were photographed by stereo microscopy at a magnifying power of 25 and their angulations were measured with a computer-based measuring tool. The bonding base morphology of the brackets was evaluated by stereo microscopy. To evaluate the micro hardness the specimens were embedded in epoxy resin, ground with water coolant SiC papers from 220 to 2000 grit, and polished up to 0.05 mm alumina slurry in a grinding/polishing machine . Specimens were cleaned in an ultrasonic bath for five minutes and vacuum coated with a thin layer of conductive carbon. The embedded specimens were repolished, and the exposed surfaces were used for the assessment of Vickers hardness (HV200), using a micro hardness tester.

Arch wire torque test was used to determine the force needed to deform brackets, this involved ligating a full size archwire into the slot of the bracket bonded to metal base discs, holding the disc with a bolt onto the customized metal frame. A torqueing key was engaged on the arch wire, and the arch wire torqued until the bracket failed. Bracket bonding and ligation- In preparation of the arch wire torque test, each bracket was bonded to a metal base with a standard adhesive. Round wire mesh, made from 0.0045 inch round stainless steel wire was soldered to one of the surfaces of each disc. To facilitate good bond the bonding surfaces of disc were sandblasted.

Stastical Analysis

Values are Mean ± Standard deviation. P-values are obtained by using one-sample't' test. P-value < 0.05 is considered to be statistically significant. S: Statistically Significant, NS: Statistically Non-Significant.

Result

Only AO Low profile brackets showed least difference with their dimensions, whereas Dent arum brackets showed the highest difference. Dimensional accuracy test showed that the Orthosystem-II brackets had highest amount of difference in torque value while 3M- Gemini brackets had the least difference in their torque values. For angulation Fine series brackets had highest amount of difference in their angulation values (1.68), while. 3M –Victory and Abzil brackets had the least difference in their angulation values. Metro orthodontics brackets showed the highest Vickers Hardness (270.24 HV) followed by Abzil orthodontics and Dent aurum brackets for the alloy used (316L-225HV) for manufacturing the brackets. According to statistical analysis, all HV values demonstrated significant difference among the groups tested. Orthosystem-II brackets with -7 torqueing angle required the highest force to deform. The results of surface texture investigation showed AO-low profile brackets showed the most dense mesh work followed by Abzil and 3M Gemini. Brackets.

- The average Slot Top did not differ significantly between Group 1 and Group 2 of brackets (P-value > 0.05).
- The average Slot Top is significantly higher in Group 1 brackets compared to Group 3 brackets (P-value < 0.001).
- The average Slot Top is significantly higher in Group 2 brackets compared to Group 3 brackets (P-value < 0.001).
- The average Slot Base did not differ significantly between Group 1 and Group 2 of brackets (P-value > 0.05).
- The average Slot Base is significantly higher in Group 1 brackets compared to Group 3 brackets (P-value < 0.001).
- The average Slot Base is significantly higher in Group 2 brackets compared to Group 3 brackets (P-value<0.001).
- The average Difference in Slot Top and Base did not differ significantly between Group 1 and Group 2 of brackets (P-value > 0.05).
- The average Difference in Slot Top and Base did not differ significantly between Group 1 and Group 3 of brackets (P-value > 0.05).
- The average Difference in Slot Top and Base is significantly higher in Group 2 brackets compared to Group 3 brackets (P-value < 0.01).
- The average Slot Top is significantly different than the standard value of Slot Top in Group 1 (P-value < 0.001).
- The average Slot Top is significantly different than the standard value of Slot Top in Group 2 (P-value < 0.001).
- The average Slot Top is significantly different than the standard value of Slot Top in Group 3 (P-value < 0.001).
- The average Slot Base is significantly different than the standard value of Slot Base in Group 1 (P-value < 0.001).
- The average Slot Base is significantly different than the standard value of Slot Base in Group 2 (P-value < 0.001).
- The average Slot Base did not differ significantly than the standard value of Slot Base in Group 3 (P-value > 0.05).
- The average Torque did not differ significantly between Group 1 and Group 2 of brackets (P-value > 0.05).
- The average Torque did not differ significantly between Group 1 and Group 3 of brackets (P-value > 0.05).
- The average Torque did not differ significantly between Group 2 and Group 3 of brackets (P-value > 0.05).
- The average Angulation is significantly higher in Group 1 brackets compared to between Group 2 of brackets (P-value < 0.001).
- The average Angulation is significantly higher in Group 1 brackets compared to between Group 3 of brackets (P-value < 0.001).
- The average Angulation did not differ significantly between Group 2 and Group 3 of brackets (P-value > 0.05).
- The average Torque is significantly different than the standard value of Torque in Group 1 (P-value < 0.01).
- The average Torque is significantly different than the standard value of Torque in Group 2 (P-value < 0.001).
- The average Torque is significantly different than the standard value of Torque in Group 3 (P-value < 0.05).
- The average Angulation is significantly different than the standard value of Angulation in Group 1 (P-value < 0.001).
- The average Angulation is significantly different than the standard value of Angulation in Group 2 (P-value < 0.001).
- The average Angulation is significantly different than the standard value of Angulation in Group 3 (P-value < 0.01).
- The average Microhardness is significantly higher in Group 2 compared to Group 1 of brackets (P-value < 0.001).
- The average Microhardness did not differ significantly between Group 1 and Group 3 of brackets (P-value > 0.05).
- The average Microhardness is significantly higher in Group 2 compared to Group 3 of brackets (P-value < 0.001).
- The average Tensile Strength did not differ significantly between Group 1 and Group 2 of brackets (P-value > 0.05).
- The average Tensile Strength did not differ significantly between Group 1 and Group 3 of brackets (P-value > 0.05).
- The average Tensile Strength did not differ significantly between Group 2 and Group 3 of brackets (P-value > 0.05).

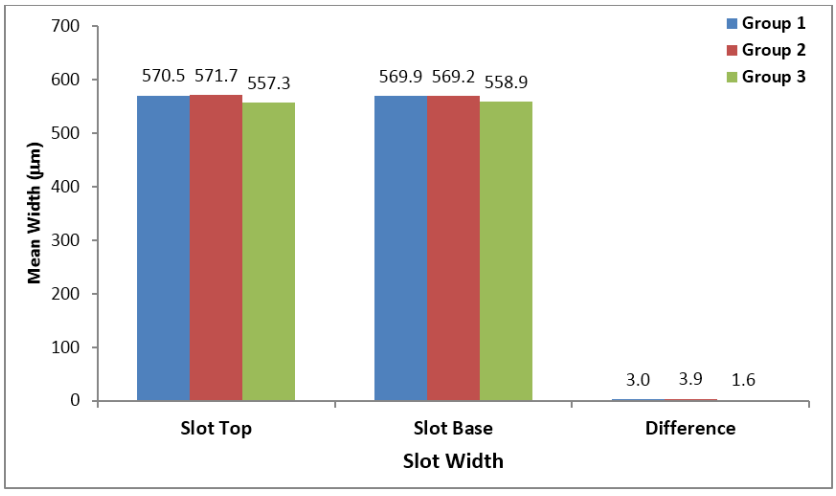
- The average Microhardness is significantly different than the standard value of Microhardness in Group 1 (P-value < 0.01).
- The average Microhardness is significantly different than the standard value of Microhardness in Group 2 (P-value < 0.01).
- The average Microhardness is significantly different than the standard value of Microhardness in Group 3 (P-value < 0.01).

Study Group	Brand name	Slot Top Width (µm)	Slot Base Width (µm)	Absolute Difference (Top – Base) (µm)
Group 1 (n = 25)	Dentos	566.6 ± 9.7	568.2 ± 10.9	2.8 ± 1.9
	Centrino	574.3 ± 15.6	572.7 ± 14.9	2.4 ± 1.3
	Modern	570.4 ± 14.7	569.9 ± 11.4	3.3 ± 1.8
	Fine series	577.2 ± 13.8	573.4 ± 12.1	4.2 ± 2.7
	Ortho brackets	564.1 ± 6.5	565.6 ± 7.8	2.4 ± 1.8
	Overall	570.5 ± 12.4	569.9 ± 11.0	3.0 ± 1.9
Group 2 (n = 25)	Orthosystem-I	569.8 ± 7.4	570.4 ± 3.5	5.1 ± 2.2
	URA-Mini	582.6 ± 9.2	581.4 ± 10.3	2.4 ± 0.9
	Dentaurum	568.0 ± 7.9	561.2 ± 8.9	6.8 ± 5.4
	Orthosystem-II	568.8 ± 8.7	566.9 ± 8.2	1.9 ± 0.9
	Metro orthodontics	569.4 ± 3.2	566.0 ± 3.2	3.4 ± 3.9
	Overall	571.7 ± 8.9	569.2 ± 9.7	3.9 ± 3.5
Group 3 (n = 25)	3M-Gemini	556.5 ± 3.0	558.3 ± 1.2	1.8 ± 1.8
	AO-Master Mini	557.3 ± 1.7	558.4 ± 1.3	1.1 ± 0.6
	3M-Victory	558.1 ± 1.3	559.6 ± 1.7	1.4 ± 0.8
	Abzil	557.4 ± 1.4	560.0 ± 3.2	2.6 ± 4.6
	AO-Low Profile	557.1 ± 1.5	558.1 ± 0.9	0.9 ± 0.6
	Overall	557.3 ± 1.8	558.9 ± 1.9	1.6 ± 2.2
Inter-Group Comparisons				
Group 1 v Group 2	--	0.999 (NS)	0.999 (NS)	0.639 (NS)
Group 1 v Group 3	--	0.001 (S)	0.001 (S)	0.168 (NS)
Group 2 v Group 3	--	0.001 (S)	0.001 (S)	0.006 (S)

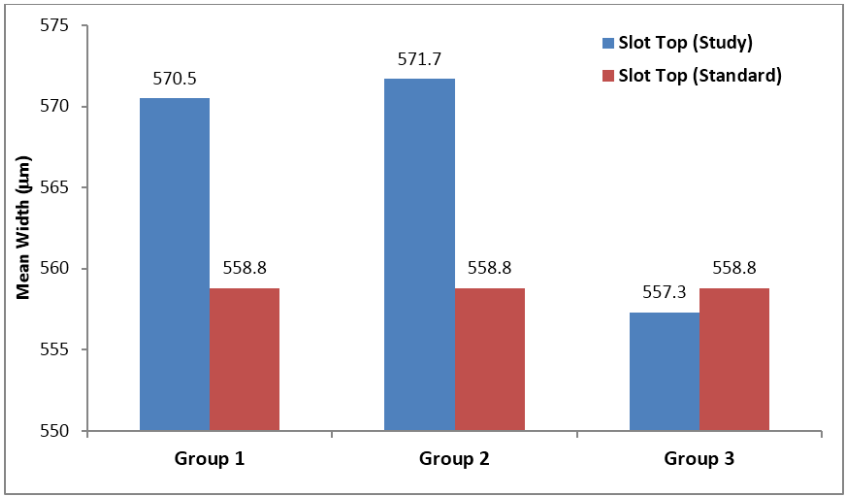
Table 1: *Inter-Group comparison of Slot width (Top and Base) across various Brands.*

Study Group	Study Slot Top Width (µm)	Std Value (µm)	P-value (Study v Std)	Study Slot Base Width (µm)	Std Value (µm)	P-value (Study v Std)
Group 1 (n = 25)	570.5 ± 12.4	558.8	0.001 (S)	569.9 ± 11.0	558.8	0.001 (S)
Group 2 (n = 25)	571.7 ± 8.9	558.8	0.001 (S)	569.2 ± 9.7	558.8	0.001 (S)
Group 3 (n = 25)	557.3 ± 1.8	558.8	0.001 (S)	558.9 ± 1.9	558.8	0.832 (NS)

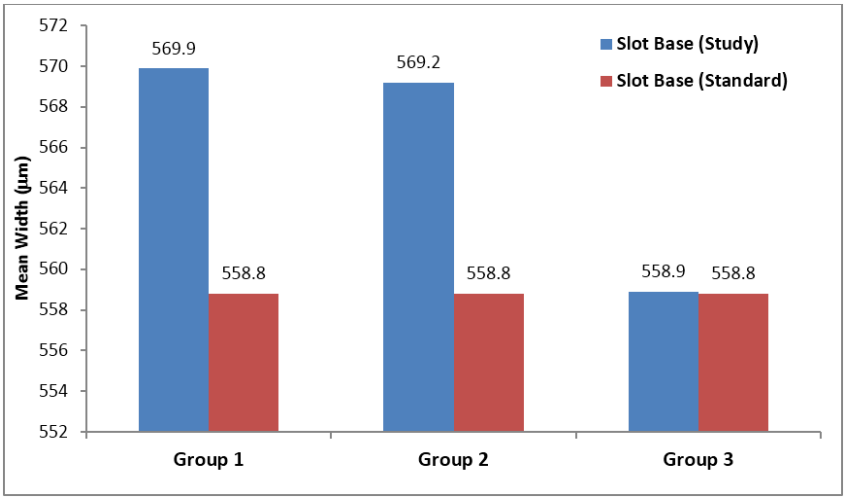
Table 2: *Comparison of Slot width (Top and Base) with the Standard value across three study groups.*



Graph 1: *Inter-Group comparison of Slot width (Top and Base).*



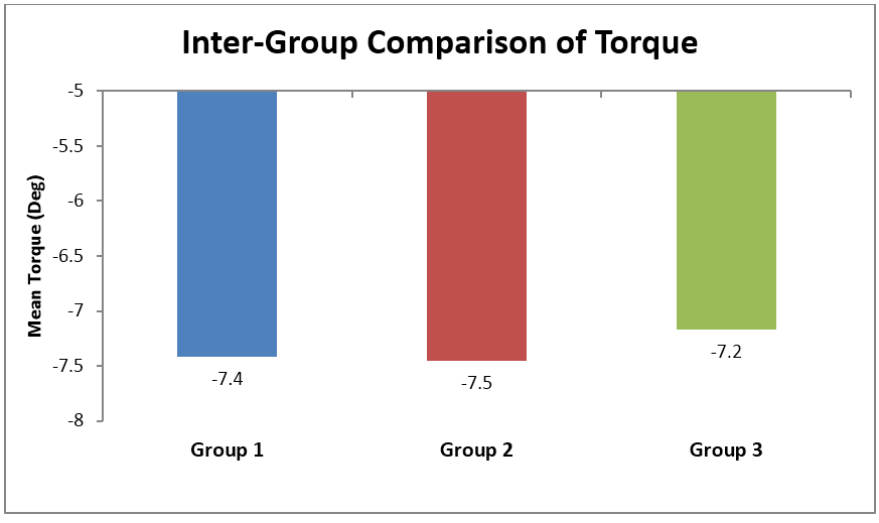
Graph 2a: *Comparison of Slot Top with the Standard value across three study groups.*



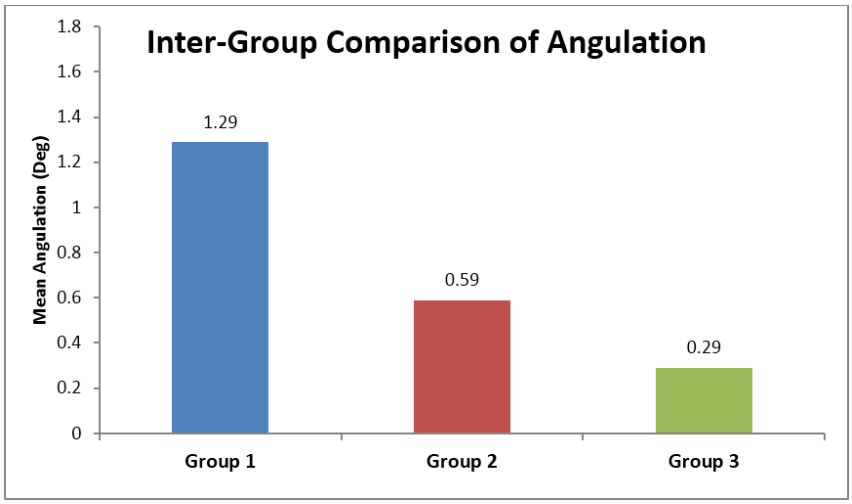
Graph 2b: *Comparison of Slot Base with the Standard value across three study groups.*

Study Group	Brand Name	Torque (Deg)	Angulation (Deg)
Group 1 (n = 25)	Dentos	-6.98 ± 0.32	0.90 ± 0.55
	Centrino	-7.86 ± 0.79	1.48 ± 0.87
	Modern	-7.16 ± 0.83	1.46 ± 1.09
	Fine series	-7.82 ± 0.86	1.68 ± 0.77
	Ortho brackets	-7.28 ± 0.52	0.96 ± 0.46
	Overall	-7.42 ± 0.73	1.29 ± 0.78
Group 2 (n = 25)	Orthosystem-I	-7.50 ± 0.48	0.62 ± 0.59
	URA-Mini	-7.56 ± 0.34	0.94 ± 0.42
	Dentaurum	-6.98 ± 0.29	0.40 ± 0.38
	Orthosystem-II	-8.08 ± 0.85	0.62 ± 0.61
	Metro orthodontics	-7.14 ± 0.28	0.38 ± 0.42
	Overall	-7.45 ± 0.59	0.59 ± 0.49
Group 3 (n = 25)	3M-Gemini	-7.02 ± 0.04	0.26 ± 0.42
	AO-Master Mini	-7.52 ± 0.84	0.68 ± 0.79
	3M-Victory	-7.14 ± 0.19	0.16 ± 0.23
	Abzil	-7.06 ± 0.09	0.16 ± 0.31
	AO-Low Profile	-7.12 ± 0.13	0.20 ± 0.23
	Overall	-7.17 ± 0.40	0.29 ± 0.46
Inter-Group comparisons			
Group 1 v Group 2	--	0.999 (NS)	0.001 (S)
Group 1 v Group 3	--	0.434 (NS)	0.001 (S)
Group 2 v Group 3	--	0.301 (NS)	0.239 (NS)

Table 3: *Inter-Group comparison of Torque and Angulation across various Brands.*



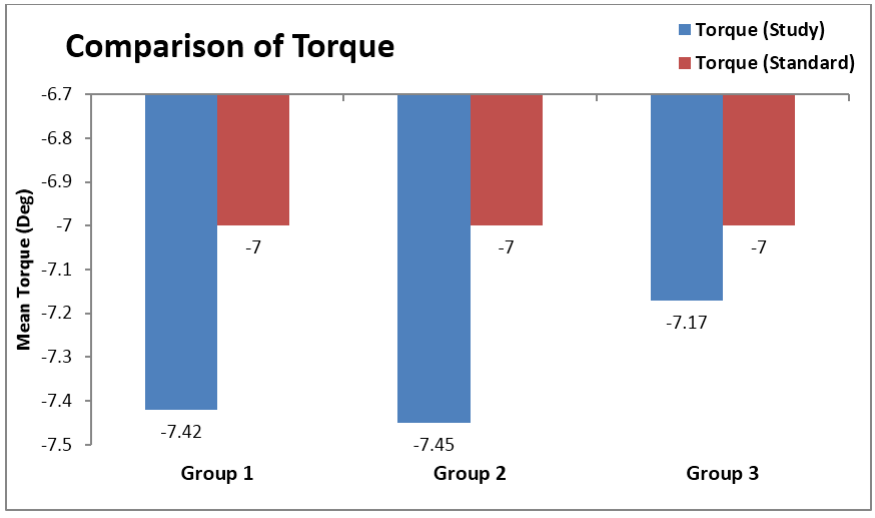
Graph 3a: *Inter-Group comparison of Torque.*



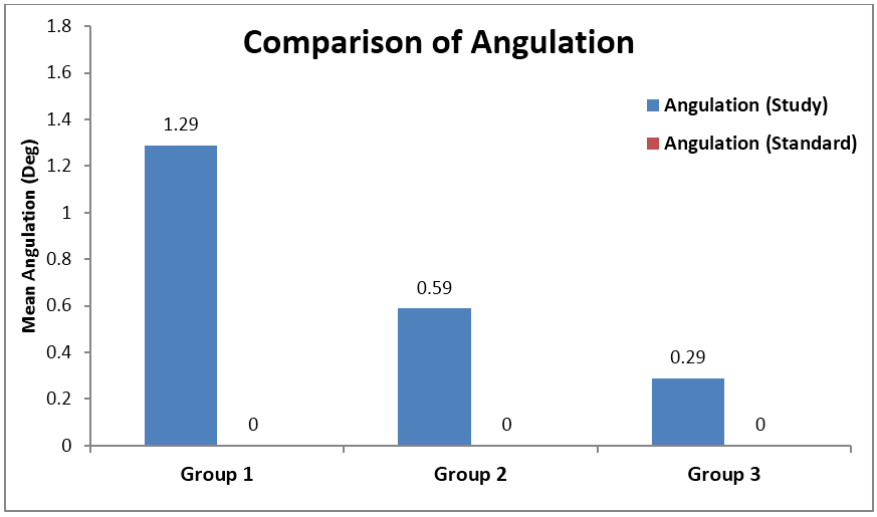
Graph 3b: *Inter-Group comparison of Angulation.*

Study Group	Study Torque (Degree)	Standard Torque (Degree)	P-value (Study v Std)	Study Angulation (Degree)	Standard Angulation (Degree)	P-value (Study v Std)
Group 1 (n = 25)	-7.42 ± 0.73	-7	0.009 (S)	1.29 ± 0.78	0	0.001 (S)
Group 2 (n = 25)	-7.45 ± 0.59	-7	0.001 (S)	0.59 ± 0.49	0	0.001 (S)
Group 3 (n = 25)	-7.17 ± 0.40	-7	0.044 (S)	0.29 ± 0.46	0	0.004 (S)

Table 4: *Comparison of Torque and Angulation with the Standard value across three study groups.*



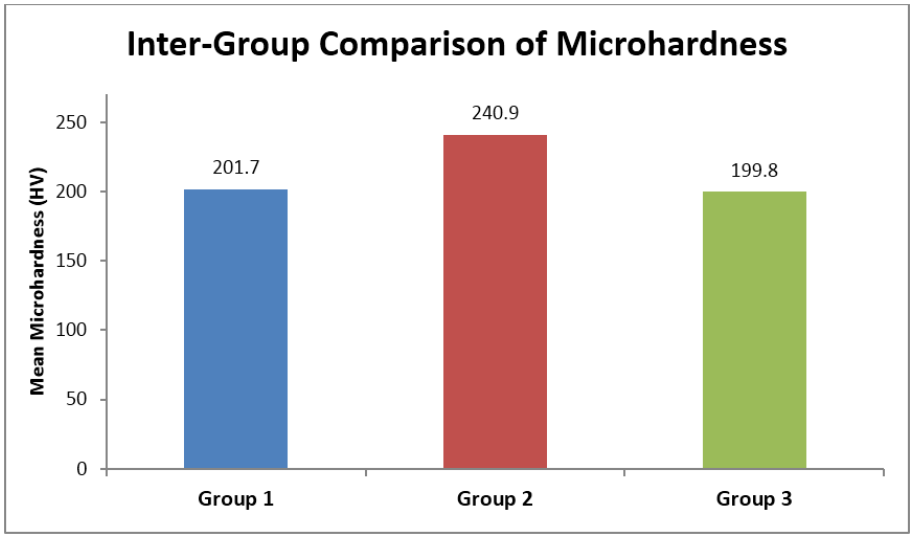
Graph 4a: *Comparison of Torque with the Standard value across three study groups.*



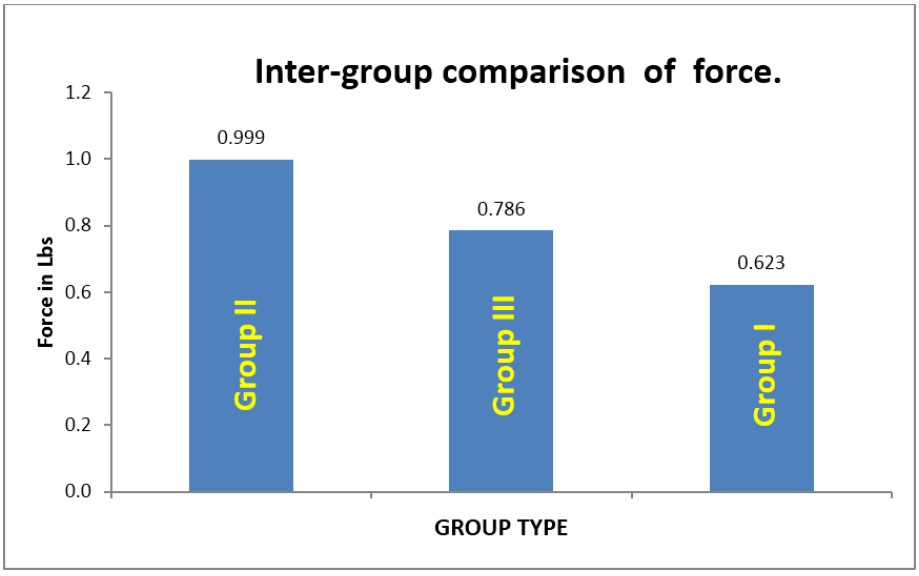
Graph 4b: *Comparison of Angulation with the Standard value across three study groups.*

Study Group	Brand Name	Microhardness (HV)	Force (Lbs)
Group 1 (n = 25)	Dentos	186.66 ± 9.48	0.39 ± 0.38
	Centrino	234.70 ± 4.80	0.66 ± 0.37
	Modern	172.44 ± 5.40	0.29 ± 0.21
	Fine series	193.84 ± 3.04	0.56 ±0.61
	Ortho brackets	220.74 ± 3.97	0.38 ± 0.37
	Overall	201.68 ± 23.85	0.46 ± 0.39
Group 2 (n = 25)	Orthosystem-I	237.66 ± 2.61	0.44 ± 0.43
	URA-Mini	201.56 ± 2.24	0.69 ± 0.47
	Dentaurum	263.12 ± 2.01	0.58 ± 0.55
	Orthosystem-II	231.86 ± 1.04	0.74 ± 0.49
	Metro orthodontics	270.24 ± 1.16	0.53 ± 0.67
	Overall	240.89 ± 25.04	0.59 ± 0.49
Group 3 (n = 25)	3M-Gemini	219.16 ± 2.57	0.47 ± 0.33
	AO-Master Mini	166.06 ± 1.59	0.47 ± 0.19
	3M-Victory	167.06 ± 2.35	0.37 ± 0.30
	Abzil	264.92 ± 0.92	0.19 ± 0.05
	AO-Low Profile	181.82 ± 1.16	0.44 ± 0.12
	Overall	199.80 ± 38.63	0.39 ± 0.23
Inter-Group comparisons			
Group 1 v Group 2	--	0.001 (S)	0.623 (NS)
Group 1 v Group 3	--	0.999 (NS)	0.999 (NS)
Group 2 v Group 3	--	0.001 (S)	0.786 (NS)

Table 5: *Inter-Group comparison of Microhardness and Force across various Brands.*



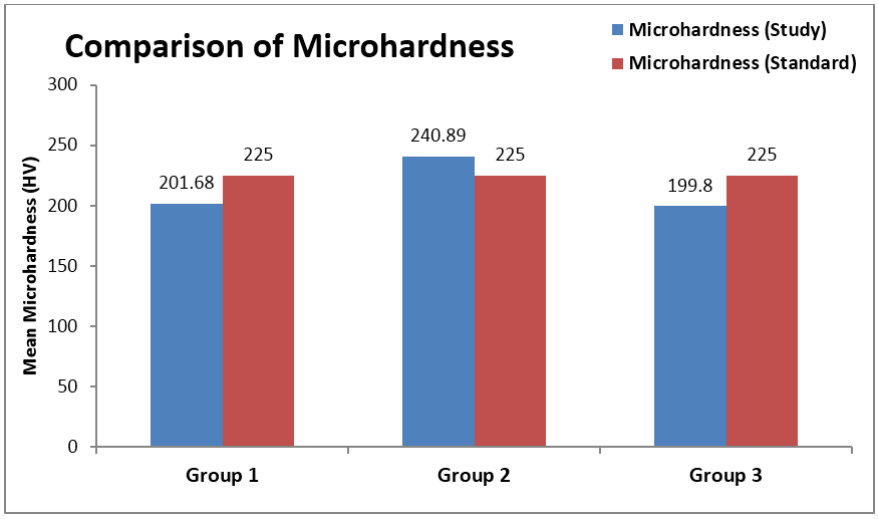
Graph 5a: *Inter-Group comparison of Microhardness.*



Graph 5b: *Inter-group comparison of force.*

Study Group	Study Microhardness (HV)	Standard Microhardness (HV)	P-value (Study v Std)
Group 1 (n = 25)	201.68 ± 23.85	225	0.001 (S)
Group 2 (n = 25)	240.89 ± 25.04	225	0.004 (S)
Group 3 (n = 25)	199.80 ± 38.63	225	0.003 (S)

Table 6: *Comparison of Microhardness with the Standard value across three study groups.*



Graph 6: *Comparison of Micro hardness with the Standard value across three study groups.*

Discussion

Three-dimensional orthodontic tooth positioning occurs as a result of the interaction between orthodontic arch wires and pre-programmed brackets on teeth within a healthy supporting periodontium. In a medical environment striving for excellence in both patient care and treatment outcomes, it is disappointing to find that, in some cases, the tools of an orthodontist's trade may be inaccurately manufactured. [6,14] Previous clinical studies have also suggested that brackets need to be fabricated from a strong material, with enough bulk and a slot designed to prevent permanent deformation during orthodontic treatment. [7,8] Fifteen commercially available metal brackets were evaluated for different parameters: Dimensional Accuracy Test , Torque/Angulation, Surface morphology, Micro-Hardness test ,Load required for bracket deformation .Although pricing might have nothing to do with the technical properties tested, the question was whether bracket brands in the higher price ranges were better conformed to standards and ideal properties. This aspect was specially examined with respect to slot characteristics and mechanical properties.

1. Firstly, Relating to dimensional accuracy of the bracket slot, the effects of oversized brackets on anterior torque loss was illustrated by Siatkowski, [15]. In our study we found that sample 15(American Orthodontics LP) in Group 3 had showed the least difference with their stated dimensions, whereas Dent arum brackets from Group 2 showed the highest difference. Also in general, samples in Group 3 better conformed to their stated dimensions, showed lesser variation from the ideal dimensions the inadvertent use of orthodontic brackets with oversized slots may cause three dimensional loss of tooth positioning.
2. Secondly, angulation and torque of the bracket slot, which are complicated parameters, were measured in the present study using optical microscopy. Thus there would be precision added to visualization. In this study, all the bracket samples showed manufacturing errors in angulation while the Fine Series brackets appeared to have the largest deviation from the standard values. The results of the test showed that the Orthosystem-II brackets had highest amount of difference in torque value as compared to their standard values, while 3M- Gemini brackets had the least difference in their torque values as compared to their standard value. The intergroup comparisons for torque and angulation with standard values showed that Group 3 had the least difference in their torque and angulation values (-7.17 & 0.044). If the brackets do not present a high level of precision, there would be no reason for the orthodontist to use brackets with pre-adjustments in daily clinic [17].

3. Thirdly, The results of surface texture investigation showed significant differences in base morphology among the brackets tested. Although all brackets tested were produced by Metal Injection Moulding (MIM), each bracket demonstrated a different surface morphology. AO-low profile bracket showed the most dense mesh work followed by Abzil and 3M Gemini. The results of surface texture investigation showed that significant difference exists in the morphology of the retentive pads, which may affect the clinical performance of orthodontic brackets [16].
4. Fourthly, under the experimental conditions of this study, Vickers indentations were made by using 100 g and 15-second contact time. This load produces a small pyramidal size indentation, giving the ability to avoid the adverse effect of porosity on hardness measurements because intact areas were used for Vickers indentations. The Vicker's hardness of the brackets tested varied from 166 HV to 270 HV. Metro orthodontics showed the highest (270.24 HV) followed by Abzil(and Dentaurum as compared to standard value of the alloy used (316L-225HV) for manufacturing the brackets. [13] The mismatch between hardness should be minimized to avoid wear phenomena during orthodontic treatment. The results of Vickers hardness (HV) measurements demonstrated significant difference among the groups tested, perhaps due to elemental composition or the brackets were subjected to thermal treatments after fabrication such as stress-relief annealing from the manufacturing process and thus hardness.
5. Archwire Torque test was used to determine the force needed to deform brackets, which involved ligating a full size archwire into the slot of the bracket bonded to metal base discs, holding the disc with a bolt onto the customized metal frame. A torquing key was engaged on the archwire, and the archwire torqued until the bracket failed, in a universal testing machine (Instron). A previous study by Flores7 had stated that the raw material used to manufacture the bracket had a significant effect on the force required to deform the bracket in an Archwire torque test. Thus we decided to regroup the samples tested in this study into groups based on the alloy grades used as derived in Table No. 7. Although all the samples used in this study had similar slot torque and design, the samples differed in the nature of the AISI stainless steel alloy grades (174 PH, 304, 304 L, 316, 316 L and 317) used which could have a significant effect on force required for deformation of these metal brackets. We did find a variation in the force required to deform the brackets between the samples regrouped on the basis of the 6 different AISI alloy grades, reiterating the conclusion that raw material had a significant effect on this parameter, although we could not obtain a statistically significant difference in a intergroup comparison. Brackets made with 174 PH stainless steel alloy grade required the highest force for deformation while brackets made with 304 stainless steel alloy grade required the least force for deformation. Based on the results of this study the bracket samples tested needed to be fabricated from a strong material with enough bulk and slot designed to prevent permanent deformation during orthodontic treatment.

The 15 commercial bracket samples available in the Indian market and tested in this study showed a wide variation in the raw material used, which underlines the need for more uniform norms for bracket manufacture, as this could have a significant impact on the material properties of clinical relevance of these brackets. There needs to be clear mention on the bracket kits supplied (which is lacking at present at least in the Indian scenario), of the raw material used and other relevant manufacturing parameters which shall aid the clinician to better select the desired bracket systems. The presented results can be applied to establish national standards for orthodontic brackets and to evaluate commercially available products.

Conclusion

For the fifteen orthodontic metallic brackets commercially available in the Indian market, that were tested in this study, the following conclusions were reached: Orthodontic bracket slots are larger than that stated by the manufacturers. Slot geometry and the standard of bracket finish varied greatly between the bracket groups. Torque and Tip values varied from the ideal MBT prescription values for all the bracket samples tested with Orthosystem-II brackets having the highest amount of difference in torque value(-8.08 deg) and Fine series brackets having the highest amount of difference in their angulation values.

1. A significant difference exists in the morphology of the retentive pads, which may affect the clinical performance of orthodontic brackets.
2. Vickers hardness (HV) measurements varied among the brackets tested. The mismatch between hardness should be minimized to avoid wear phenomena during orthodontic treatment. The clinical significance of the hardness finding may pertain to the fact that low-hardness may complicate the force transfer characteristics from activated arch wires to teeth because it may preclude full engagement of the wire to the slot wall and possible plastic deformation of wing.
3. Conclusion of arch wire torque test suggested that the material parameter was an important factor which influenced the force needed to deform metal brackets. Brackets need to be fabricated from a strong material with enough bulk and slot design to prevent permanent deformation during orthodontic treatment.
4. Among the parameters tested, we found that with reference to parameters 1, 2 and 3 (dimensional accuracy, torque and angulation and surface texture) bracket samples in Group 3 (higher price range) better conformed to standards than the bracket samples from the other two groups (mid and low price ranges).

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