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Effect of Elastomeric Module Degradation and Ligation Methods on Kinetic Friction on NiTi wires with Stainless Steel Brackets

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Abstract: ***Introduction**: The reduction of resistance to sliding between the archwire and bracket promotes more seamless tooth movement, leading to a faster and improved orthodontic treatment experience. This research aimed to examine how the degradation of elastomeric modules, different ligation methods, bracket-wire angle, and nickel-titanium wire have an impact the kinetic friction resulting from the interaction between NiTi and SS brackets. **Materials and Methods**: The current in vitro study was conducted on NiTi wires, with two types of ligations (O-ring, SS wire ligature) and two bracket-wire angles (0° and 10°). The kinetic friction in each group was measured using a Universal Testing Machine at four time intervals: baseline, day one, week one, and week four. Repeated measures ANOVA, and Greenhouse-Geisser test, and relevant post hoc tests were used for statistical analysis (P). **Results**: There is a decrease in kinetic friction in all types of ligations, which confirmed the effect of time on the degradation of ligation modules. The kinetic friction is equal in both O-ring and SS wire ligations. No difference was observed between O-ring and SS wire ligations. Furthermore, the bracket-wire angle did not affect friction. **Conclusion**: It is concluded that both O-ring and SS ligation can be used for ligation, as both have equal frictional resistance.*

Keywords: Orthodontic Wires; Orthodontic Friction; Orthodontic Brackets.

1. Introduction

In fixed orthodontics, tooth movement occurs using brackets and archwires through sliding or frictionless (utilizing loops) methods. It takes place when the force exerted is greater than the amount of frictional force and binding between the bracket slot and archwire [1]. In the sliding method, the friction between the wire and the bracket consumes almost 12% to 60% of the orthodontic force, necessitating the exertion of additional force to overcome the friction. This might cause anchorage loss and increase the risk of tooth root resorption [2,3]. According to the literature, factors affecting the friction between the wire and the bracket include the archwire material, its dimensions, surface structure, the angle of the wire and bracket slot [4,5], bracket type [6,7], ligation techniques [8], and saliva [9]. Also, the amount of force applied by the ligation is one of the factors affecting the amount of wire and bracket friction in an orthodontic system. This force has been reported in most studies to be 50 to 300 grams [10-13].

Various methods have been introduced to reduce frictional force, such as changing the size and material of the wire, changing the design of the bracket, wire surface coverage with different materials [14], application of lubricants [15], and using different types of ligatures and different methods of ligation [16]. It has been stated that the various techniques of ligation in elastomeric ligatures might alter the amount of friction by making complete or incomplete contact with the archwire [17]. As aforementioned, different ligatures and ligation types affect the amount of friction. There are two common ligatures widely used by orthodontists: 1) Elastomeric modules and 2) Stainless Steel (SS) wire ligatures [18]. Elastomeric ligatures are made of polyurethane rubber. These materials replaced latex rubber elastics due to the possibility of causing allergic reactions [19,20]. Various intraoral factors, like chemicals present in food, saliva, and dentifrices can affect the properties of elastomeric modules. Also, their characteristics can be changed by temperature alterations due to the consumption of hot or cold food. Furthermore, elastomeric modules degrade in the oral environment, and the amount of force they apply decreases over time. As a result, the friction between the wire and the bracket can be affected [21-24]. Regarding the wire alloy, it has been stated that SS wires provide a complete and stable connection between the orthodontic bracket and the wire. However, they create a significant amount of friction during archwire sliding [18]. On the other hand, Nickel Titanium (NiTi) wires are more flexible and exert light forces. They also have super-elasticity and shape memory characteristics [25]. However, some authors have stated that the friction caused by NiTi archwires is greater than stainless steel [3].

Demonstrated evidence suggests that minimizing friction between the archwire and bracket promotes more efficient tooth movement, accelerating and improving the overall quality of orthodontic treatment. However, there is a lack of research focusing on friction across different ligation techniques, particularly concerning the use of NiTi archwires. To provide sufficient information to help select the best ligation method in terms of frictional properties, this study is aimed at the effect of the degradation process of elastomeric modules and different ligation methods on the friction between NiTi wire with SS brackets.

2. Materials and Methods

A total of 40 samples (10 samples in each of the 4 groups) were prepared. Study groups. Each sample unit in the study consisted of 2 brackets adhered to a metal plate with an archwire tied by ligatures. The materials used to prepare the sample units were: 1. eighty standard 0.022-inch right and left lower central incisor teeth SS brackets (two brackets for every sample unit). One right-side and one left-side bracket were used for each sample. 2. 60 round 0.016-inch NiTi wires in 18 cm pieces. 3. Two types of ligature materials, including an elastomeric module and SS wire ligature wires. Each sample unit consisted of one right and one left bracket. Both brackets were ligated with the same ligating method in each sample (Figure 1). Elastomeric modules were ligated at, 0˚ and 10˚ wire-bracket angles were used for NiTi wires. In 0˚ bracket wire angle positioning, two brackets were placed in a parallel situation. In the 10˚ bracket wire angle, the angle of one bracket was zero, and the angle of the second bracket was 10˚ relative to the wire and the first bracket. The centers of all brackets' slots were in a straight line (Figure 1).

The groups were arranged as follows:

1) Ten sample units composed of a round 0.016 inch NiTi wire inserted into two SS brackets, both ligated with "O-ring" elastomeric ligatures. The angle between the two brackets was 0˚ (NiTi/0˚/O-ring).
2) Ten sample units made up of a round 00.016-inch NiTi wire inserted into two SS brackets, both ligated with SS wire ligatures. The angle between the two brackets was 0˚ (NiTi/0˚/SS-lig).
3) Ten sample units made up of a round 0.016 inch NiTi wire inserted into two SS brackets, both ligated with "O-ring" elastomeric ligature, and the angle between the two brackets was 10˚ (NiTi/10˚/O-ring).
4) Ten sample units consisting of a round 0.016 inch NiTi wire inserted into two SS brackets, both ligated with SS wire ligatures. The angle between the two brackets was 10˚ (NiTi/10˚/SS-lig).

Sample Preparation

The brackets were attached perpendicular to the longitudinal axis of rectangular aluminum plates according to the aforementioned groups with cyanoacrylate adhesive (3M liquid superglue, USA). The distance between the two brackets was 10mm, and both of the brackets had 0˚ standard torque. Then, the aluminum plate was connected with two screws to the base of the Universal Testing Machine, horizontally, to perform sliding movements to measure kinetic friction (Figure 2). A 150-gram weight was hung from the bottom of the wire, and the upper part of the wire was connected to the arm of the machine. To simulate sliding movement, the arm stretched the upper part of the wire at a speed of 0.5 mm/s for 20 seconds, and the force was measured by the machine and recorded in computer software. To simulate the degradation of elastic modules, all samples were stored in artificial human saliva at a temperature of 37˚ Celsius for one day, one week, and four weeks after sample unit preparation in an incubator. The saliva was poured by pipette at a rate of 1ml/min at the point of contact between the wire and the brackets. In total, the tests were performed immediately after the sample preparation day (Baseline), and one day, one week, and four weeks later. The computer connected to the universal machine began recording after 0.1 seconds of wire movement, so only the dynamic frictional force was measured.

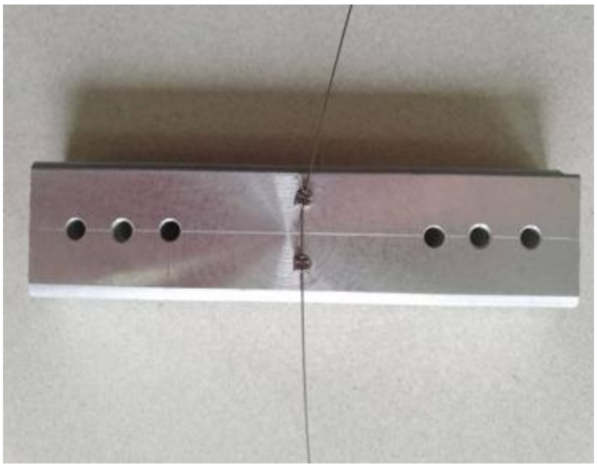


Figure 1: Positioning of brackets on aluminum plates

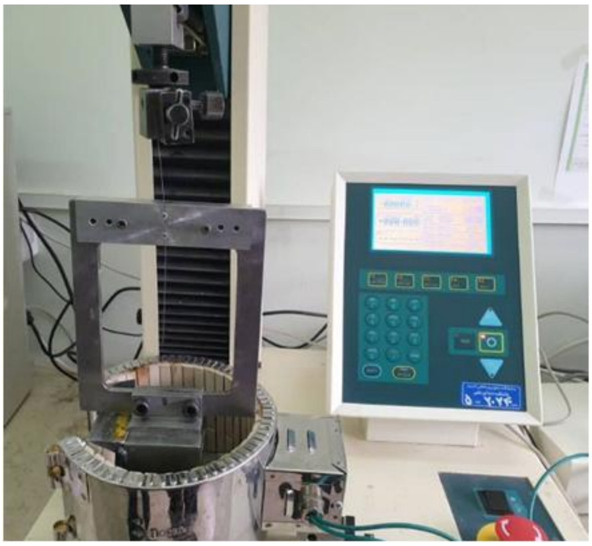


Figure 2: Attachment of the aluminum plate to the base of the Universal testing machine.

Statistical Analyses

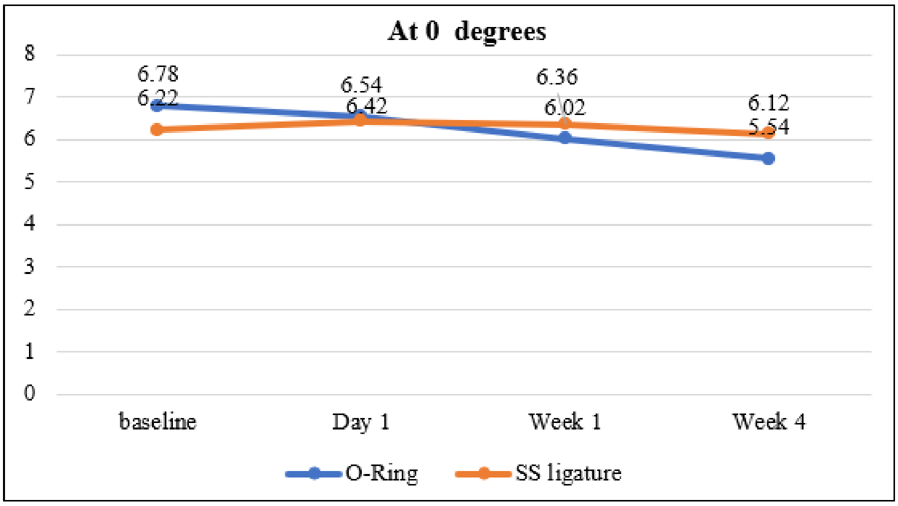
The amount of friction in each group was reported as mean±standard deviation (mean±SD). To analyze the effect of time, wire type, and archwire-bracket angle on the frictional force, the authors used repeated measures ANOVA. Significant results of the were followed by the Greenhouse-Geisser test for statistical correction. Appropriate post hoc analysis was carried out when necessary. $P<0.05$ was considered significant.

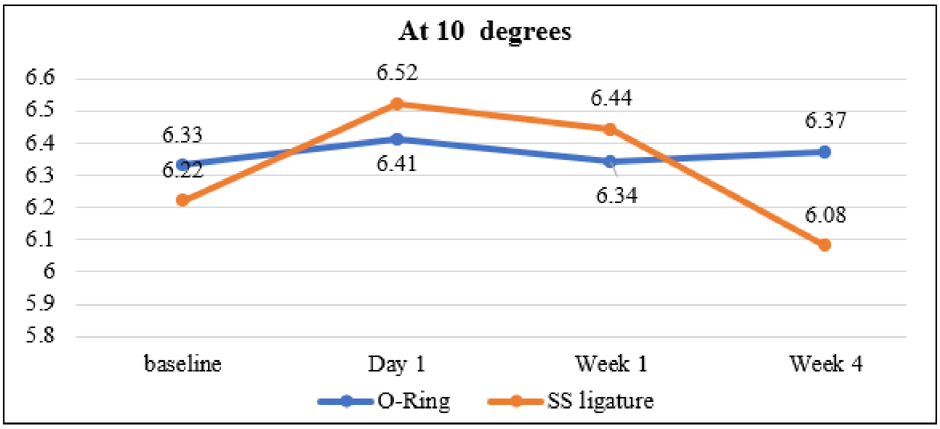
3. Results

The mean values and standard deviation for kinetic friction over time for each ligation method for the NiTi archwires are shown in Table 1. The results of the ANOVA test showed that the interaction of time and ligation ($p= 0.097$). However, the effect of time on the mean frictional forces, after considering the Greenhouse Geisser correction, was statistically significant, and the analysis showed that the frictional force decreases as time goes forward. The results of the repeated measures ANOVA test showed no statistically significant change in the amount of frictional force after changing the angle between the archwire and bracket from 0 to 10 degrees ($P=0.141$). However, the mean frictional force had a statistically significant difference among the different ligation methods.

Table 1: The mean values ± standard deviation of kinetic friction (N) over time for each group of nickel-titanium wires

Angle	Ligation method	baseline	Day 1	Week 1	Week 4
0 °	O-Ring	6.78 ±1.75	6.54±0.44	6.02±0.48	5.54±0.35
0 °	SS ligation	6.22±0.28	6.42±0.24	6.36±0.23	6.12±0.17
10 °	O-Ring	6.33±0.36	6.41±0.46	6.34±0.11	6.37±0.28
10 °	SS ligation	5.95±0.33	6.52±0.53	6.44±0.49	6.08±0.8





4. Discussion

As orthodontic tooth movement occurs, the frictional force generated in the bracket-wire ligature assembly confronts the orthodontic force, which necessitates exerting more force to overcome the friction that might cause loss of anchorage and increase the risk of tooth root resorption. According to the literature, classical friction is generated when there is only a bracket-wire interface; however, with the addition of ligature, “binding” creates a type of friction that is more complex than classical friction [1-3]. During orthodontic tooth movement, a constant alteration occurs between the kinetic and static friction, and it is not a smooth translation. In other words, the orthodontic tooth movement occurs in a stepwise, but not a continuous manner [30]. Therefore, both friction types have been considered important and should be evaluated in the studies. As aforementioned, the authors found a decreasing pattern in all three types of ligations. A study by Edwards et al. [31] evaluating the effect of degradation of elastomeric modules on static friction showed a similar result as ours. They found a decrease in the static friction over time in elastic modules stored in artificial saliva. In another study by Dowling et al. [32], they observed both decrease, increase, and no change in frictional resistance over time in different groups. The issue was that the tests were conducted in the absence of natural or artificial saliva, which might have affected the results.

These observations prevent us from attributing the changes in the friction only to the degradation process of elastomeric modules. Though it is possible that the friction results from a combination of different factors, including orthodontic material (e.g., bracket, archwire, ligation module) structure and surface characteristics, oral environment factors, and contacts made from the bracket wire-ligature assembly affecting at different levels in the lifespan of an elastomeric module. On the other hand, stress release of SS wire ligatures over time and their loosening might be an important factor in friction decrease in this group. The results show that regardless of wire type and the bracket-wire angulation, the figure of 8 ligations created the most friction compared to O-ring and SS wire ligations. Similar results were obtained by Edwards et al. [26] and Voudouris et al. [34]. According to Khambay et al. [27] and Bazakidou et al. [35], SS wire ligatures generated the lowest friction among different ligatures. Some of the studies in the literature also did a comparison of frictional forces between different archwire materials. Tselepis et al. [30] and Peterson et al. [36] showed that the frictional force did not differ between NiTi and SS archwires. However, other studies have stated that there were significant differences in the created friction among assemblies containing NiTi and SS wires [9,10,13,37]. The authors' results showed the neutral effect of bracket-wire angle alteration on kinetic friction. A study by Samorodnitzky-Naveh et al. [29] evaluated the impact of a specific coating of NiTi wires on both static and kinetic friction coefficients and showed that by increasing the angle from 2˚ to 3.8˚ and from 3.8˚ to 5˚ in uncoated wires, the kinetic friction coefficient decreased. In other studies by Tselepis et al. [30] and Jang et al. [28], it was stated that the higher bracket wire angulations increased the kinetic friction. The reason for these controversies might be that the angle alteration impacts the static and kinetic coefficients at different levels. Furthermore, there are significant methodological variations in study settings that make it hard to compare the results, like different friction simulation settings (e.g., using one or couple brackets to simulate second order bend, the differences in designing paths to mimic archwire movement, etc.), the materials used from different manufacturers which might have different surface and structural characteristics and the machine used to record friction. Another reason for these controversies might be the dimension of NiTi wires used in this study, which creates a noticeable amount of wire play in the bracket slot and helps the wires to move more freely, not engaging the bracket's internal walls. These results might be different with using thicker wires.

The limitation of this study was that the complete simulation of the oral environment, such as tooth translation in the bone as a living element, the effect of adjacent teeth, muscular and occlusal force, was almost impossible. Therefore, it suggests that more standardized studies should be conducted for each of these three variables and minor attributes which belong to each of them in standard and constant conditions.

5. Conclusion

There was no difference between SS wire and O-ring ligatures. These results are promising because ligating the bracket with an O-ring is more straightforward, safer, and less time-consuming than SS ligation, and there might be no need to use the SS ligation technique only to overcome friction and sliding difficulties. The kinetic friction had decreasing patterns for the two ligation methods due to degradation processes of the elastomeric or ligature ties (O-Ring, and SS wire ligatures)

References

[1] Articolo LC, Kusy RP. Influence of angulation on the resistance to sliding in fixed appliances. Am J Orthod Dentofacial Orthop. 1999 Jan;115(1):39-51.

[2] Harry MR, Sims MR. Root resorption in bicuspid intrusion. A scanning electron microscope study. Angle Orthod. 1982 Jul;52(3):235-58.

[3] Kusy RP, Whitley JQ. Friction between different wire-bracket configurations and materials. Semin Orthod. 1997 Sep;3(3):166-77.

[4] Redlich M, Mayer Y, Harari D, Lewinstein I. In vitro study of frictional forces during sliding mechanics of "reduced-friction" brackets. Am J Orthod Dentofacial Orthop. 2003 Jul;124(1):69-73.

[5] Doshi UH, Bhad-Patil WA. Static frictional force and surface roughness of various bracket and wire combinations. Am J Orthod Dentofacial Orthop. 2011 Jan;139(1):74-9.

[6] Henao SP, Kusy RP. Frictional evaluations of dental typodont models using four self-ligating designs and a conventional design. Angle Orthod. 2005 Jan;75(1):75-85.

[7] Ehsani S, Mandich MA, El-Bialy TH, Flores-Mir C. Frictional resistance in self-ligating orthodontic brackets and conventionally ligated brackets. A systematic review. Angle Orthod. 2009 May;79(3):592-601.

[8] Shivapuja PK, Berger J. A comparative study of conventional ligation and self-ligation bracket systems. Am J Orthod Dentofacial Orthop. 1994 Nov;106(5):472-80.

[9] Stannard JG, Gau JM, Hanna MA. Comparative friction of orthodontic wires under dry and wet conditions. Am J Orthod. 1986 Jun;89(6):485-91.

[10] Frank CA, Nikolai RJ. A comparative study of frictional resistances between orthodontic bracket and arch wire. Am J Orthod. 1980 Dec;78(6):593-609.

[11] Drescher D, Bourauel C, Schumacher HA. Frictional forces between bracket and arch wire. Am J Orthod Dentofacial Orthop. 1989 Nov;96(5):397-404.

[12] Andreasen GF, Quevedo FR. Evaluation of friction forces in the 0.022 x 0.028 edgewise bracket in vitro. J Biomech. 1970 Mar;3(2):151-60.

[13] Pratten DH, Popli K, Germane N, Gunsolley JC. Frictional resistance of ceramic and stainless steel orthodontic brackets. Am J Orthod Dentofacial Orthop. 1990 Nov;98(5):398-403.

[14] Cash A, Curtis R, Garrigia-Majo D, McDonald F. A comparative study of the static and kinetic frictional resistance of titanium molybdenum alloy archwires in stainless steel brackets. Eur J Orthod. 2004 Feb;26(1):105-11.

[15] Dridi A, Bensalah W, Mezlini S, Tobji S, Zidi M. Influence of bio-lubricants on the orthodontic friction. J Mech Behav Biomed Mater. 2016 Jul;60:1-7.

[16] Natt AS, Sekhon AK, Munjal S, Duggal R, Holla A, Gupta P, et al. A comparative evaluation of static frictional resistance using various methods of ligation at different time intervals: an in vitro study. Int J Dent. 2015;2015:407361.

[17] Khambay B, Millett D, McHugh S. Archwire seating forces produced by different ligation methods and their effect on frictional resistance. Eur J Orthod. 2005 Jun;27(3):302-8.

[18] Marques IS, Araújo AM, Gurgel JA, Normando D. Debris, roughness and friction of stainless steel archwires following clinical use. Angle Orthod. 2010 May;80(3):521-7.

[19] Kamisetty SK, Nimagadda C, Begam MP, Nalamotu R, Srivastav T, Gs S. Elasticity in Elastics-An in-vitro study. J Int Oral Health. 2014 Apr;6(2):96-105.

[20] A Rolland JM, O'Hehir RE. Latex allergy: model for therapy. Clin Exp Allergy. 2008 Jun;38(6):898-912.

[21] Chimenti C, Franchi L, Di Giuseppe MG, Lucci M. Friction of orthodontic elastomeric ligatures with

different dimensions. Angle Orthod. 2005 May;75(3):421-5.
[22] De Genova DC, McInnes-Ledoux P, Weinberg R, Shaye R. Force degradation of orthodontic elastomeric chains--a product comparison study. Am J Orthod. 1985 May;87(5):377-84.
[23] Ash JL, Nikolai RJ. Relaxation of orthodontic elastomeric chains and modules in vitro and in vivo. J Dent Res. 1978 May-Jun;57(5-6):685-90.
[24] Kuster R, Ingervall B, Bürgin W. Laboratory and intra-oral tests of the degradation of elastic chains. Eur J Orthod. 1986 Aug;8(3):202-8.
[25] Cobb NW 3rd, Kula KS, Phillips C, Proffit WR. Efficiency of multi-strand steel, superelastic Ni-Ti and ion-implanted Ni-Ti archwires for initial alignment. Clin Orthod Res. 1998 Aug;1(1):12-9.
[26] Edwards GD, Davies EH, Jones SP. The ex vivo effect of ligation technique on the static frictional resistance of stainless steel brackets and archwires. Br J Orthod. 1995 May;22(2):145-53.
[27] Khambay B, Millett D, McHugh S. Evaluation of methods of archwire ligation on frictional resistance. Eur J Orthod. 2004 Jun;26(3):327-32.
[28] Jang TH, Kim SC, Cho JH, Chae JM, Chang NY, Kang KH. The comparison of the frictional force by the type and angle of orthodontic bracket and the coated or non-coated feature of archwire. Korean J orthod. 2011 Dec 1;41(6):399-410.
[29] Samorodnitzky-Naveh GR, Redlich M, Rapoport L, Feldman Y, Tenne R. Inorganic fullerene like tungsten disulfide nanocoating for friction reduction of nickel-titanium alloys. Nanomedicine (Lond). 2009 Dec;4(8):943-50.
[30] Tselepis M, Brockhurst P, West VC. The dynamic frictional resistance between orthodontic brackets and arch wires. Am J Orthod Dentofacial Orthop. 1994 Aug;106(2):131-8.
[31] Edwards IR, Spary DJ, Rock WP. The effect upon friction of the degradation of orthodontic elastomeric modules. Eur J Orthod. 2012 Oct;34(5):618-24.
[32] Dowling PA, Jones WB, Lagerstrom L, Sandham JA. An investigation into the behavioural characteristics of orthodontic elastomeric modules. Br J Orthod. 1998 Aug;25(3):197-202.
[33] Bortoly TG, Guerrero AP, Rached RN, Tanaka O, Guariza-Filho O, Rosa EA. Sliding resistance with esthetic ligatures: an in-vitro study. Am J Orthod Dentofacial Orthop. 2008 Mar;133(3): 340.e1-7.
[34] Voudouris JC. Interactive edgewise mechanisms: form and function comparison with conventional edgewise brackets. Am J Orthod Dentofacial Orthop. 1997 Feb;111(2):119-40.
[35] Bazakidou E, Nanda RS, Duncanson MG Jr, Sinha P. Evaluation of frictional resistance in esthetic brackets. Am J Orthod Dentofacial Orthop. 1997 Aug;112(2):138-44.
[36] Peterson L, Spencer R, Andreasen G. A comparison of friction resistance for Nitinol and stainless steel wire in edgewise brackets. Quintessence Int Dent Dig. 1982 May;13(5):563-71.
[37] Kapila S, Angolkar PV, Duncanson MG Jr, Nanda RS. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. Am J Orthod Dentofacial Orthop. 1990 Aug;98(2):117-26