

**COMPARATIVE EVALUATION OF FRICTION AND
FRICTIONLESS MECHANICS IN SELF-LIGATING
BRACKETS – A FEM STUDY**

DISSERTATION

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By

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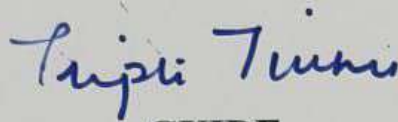
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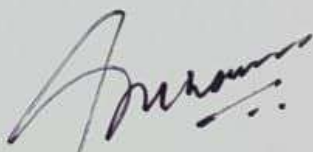

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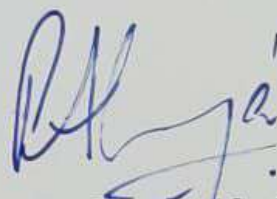
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LIST OF ABBREVIATIONS

S.NO	ABBREVIATED FORM	FULL FORM
1.	CBCT	Cone-beam computed tomography
2.	CAD	Computer-aided design
3.	SLB	Self Ligating Bracket
4.	SS	Stainless steel
5.	TMA	Titanium Molybdenum Arch wire
6.	NiTi	Nickel Titanium
7.	FEM	Finite Element Method
8.	CR	Centre of resistance
9.	MPa	MegaPascal
10.	mm	Millimetre
11.	Group I a	Loop mechanics with 250 g force.
12.	Group I b	Loop mechanics with 200 g force.
13.	Group II a	Sliding mechanics with 250 g force.
14.	Group II b	Sliding mechanics with 200 g force.
15.	N	Newton.
16.	g	Grams.

Aim: To evaluate and compare the stresses and displacement in anterior and posterior segment during enmass space closure with loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system.

Material and Method: A maxillary arch was modeled on the basis of CBCT images using Fusion 360 software. Passive self ligating bracket (0.022 slot), molar tube, NiTi closed coil spring, crimpable hook, stainless-steel archwire of 0.019" X 0.025" inch and Mushroom loop arch wire of 0.019" X 0.025" inch TMA fabricated on typhodont was scanned and CAD model was made. SOLIDWORKS modeling software was used for construction of geometric model and FEM models were made using HYPERMESH. Maxillary arch with bonded passive self ligating bracket along with placement of 0.019" x 0.025" TMA mushroom loop arch wire was simulated. Enmass space closure was attempted with frictionless mechanics using a mushroom loop placed between the canine and 2nd premolar bracket. Maxillary arch model with bonded passive self ligating bracket along with placement of 0.19x0.25 stainless steel wire with crimpable hook attached between Lateral Incisor and canine bracket was simulated. Enmass space closure was attempted with frictional mechanics using a using NiTi closed coil spring stretched between crimpable hook and auxiliary hook on molar tube.

Two FEM model was constructed and boundary conditions was applied. Variable forces (200 g and 250g) were simulated by software for each group. Stress and displacement in X, Y and Z axis was measured.

Result: Enmass retraction of anterior teeth was more in sliding mechanics than loop mechanics at each force level. Anchorage taxation was more in sliding mechanics than loop mechanics at each force level. For either of the mechanics displacement increased as force increased both for anterior and posterior segment. In all models stress was more at occlusal surface than at apex of all teeth suggestive of tipping of teeth in the anterior segment. Von Mises stress in the cancellous bone and cortical bone was higher for sliding mechanics in comparison to loop mechanics for both the forces. Stress on PDL was more for loop mechanics than sliding mechanics.

Conclusion: Loop mechanics is equally effective for retraction of anterior teeth using self ligating brackets and type of mechanics must be decided as pre individual case requirement.

Key words: Loop mechanics, Sliding mechanics, Self ligating brackets, Friction.

Orthodontic tooth movement occurs when applied force overcome the friction between the bracket and archwire. Friction has been defined as the resistance to movement when an object is moved with respect to another one and it operates at the direction opposite to the movement on contact surfaces.^[1] Friction is an important criterion during space closure in orthodontics. Enmasse retraction of anterior teeth during space closure can be achieved through two types of mechanics i.e., frictionless (loop) mechanics or friction (sliding) mechanics.^[2]

Loop mechanics is considered as frictionless mechanics where anterior teeth are retracted by activation of loops placed in extraction space and the wire does not slide in the brackets as it does in the continuous archwire used in sliding mechanics.^[2] Space closure by this mechanics is accomplished using vertical loop, T loop^[3], mushroom loop, opus loop, snail loop, K-SIR (Kalra simultaneous intrusion and retraction)^[4] etc. The placement of loop varies based on the required tooth movement and the mechanics chosen. The superiority of the "T" loop to the vertical loop was well established in delivering high moment to force ratio and low load deflection rate, thus is used commonly for space closure in loop mechanics achieving more controlled movement with higher activation. The Mushroom loop advocated by Nanda is an adaptation of T loop where length of the horizontal arm was reduced and was more curved in comparison to T loop making it more comfortable for the patient. He advocated mushroom loop to be better than the T loop as it produces increased moment to force ratio and lower force levels, thus providing faster and more controlled space closure thereby increasing its popularity for space closure using loop mechanics. Hence it was decided to evaluate space closure using mushroom loop in present study.^[5]

Sliding mechanics involves frictional mechanics. As a continuous arch wire moves through posterior brackets during the retraction of anterior teeth, friction arises from direct contact among the bracket, arch wire, and ligature.^[2] Retraction is accomplished using elastics, active tie backs, elastomeric links, NiTi closed coil springs etc. According to previous studies^[6,7] NiTi closed coil springs exhibited the faster rate of space closure, making them a preferred treatment option. Hence it was decided to evaluate space closure using sliding mechanics with NiTi closed coil spring in the present study.

Friction during orthodontic sliding mechanics represents a clinical challenge to the Orthodontists because high level of friction may require the application of higher amount of orthodontic forces which may compromise the amount of Orthodontic tooth movement obtained as well as complicate the anchorage control there by reducing the effectiveness of mechanics.^[8]

There are various factors influencing friction between arch wire and bracket i.e size of the wire, material of the arch wire, ligation technique etc^[9]. Less friction is encountered whenever there is more play between arch wire and bracket as in cases of round and smaller size wire. However, the main requisite for space closure is using wire of higher dimension with less play for adequate three-dimensional control.^[9] Thus, sliding mechanics in brackets with 0.022x0.028 slot is accomplished on 19x25 stainless steel wire whereas for loop mechanics 19x25 TMA wire is preferred. The friction exerted during any mechanics depends on the material of the arch wire as well. As stainless steel has least amount of friction hence it is a preferred material for frictional or sliding mechanics. TMA wire is preferred for loop mechanics despite of high friction as it is a frictionless mechanics and has more spring back and less load deflection rate that is favourable for loop mechanics. Hence 19x25" SS arch wire for sliding mechanics and 19x25 TMA wire for loop mechanics was considered for this study.

In conventional orthodontics, arch wire is tied to brackets and ligation is considered as an established parameter affecting the resistance to applied forces. Ligation is accomplished using ligature wire or elastic ligature ties. Elastic ligature ties provide more friction than SS ligature wire. Iwasaki et al calculated that 31-54% of the total frictional force generated by a premolar bracket moving along 0.019x0.025 stainless steel archwire was due to the friction of ligation and the remaining 46-69% was due to elastic binding.^[10]

The advent of self-ligating brackets was based on the fact that, elimination of ligating wire to tie the wire to bracket slot would reduce friction. Self-ligating brackets have been designed with select accessories like clips or lock gates, which keep the arch wire in the slot, unlike conventional ligation, which is obtained with elastomeric or metallic ligatures.^[12] Self-ligating bracket are comfortable for the patient and have added advantage of less chair side time, elimination of unesthetic discoloration of elastomeric ligature and lighter forces.^[13]

The efficacy of SLB in reducing friction in comparison to conventional brackets has been evaluated, various studies^[12] compared the effect of self-ligating bracket with conventional ligation system using five different brackets (the Aactiva, edgeloock, speed, standard metal and a ceramic bracket) and observed that self-ligating bracket systems displayed a significantly lower level of frictional resistance, less chair side time and improved infection control compared to metal or ceramic brackets^[14]. Another study^[15], also concluded that self-ligating brackets had lower levels of friction in comparison to traditional edgewise brackets^[15]. On the other hand, Emily Ong found no significant difference between the two (SL Damon 3MX brackets and CL Victory Series) and concluded that Ligation technique is only one of many factors that can influence the efficiency of treatment^[16].

It was seen that reduced friction with self-ligating brackets was only in initial stages where play was more between the wire and the bracket slot, however on engaging full dimension wire, reduction in friction was not evident^[17]. In another study frictional resistance was similar between self-ligating bracket and conventional bracket with low friction ligature during space closure with sliding mechanics, however stress was much lesser in passive self-ligating bracket system (Gomez et al)^[1]. The efficacy of SLB during space closure using sliding and frictionless mechanics has not been widely evaluated in previous studies. Various studies have compared self ligating brackets with conventional brackets in terms of rate of anchorage loss molar rotation Incisor inclination etc using sliding mechanics.^[18] However frictionless mechanics have not been studied till date for self-ligating bracket system. Also, as results are controversial in previous studies it was decided to further evaluate efficacy of self-ligating bracket during space closure with two commonly used mechanics that is sliding and loop mechanics.

In Self ligating bracket (SLB) system there are two main designs, based on the mechanism of lid closure i.e. active and passive self-ligating brackets. Active SLBs can apply force on the arch wire, owing to the spring clip, whereas Passive SLBs do not exert any active force.^[11] The reduced friction and forces associated with passive brackets^[8],^[19] can lead to more predictable and controllable stress distribution during orthodontic tooth movement. Another study^[14] reported reduced frictional resistance with passive self ligating bracket (Edgeloock) in comparison to active self ligating bracket (Aactiva, Speed) For stress analysis, passive self-ligating brackets are often

considered preferable. The minimal interference from the passive bracket system allows for a clearer understanding of the biomechanics involved, making it easier to analyse and model in finite element simulations^[1]. this additional advantage was also the reason for selecting passive SLB was preferred in present in vitro study using FEM. Hence it was decided to use passive self ligating bracket in the present study.

Several clinical studies have shown efficacy of SLB however little information regarding pattern of mechanical stresses in tissue around teeth during space closure is available. As quantification of stress is difficult in clinical studies, hence various in vitro methods have been proposed like photoelastic strain analysis, mathematical models, laser holography, strain gauges, FEM etc^[20]. FEM is a mathematical method where in the shape of complex geometric objects and their physical properties are computer constructed and, stress and displacement can be predicted with significant accuracy^[21]. Finite Element Method (FEM) allows for a detailed analysis of biomechanical factors involved in tooth movement and treatment outcome in terms of stress and displacement. It enables simulation of complex interactions between teeth, bones, and orthodontic appliances, providing insights into stress distribution, force application, and structural changes^[22]. Hence, FEM was used for analysing enmasse space closure using friction and frictionless mechanics in the present study.

Optimum orthodontic force during canine retraction using sliding and loop mechanics in conventional brackets depends on difference in friction between arch wire and Bracket and was found to be lesser for loop mechanics in comparision to sliding mechanics^[23]. As self ligating brackets have lower frictional resistance ^[11] hence it is anticipated that amount of stress during space closure would also be lesser. Hence, forces for enmasse space closure might be lesser than those needed conventionally for similar displacement of anterior segment hence it was decided to employ two forces i.e 250 g (regularly recommended for space closure using conventional brackets) and a lesser value of 200 gms of force, so as to see amount of stress and displacement generated using sliding or loop mechanics for space closure in self ligating brackets. Considering this, the aim of the present study was to evaluate and compare sliding (frictionless) and loop (frictional) mechanics in passive self ligating bracket system during enmasse space closure using FEM at two force levels (250, 200 gms).

AIM

To evaluate and compare the stress and displacement in anterior and posterior segment during enmasse space closure with loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system using FEM.

OBJECTIVES

1. To evaluate the stress and displacement in the anterior segment (incisors and canine) during enmasse space closure with sliding mechanics in self-ligating bracket system.
2. To evaluate the stress and displacement in the posterior segment (second premolar, first and second molar) during enmasse space closure with sliding mechanics in self-ligating bracket system.
3. To evaluate the stress and displacement in the anterior segment (incisors and canine) during enmasse space closure with loop mechanics in self-ligating bracket system.
4. To evaluate the stress and displacement in the posterior segment (second premolar, first and second molar) during enmasse space closure with loop mechanics in self-ligating bracket system.
5. To make intra and inter group comparison of stress and displacement for anterior and posterior segment during enmasse space closure with friction (sliding) and frictionless (loop) mechanics in self-ligating bracket system.

For a definitive stable result in enmasse space closure loop and sliding mechanics are the two options. Whenever forces are applied on teeth for various orthodontic movement there is stress build up on the teeth, surrounding periodontal ligaments and bone. And the stress distribution depends on the size and shape of tooth and amount of bone present around the tooth and its root surface. For the purpose of study, the review of literature will cover articles from the following topics-

- Comparison of sliding vs loop mechanics.
- Comparison of conventional vs self ligating brackets.
- Comparison of active vs passive self ligating brackets.
- FEM studies on space closure and self-ligating brackets.
- Effect of ligation and arch wire dimension on friction.

1. **Stolzenberg J (1935)**^[24] introduced self-ligating bracket and described the features of the Russell Lock edgewise attachment, they are generally smoother for the patients because of the absence of wire ligature. The precision arm or the sliding fourth wall accurately locks the arch wire within the dimensions of the slot providing robust ligation and controlled tooth movement.
2. **Kemp DW (1992)**^[15]. compared the frictional forces between self-ligating and traditional edgewise brackets with various archwire size, alloy, or second order angulations. A testing device was created to simulate the clinical scenario in which a maxillary canine is retracted along a continuous archwire during the extraction of a first premolar using sliding mechanics. The findings showed that self-ligating brackets had lower levels of friction at 0° and 10° angulation.
3. **Shivapuja PK, Berger J (1994)**^[14] compared the effect of self-ligating bracket with conventional ligation system using five different brackets (the Activa, edgelock, speed, standard metal and a ceramic bracket). An in vitro and clinical investigation was undertaken to evaluate and compare these distinctly different groups using Instron testing machine. In the first phase instron test was carried out in normal saline solution and the analysed through the Anova analysis. The second portion was designed to evaluate the influence of the elastomeric power module on the translatory movement of teeth. The final phase of the study involved a comparative clinical evaluation of the time required to remove and replace the mode

of ligation. It was observed that self-ligating bracket systems displayed a significantly lower level of frictional resistance, less chair side time and improved infection control compared to metal or ceramic brackets.

4. **Warita et al. (1996)** ^[25] study compared the effects of two orthodontic forces applied to rat molars over 39 days: a light, continuous force of 5 grams and a light, dissipating force of 10 grams. They found that the continuous force resulted in 1.8 times greater tooth movement, indicating its superior effectiveness. Histological observations showed that the periodontal ligament (PDL) subjected to the continuous force appeared to be better preserved in a physiological sense compared to the PDL subjected to the dissipating force.
5. **Read-Ward GE, Jones SP, Davies EH (1997)** ^[12]. The static frictional resistance of three self-ligating brackets and an ordinary steel ligated Ultra-trim bracket were compared by the impact of bracket-archwire angulation, archwire size, and the presence of unstimulated human saliva was investigated. The study showed that all bracket types tested had their static frictional resistance increased with increases in wire size and bracket-arch wire angulation, but self-ligating brackets only did so in certain circumstances when compared to steel ligated brackets.
6. **Kusy RP, Whitley JQ (1999)** ^[26] divided resistance to sliding (RS) into 3 components:
 - a) **friction**, static or kinetic (FR), due to contact of the wire with bracket surfaces;
 - b) **Binding** (BI), created when the tooth tips or the wire flexes so that there is contact between the wire and the corners of the bracket (when a force is applied to a bracket to move a tooth, the tooth tips in the direction of the force until the wire contacts the corners of the bracket, and binding occurs)
 - c) **Notching** (NO), when permanent deformation of the wire occurs at the wire-bracket corner interface. This often occurs under clinical conditions. Tooth movement stops when a notched wire catches on the bracket corner and resumes only when the notch is released.
7. **Rhee JN, Chun YS, Row J** ^[18] –explored the differences between friction and frictionless mechanics for maxillary canine retraction with the use of a new typodont simulation system, the Calorific machine system. Sliding mechanics was carried out along .016” X .022” stainless steel arch wire and a NiTi coil spring. For frictionless mechanics a canine retraction spring (Paul G jessing type) was used.

The patterns of tooth movement obtained with both of these mechanics were measured 5 times each. Friction mechanics were superior to frictionless mechanics in terms of rotational control and dimensional maintenance of the arch. Frictionless mechanics were shown to be more effective at reducing tipping and extrusion. However, the observed differences between the 2 methods were relatively small in terms of their clinical significance, and no differences were found in anchorage control. In conclusion, this study indicated that friction and frictionless mechanics perform similarly.

8. **Dinç M, Gülsen A, Türk T (2000)** ^[27] in his study compared the effects of PG springs and closed coil springs for retracting upper incisors in 36 subjects with Class I or II malocclusions. who had two upper first premolars extracted, creating at least a 3mm space distal to the lateral incisors after canine retraction. These subjects were divided into two groups: the PG group (17 subjects) and the coil group (19 patients). Both groups had their springs activated to generate an initial force of 150 g per side. The study assessed 20 parameters, including the type of movement of anterior and posterior teeth, as well as the time and rate of space closure. Statistical analysis involved Wilcoxon and Mann-Whitney U-tests. the PG group exhibited more pronounced distal movement of the root apex of the incisors compared to the coil group ($P < 0.01$). Notably, the PG springs induced significant incisor intrusion, resulting in a decrease in overbite. In contrast, the coil spring group experienced a significant increase in deep bite.
9. **Thorstenson GA (2002)** ^[28] In this study frictional resistance of conventional bracket and different types of self ligating bracket (1 with a slide, 3 with clips) coupled with 5 kinds of arch wire was measured and compared. For brackets requiring ligation stainless steel ligature wire were used with a ligation force ranging from 200 to 600 cN. It was found that when clearance existed between the bracket and the wire, the self-ligating brackets that were open showed equivalent frictional resistance to the conventional brackets, but the self-ligating brackets that were closed showed no friction. When clearance no longer existed, all brackets showed greater sliding resistance as the angulation was increased. Due to the lack of a ligation force when the slide restrained the archwire, the closed self-ligating brackets' sliding resistances were lower overall than those of conventional brackets.

10. **Hayashi K, Uechi J, Murata M, Mizoguchi I (2004)**^[13] in his study compared the retraction of maxillary canines using sliding mechanics and a Ricketts canine retraction spring. For sliding mechanics a NiTi coil spring with 0.45mm stainless steel wire in a standard edgewise bracket (0.022 x 0.028 inch slot) was used. A Ricketts maxillary canine retractor (Cuspid Retractor, RMO, Denver, USA) and standard edgewise brackets with an 0.018 x 0.025 inch slot were used for loop mechanics. Midpalatal orthodontic implant was used as a measurement reference. Eight patients (three males and five females) underwent examination, utilizing osseointegrated midpalatal implants for maximum posterior anchorage. Tooth movement was assessed by creating impressions of the maxillary arch at each appointment, cast in die stone, and employing a three-dimensional (3D) surface scanning system with a slit laser beam. The findings revealed that 3D analysis using a midpalatal orthodontic implant provided detailed information on canine retraction. Results suggested that a canine retracting force of 1 N or less was more effective for both sliding mechanics and the retraction spring. However, sliding mechanics showed superiority in rotational control compared to the retraction spring.
11. **Hain M, Dhopatkar A, Rock P (2006)**^[29] conducted a in-vitro study to compared the frictional properties, effect of abrasion on module and effect of prolonged exposure to saliva was examined for six ligation methods (regular uncoated, slick [coated], conventional silver, easy-to-tie, silicone-impregnated, and standard silver modules) used with standard stainless steel brackets and 0.019 × 0.025-in archwires, and resistance to movement was measured. Two self-ligating (Speed [Strite Industries, Cambridge, Ontario, Canada] and Damon 2 [Sybron Dental Specialities Ormco, Orange, Calif]) brackets were also tested. The Damon 2 self-ligating brackets produced less friction than the other ligation methods, followed by the coated modules. There was no significant difference between the frictional resistance of brackets ligated with regular uncoated, silicone-impregnated, and easy-to-tie modules. Speed self-ligating brackets produced less friction than regular uncoated, conventional silver, and standard silver modules. The frictional properties of coated modules were not significantly affected by repeating the test 5 times or by storage in saliva for a week. Conclusions: Damon 2 brackets produced no recordable friction of ligation. Coated modules produced 50% less friction than all

other ligation methods except Damon 2. The coating was resistant to the simulated effects of the oral environment. Different methods of human saliva application were found to affect the frictional properties of the coating.

12. **Krishnan M, Kalathil S, Abraham KM (2007)** ^[19] conducted a study to compare the effects of stainless steel, nickel-titanium, and beta-titanium archwires on frictional forces of passive and active self-ligating brackets with a conventional bracket. All brackets had 0.022-in slots, and the wires were 0.019 * 0.025 in. Friction was evaluated in a simulated half-arch fixed appliance on a testing machine. The static and kinetic friction data were analyzed with 1-way analysis of variance (ANOVA) and the post-hoc Duncan multiple range test. Archwire alloy and bracket effects were evaluated with 2-way ANOVA. The results showed that Static and kinetic frictional forces were lower for both the passive and active designs than for the conventional brackets. Maximum values were seen with the beta-titanium archwires, and significant differences were observed between nickel titanium and stainless steel archwires. With the passive or active self-ligating brackets, stainless steel wire did not produce a significant difference, but differences were significant with nickel-titanium and beta-titanium wires. When nickel-titanium and beta-titanium wires are used for guided tooth movement, passive appliances can minimize frictional resistance.
13. **Zhang DQ, Su JH, Xu LY, Zhong PP (2008)** ^[30] investigated the displacement and stress distribution of maxillary anterior teeth during retraction using the finite element method. A three-dimensional finite element model of six maxillary anterior teeth with a straight wire appliance on intermaxillary bone was established in ANSYS 8.1. Oriental preadjusted orthodontic brackets (with a 0.559-mm slot and Kosaka prescription, TOMY, Japan) were used. Retractions in two typical force directions were simulated: case 1 simulated routine anterior tooth retraction by a force of 150g applied between the anterior hook of 2.0 mm and the first molar tube; case 2 simulated anterior tooth retraction by a force of 150 g between the anterior hook of 4.0 mm and the implant 10.0 mm towards the gingiva from the first molar tube. The study concluded that during routine anterior tooth retraction by sliding mechanics, the crown of anterior teeth tends to tip lingually. Retraction force passing near the center of resistance of six anterior teeth makes their displacement and stress distribution more uniform (case 2), but their translation is still

undetectable. Loading on lateral incisors is greater than that on other teeth and stress concentration at its lingual apex should be considered.

14. **Ehsani S, Mandich MA, El-Bialy TH, Flores-Mir C (2009)** ^[31]. conducted this study to compare the amount of expressed frictional resistance between orthodontic self ligating brackets and conventionally ligated brackets in vitro as reported in the literature. The results showed that compared with conventional brackets, self-ligating brackets produce lower friction when coupled with small round archwires in the absence of tipping and/or torque in an ideally aligned arch. Sufficient evidence was not found to claim that with large rectangular wires, in the presence of tipping and/or torque and in arches with considerable malocclusion, self-ligating brackets produce lower friction compared with conventional brackets.
15. **Tominaga JY, Tanaka M, Koga Y, Gonzales C, Kobayashi M, Yoshida N (2009)** ^[32] conducted a FEM study determine optimal loading conditions such as height of retraction force on the power arm and its position on the archwire in sliding mechanics during enmasse retraction. An appliance with 0.018-in bracket slots and an 0.018 _ 0.025-in stainless steel archwire was generated. Power arms were attached to the archwire at sites mesial and distal to the canine bilaterally and perpendicular to the archwire at three different levels (0mm, 5.5mm, 10mm). Titanium mini screws were used for anchorage. When the power arm was placed mesial to the canine, at the level of 0 mm (bracket slot level), uncontrolled lingual crown tipping of the incisor was observed and the anterior segment of the archwire was deformed downward. At a power arm height of 5.5 mm, bodily movement was produced and the archwire was less deformed. When the power arm height exceeded 5.5 mm, the anterior segment of the archwire was raised upward and lingual root tipping occurred. When the power arm was placed distal to the canine, lingual crown tipping was observed up to a level of 11.2 mm.
16. **Kojima Y, Fukui H (2010)** ^[33] In his study utilized finite element simulation to analyze long-term tooth movements in en-masse sliding mechanics as described by McLaughlin and Bennett in a 0.019x0.025" arch wire and bracket width of 3mm. Retraction force of 1 N was applied. Initially, anterior teeth exhibited tipping under retraction forces, followed by a transition to almost bodily movement with friction at the bracket-wire interface. The net force transferred to anterior teeth was around one fourth of the applied force, and mesial force on posterior teeth equaled that on

anterior teeth. Regardless of friction, the movement ratio between posterior and anterior teeth remained consistent. Increased force or reduced friction led to rapid tooth movement, but it also increased tipping of anterior teeth due to archwire elastic deflection. The study concluded that long-term tooth movement couldn't be predicted solely from the initial force system, friction wasn't detrimental to anchorage, and excessive force or reduced friction for faster movement might cause undesirable tipping.

- 17. Ong E, McCallum H, Griffin MP, Ho C (2010)** ^[16] Compared the efficiency of self-ligating (SL) and conventionally ligated (CL) brackets in patients who had undergone premolar extraction during the first 20 weeks of extraction treatment using study models. Forty-four arches received SL Damon 3MX brackets, and 40 arches received either CL Victory Series or Mini-Diamond brackets. The models were evaluated for anterior arch alignment, extraction spaces, and arch dimensions at pretreatment (T0), 10 weeks (T1), and 20 weeks (T2). The results showed no significant difference between the two and concluded that Ligation technique is only one of many factors that can influence the efficiency of treatment.
- 18. Pliska BT, Beyer JP, Larson BE (2011)** ^[34] conducted a study to test the null hypotheses that at clinically relevant amounts of applied moment, there are no differences in the amount of resistance to sliding between self-ligating (Damon3, In-Ovation R, Smartclip,) and conventionally ligated (Victory) brackets on both stainless steel and nickel-titanium archwire of 0.019" x 0.025" dimension. a custom-built device was used to simulate canine retraction mechanics which allowed for simultaneous and continuous measurement of resistance to sliding and applied moment at the bracket-archwire interface. The resistance to sliding at calculated moments of 2000 g-mm and 4000 g-mm was determined and compared between the various brackets and both archwire types. Greater amount of resistance was seen for NiTi arch wire than SS arch wire in all brackets. At low values of applied moment, some statistical differences were found amongst the various SL and CL brackets however, no significant difference was found at higher moments.
- 19. Mezomo M, de Lima ES, de Menezes LM, Weissheimer A, Allgayer S (2011)** ^[35] measured space closure during the retraction of upper permanent canines with self-ligating bracket (smart clip) and conventional (Gemini) brackets of 0.022 x 0.028" slot size. Fifteen patients who required maxillary canine retraction into first

premolar extraction sites as part of their orthodontic treatment were selected. Retraction was performed using an elastomeric chain with 150 g of force. The movement of the canines was based on measurements of the distance between the contact points on the distal surface of the canines and the mesial surface of the second premolars. The rotation of upper canines was represented by the angle formed between the median palatine suture and a line passing through the mesial and distal contact points of the canines. The amount of movement and the rotation of the canines as well as anchorage loss of the upper first molars were evaluated. There was no difference between self-ligating and conventional brackets regarding the distal movement of upper canines and mesial movement of first molars (P, .05). Rotation of the upper canines was minimized with self-ligating brackets (P, .05).

20. **Ansari TA, Mascarenhas R, Husain A, Salim M (2011)** ^[36] evaluated the effectiveness of the power arm in bringing about bodily movement and to determine the ideal length and location of the power arm. A geometric model of the maxillary right canine was constructed and subsequently converted to a finite element model. The study concluded that the attachment of the power arm at the cervical third brought about maximum bodily movement, followed by the middle and incisal thirds. Variations in length of the power arm at different sites of attachment did not bring any change in the outcome.
21. **Huang TH, Luk HS, Hsu YC, Kao CT (2012)** ^[37] - compared the static and kinetic frictional forces generated by various contemporary designs of self-ligating brackets (SLB s) and different wire alloys. Four passive type SLB (Axis, Damon SL, Carriere LX and Smart clip), one active SLB (mini-clippy), and one conventional bracket (OPA-K) were investigated using stainless steel, nickel – titanium, and titanium – molybdenum alloy arch wires of several sizes. The friction forces were measured by sliding on a bracket – wire combination system in an EZ instron testing machine. This study shows that passive SLB s are associated with lower static or kinetic friction forces than those of active SLB s or conventional brackets.
22. **Huang Y, Keilig L, Rahimi A, Reimann S, Bourauel C** ^[38] conducted a FEM study to investigate the torque capacity of conventional and self-ligating brackets under the effect of varying bracket width and free wire length. Finite element models of three kinds of orthodontic brackets in the 0.022-inch slot size were

investigated: Discovery, Damon 3MX, Speed. A torque of 20 was applied to the upper right incisor with $0.46 \cdot 0.64 \text{ mm}^2$ ($0.018\text{¢¢} \cdot 0.025\text{¢¢}$) and $0.48 \cdot 0.64 \text{ mm}^2$ ($0.019\text{¢¢} \cdot 0.025\text{¢¢}$) wires. Wires made of stainless steel, titanium molybdenum and nickel titanium were studied. Torque angle/moment characteristics were recorded.

23. Mangaleswari M (2013) ^[39] – compared the treatment time, outcome, and anchorage loss among orthodontic patients treated by self-ligating brackets (smartclip brackets 3M) and conventional brackets (Preadjusted Victory series 3M). Space closure was performed using sliding mechanics. Pre and post treatment radiographs and dental casts were used to access changes. It was found that the mean treatment time for SLBs (19.19 months) did not show a statistically significant difference from 21.25 months of CBs. There was no difference in anchorage loss between the SLB and CB groups. There were significant dental and skeletal changes among adolescent orthodontic patients regardless of the bracket used. The lingual inclination of the mandibular incisors in the CB group was more than in the SLB group.

24. Kaur G, Goyal S, Rajpal S, Gera A (2013) ^[40] compare the frictional forces generated by three different ligation methods; conventional ligation (Alastik™, 3M), self-ligation and slide low-friction ligation (Slide™, Leone SpA), using Stainless steel (Gemini series, 3M Unitek) Ceramic (InVu, TP Orthodontics) and Self-ligating (Damon SL II, (Ormco) brackets with 0.016" nitinol and 0.019" $\times$ 0.025" stainless steel wires. Frictional force was measured using Instron universal testing machine. Conventional ligation exhibited higher friction than low-friction and self-ligation methods with all the archwire-bracket combinations. Damon self-ligating system exhibited less friction than low-friction ligation with lower archwires and higher friction with higher archwires.

25. Lombardo L, Scuzzo G, Arreghini A, Gorgun Ö, Ortan YÖ, Siciliani G (2014) ^[20] - compared displacements and stress after en masse retraction of mandibular dentition with lingual and labial orthodontics using three-dimensional (3D) finite element models (FEM). GAC Roth Ovation labial and Ormco 7th Generation lingual brackets were virtually bonded to the lower teeth and threaded with 0.018×0.025 - and 0.016×0.022 -in. SS labial (Tru-Arch form, small size) and lingual (mushroom) arch wires. En masse retraction was simulated by applying 300 g of distal force from the canine to the second premolar on the 0.016×0.022 -in. SS

labial and lingual arch wires. Lingual tipping and extrusion of the anterior dentition occurred with both arch wires. At the premolars and first molars, intrusion, lingual movements, and lingual tipping were seen with the labial arch wire, while intrusion was accompanied by labial movements, mesial tipping, and buccal rotation with lingual mechanics.

26. **Monteiro MR, SILVA LE, Elias CN, Vilella OD (2014)**^[9] compared the frictional force resistance as influence of archwire material (NiTi, beta-Ti and stainless steel 0.019"x0.025" wire) and brackets design (self-ligating - Smartclip, 3M/Unitek and conventional - Gemini, 3M/Unitek). The wires were pulled from the bracket slots at a cross-head speed of 3 mm/min until 2 mm displacement. The mechanical testing was performed with a universal testing machine EMIC DL 10000. Self-ligating brackets produced significantly lower friction values compared with those of conventional brackets. Frictional force resistance values were directly proportional to the increase in the bracket/ wire angulation. With regard to conventional brackets, stainless steel wires had the lowest friction force values, followed by nickel-titanium and beta-titanium ones. With regard to self-ligating brackets, the nickel-titanium wires had the lowest friction values, significantly lower than those of other materials.
27. **Kumar S, Singh S, PR RH, Ahmed S, Bhatnagar A, Sidhu M, Shetty P (2014)**^[8] conducted a study to compare frictional resistance which was produced between conventional brackets (0.022 slot Otho-Organiser) and self ligating brackets (active Forestadent and passive Damon III) by using various arch wire combinations (0.016 Niti, 0.018 Niti, 0.017 x 0.025 SS and 0.019 x 0.025 SS). The friction which was generated by the testing unit, which consisted of the wire, brackets and ligation systems was measured under dry conditions and at room temperature by using an Instron testing machine TM Instron Corp, Canton, Mass which had a load cell of 10N. The results showed that Both Damon III and Forestadent brackets produced significantly lower levels of friction as compared to electrometrically tied conventional brackets.
28. **Montasser MA, El-Bialy T, Keilig L, Reimann S, Jäger A, Bourauel C (2014)**^[41] compared conventional and self-ligating brackets in terms of differences in the force loss during simulated archwire guided canine retraction. A conventional ligating brackets (Victory Series and Mini-Taurus), self-ligating brackets

(SmartClip: passive, and Time3 and SPEED: active), and a conventional low-friction bracket (Synergy) all with 0.022" slot size was used with 0.019 × 0.025" arch wires (SS, NiTi and TMA). Stainless steel ligatures were used with the conventional brackets. A superelastic NiTi coil spring (force: 1 N) was used for retraction of upto 4mm. the simulation was carried in Orthodontic Measurement and Simulation System (OMSS). Force loss gradually increased by about 10 per cent for each bracket type in combination with the different wires in the following sequence: stainless steel, NiTi, and TMA. SPEED brackets exhibited the highest force loss with the three wires used and was lowest for the Victory Series and SmartClip brackets with no consistent pattern of force loss when comparing conventional and self-ligating brackets or passive and active self-ligating brackets.

29. **Chaudhari CV, Tarvade SM (2015)** ^[43] compared the clinical effectiveness of nickel titanium (NiTi) closed coil spring and elastomeric chain on rate of space closure in terms of anterior enmasse retraction and anchor loss. 40 Class 1 bimaxillary protrusion patients undergoing fixed orthodontic treatment (MBT 0.022 slot) (Victory series™ Low Profile, 3M Unitek) after first premolar extraction were selected. 0.019 x 0.025 SS wire (G and H wires, USA) with hook of 8 mm in height soldered distal to the lateral incisors were engaged. Group 1 consisted of 20 patients in whom space closure was done with NiTi closed coil springs of 9mm in length stretched to 12mm and group 2 consisted of 20 patients with elastomeric chain. The amount of anterior retraction, anchor loss and rate of space closure was measured at end of 4 months clinically and radiographically. A faster rate of space closure by NiTi closed coil springs when compared with elastomeric chain was observed (P=0.001). Anchor loss was more with NiTi springs (1.1mm) as compared with elastomeric chain (0.82mm).

30. **Choudhary A, Bapat SM, Gupta S (2015)** ^[44] The M-Loop in orthodontics presents advantages over simpler designs by delivering lower and more consistent forces. This is achieved through the addition of wire in the archival configuration at the apex, which reduces the rate at which force is applied during tooth movement. Additionally, the original shape enhances the applied moment when the spring is activated. These combined effects result in a higher M/F (moment to force) ratio, enabling better control of tooth movement and anchorage. Furthermore, the use of CNA beta-titanium, recommended for the M-Loop, offers the benefit of lower

stiffness in comparison to stainless steel, ensuring a more uniform and steady force application throughout orthodontic treatment.

- 31. Prem N, Mascarenhas R, Husain A, Hashim A (2017)**^[23] – in his FEM evaluated the stress related changes in the PDL and to determine the optimum orthodontic force for both sliding (0.018” SS and 0.019”x0.025” SS) and loop mechanics (0.019X0.025” Beta titanium wire) and to determine efficacy of two loop designs namely T – loop and Tear Drop loop. The brackets considered for the study were the 3M MBT 0.22 X 0.25 inch slot brackets. In loop mechanics, at 200 grams of force the T loop design was found to be the better loop design than the Tear drop. The stress patterns clearly indicate that the optimum orthodontic force for canine retraction using sliding mechanics is 210 grams and for loop mechanics is 200 grams. In sliding mechanics, the use of 0.019 × 0.025-inch rectangular arch wire showed bodily movement while the use of round 0.018-inch arch wire only showed tipping of canine.
- 32. Makhoul M, Aboul-Ezz A, Fayed MS, Hafez H (2018)**^[47] compared the amount of tooth movement during canine retraction with friction mechanics (NiTi closed coil spring) versus frictionless mechanics (T – loop 0.017 X 0.025 TMA wire), and their effect on root resorption. 10 pts in a split-mouth design with maxillary 1st premolar extraction were chosen. A force of 150 g was applied. The force was measured and activated to keep it constant all over the retraction phase. Pre and post treatment CBCT scans were used to analyse the results. the NiTi coil spring side showed more distal movement than the T - loop side.
- 33. Gómez-Gómez SL, Sánchez-Obando N, Álvarez-Castrillón MA, Montoya-Gómez Y, Ardila CM (2019)**^[1] – conducted a fem study to compare the frictional force resulting from the bracket/arch wire interface and the stress at the root/periodontal ligament/bone interface, between passive self-ligating brackets (smartclip) and conventionally ligated brackets (logic line), during the space closure stage with different arch wire types. Stress was used as an indicator of the frictional resistance of these systems. Results showed similar frictional stress (0.50 MPa for SmartClip, 0.64 MPa for Logic Line) while using 0.019x0.025” SS wire but lower load transmission to the periodontal ligament with passive self-ligating brackets. Low-friction ligatures exhibited similar bracket/archwire friction but less stress on the bone/root interface with passive self-ligating brackets.

34. **Cai Y (2019)**^[48] aimed to assess how various archwire characteristics influence the movement of canine teeth and the stress experienced by the periodontal ligament (PDL) during self-ligating orthodontic treatment using finite element analysis. The research involved creating models representing teeth, supporting tissues, brackets, and archwires, and ten different archwires were analyzed. The findings revealed that, in the case of translation movement, increasing the cross-section area of the archwire resulted in higher maximum displacement, stress, and a parameter called Rcr. Additionally, higher friction coefficients between the bracket and archwire led to increased maximum displacement and stress. Notably, the effects varied based on archwire type (round or rectangular) and movement type (rotation or inclination).
35. **Ferreira MD, Rodrigues FR, Luersen MA, Borges PC, Nanda R, Almeida MR (2019)**^[49] conducted a FEM study to analyse the von Mises stresses on Mushroom loop archwires. Mushroom archwires made of titanium-molybdenum alloy with 0.017 x 0.025-in cross-section were used in this study. A YS of 1240 MPa and a Young's modulus of 69 GPa were adopted. The activation was performed in increments of 1.0 mm in the horizontal direction up to 5.0 mm, and considered maximum when, at any point, the archwire material reached its YS (Yield Strength) limit and, consequently, suffered permanent deformation, and the simulation process was terminated. : Tensions revealed a maximum of 1158 MPa at the whole part of the loop at 5.0mm of activation, except in a very small area situated at the top of the loop, in which a maximum of 1324 Mpa was found. Mushroom loops are capable to produce tension levels in an elastic range and could be safely activated up to 5.0mm.
36. **Goyal V, Singh G, Izhar A, Singh R, Gupta N(2019)**^[50] – conducted a study to evaluate and compare the rate of space closure and incisor retraction between mushroom loop CNA arch wire and sliding mechanics with indirect anchorage from miniscrews by placing them between first and second molar. A series of models from each patient was used to assess the change in the position with the help of a digital scanner and later superimposed to evaluate the changes. Results showed that Sliding mechanics is better than loop mechanics in anterior retraction and reducing proclination with faster space closure. Loop mechanics was found to be better in torque control and preventing bite deepening during retraction.

- 37. Rashika MD, Priya MD, Devaki V MD, Balaji R MD (2020)**^[2] – evaluated the measure of tip, rotation, anchorage loss and rate of retraction during the retraction of upper permanent canines with conventional Roth brackets and synergy Roth brackets using frictionless mechanics (paul g Jessing spring) with 100 gm of force. The results were evaluated on dental casts. The study concluded that the rate of canine retraction was statistically and clinically significant with Synergy Roth brackets but there was no Statistical difference between Conventional Roth and Synergy Roth brackets regarding the tip, rotation and anchorage loss.
- 38. Tawfik MG, Izzat Bakhit DM, El Sharaby FA, Moustafa YA, Dehis HM (2022)**^[51] – conducted a study to evaluate the effect of friction vs frictionless mechanics on the rate of anterior segment retraction (ASR) in patients with bimaxillary protrusion. Thirty females (18.3 ± 3.7 years) with bimaxillary protrusion were randomly allocated into the friction group, using elastomeric power chains, and the frictionless group, using T-loop springs for ASR. Activations were done every 4 weeks until completion of ASR. The primary outcome was the rate of ASR measured on digital models. Anchorage loss, molar rotation, and pain experienced were also assessed. The rate of ASR was 0.68 ± 0.18 mm/mo in the friction group vs 0.88 ± 0.27 mm/mo in the frictionless group, with no significant difference. A significant difference in anchorage loss of 1.63 mm and molar rotation of 7.06° was observed, being higher in the frictionless group. A comparable pain experience associated with both mechanics was reported.
- 39. Dragomirescu A.O. et al (2022)**^[17] conducted a study to determine the differences between the static frictional forces generated by stainless steel (metallic) Mini Sprint, Forestadent and polycrystalline alumina (ceramics) Discovery Pearl, Dentaaurum conventional and self-ligating brackets (Damon Q, Damon Clear Ormco). The brackets were tested with ovoid archwires (AlphaWire, Orthofocus, Bucharest, Romania) with different sizes and materials, respectively, 0.016" NiTi and 0.019×0.025 " SS. Static friction assessment was carried out in vitro with universal testing machine, HV-500N-S (Schmidt Control Instruments, Hans Schmidt & Co. GmbH), intended for measuring compression and traction forces. The study revealed significant differences in static frictional forces at the bracket-archwire interface between the tested brackets. Stainless steel brackets produced lower static friction forces than polycrystalline alumina and self ligating brackets

generally produced lower static frictional forces than conventional brackets. The reduction of frictional forces was noticeable in the first stages of treatment, when thin, flexible orthodontic archwires (0.0160 0 NiTi) are used. Engaged with large rectangular stainless steel archwires, (0.019 – 0.0250 0 SS), the frictional forces produced by conventional and self-ligating metal brackets were similar, no significant differences being observed between the two types of metallic design. However, in the case of tested ceramic brackets, the results showed that the self-ligating type allows a reduction in frictional forces even in advanced stages of treatment compared to conventionally ligation.

40. **Shibl LA, Attia AM, El-Beialy AR, Mostafa YA, Dehis HM (2023)** ^[53] compare the rate of en-masse retraction using friction versus frictionless mechanics. Anchorage loss, molar rotation, changes in the incisor position, and pain was additionally assessed. Twenty-eight patients were randomly allocated into two en-masse retraction groups using friction (group A) or frictionless (group B) mechanics. Eligibility criteria included maxillary dentoalveolar protrusion requiring maxillary 1st premolars extraction with maximum anchorage. In group A, power-chains of 200 g retraction force on 0.017" x 0.025" SS archwire and 9 mm crimpable hook were utilized. Group B comprised of T-loops using the same gauge TMA archwires and comparable force. One mini screw was inserted per quadrant for anchorage. Measurements were made on scanned 3D models, superimposed on one another, as well as pre-treatment and post-retraction cephalograms. It was a single-blinded study where the outcome assessors were blinded. For the friction group, the rate of retraction was 0.63 ± 0.18 mm per month, with a total retraction of 4.04 ± 1.41 mm spanning over 6.42 ± 1.08 months. The frictionless group was 0.75 ± 0.23 mm per month with a total retraction of 4.13 ± 1.44 mm, over 5.67 ± 1.5 months. Frictionless mechanics was only slightly faster than friction mechanics regarding the rate of retraction, not enough to make a significant difference between the two groups. Frictionless mechanics is not recommended in cases with great anchorage needs, as the molars tend to move and rotate mesially during retraction, regardless of the presence of miniscrews.
41. **Ponnar CK, Purusothaman D, Tandon A, Angrish N, Praveen K, Chandrasekharan (2023)** ^[54] – in mushroom loop the load deflection rate is reduced as it produces lower and more continuous forces. The wire specifications

are 0.017" x 0.025" CNA, while 0.016" x 0.022" may be recommended for individuals needing lower force levels. The loop can be activated up to 5 mm after it is engaged.

42. **Sardana R, Chug V et al (2023)** ^[55] compared the rate of retraction and anchorage loss during en-masse retraction of anterior maxillary teeth between friction mechanics and frictionless mechanics. Thirty-eight patients requiring en-masse retraction of protruded anterior maxillary teeth were randomly allocated into FM and FLM groups. En-masse retraction with sliding mechanics (FM) (38 patients) using an elastomeric chain was compared with continuous mushroom loop archwire mechanics (FLM) (38 patients). Study models and lateral cephalograms were taken before (T1) and immediately after retraction (T2). Intergroup comparison was performed using an independent t test. The intragroup comparison showed significant anchorage loss in FM (2.28 mm) and FLM (1.13 mm) groups; however, the intergroup comparison showed no statistically significant difference ($P = .093$). Vertical movement of the maxillary incisor and first molar showed no significant difference between FM and FLM groups. Hence concluding that the rate of en-masse retraction and anchorage loss was comparable between the FM and FLM groups. Significant anchorage loss was seen with both mechanics. The result suggests that both the mechanic group require external reinforcement to prevent anchorage loss.

This in-vitro FEM study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, Babu Banarasi Das college of Dental Sciences, Lucknow in collaboration with AnaMacDesign, to evaluate and compare the stress and displacement in anterior and posterior segment during enmasse space closure with loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system using FEM.

The approval was taken from the Ethical Committee of Babu Banarasi Das College of Dental Sciences, before conducting the study. Since the FEM study is an in-vitro study, patient consent was not required for conducting the study.

MATERIALS:

In this study, the following material were used:

1. For construction of CAD model.

- A Cone Beam Computed Tomography (CBCT) scan of an adult skull, for maxillary jaw was taken. (Figure 1)
- A maxillary arch with extracted right and left first premolars was modelled with the help of CBCT images.
- CBCT output was converted into a Stereolithographic (STL) file and was sent for further processing.
- Using the data from CBCT scans, two CAD model were constructed in order to create a finite element model of full maxillary arch.

2. Brackets and tube. (Figure 2)

- a) Passive self-ligating bracket kit for maxillary arch (0.022" X 0.028" slot Damon Q2 Ormco Corporation)
- b) Bondable buccal tubes (Triple slot) for first and second molar (0,022" x 0.028") for both right and left side.

3. Materials used for sliding mechanics (Figure 3)

- a) **Archwire** - 0.019"X 0.025" Preformed Stainless steel (SS) arch wire.
- b) **Crimpable hook** – stainless steel crimpable hook (SS) of 7 mm height.
- c) **Niti closed coil spring** – 9 mm length and 0.030" lumen size.

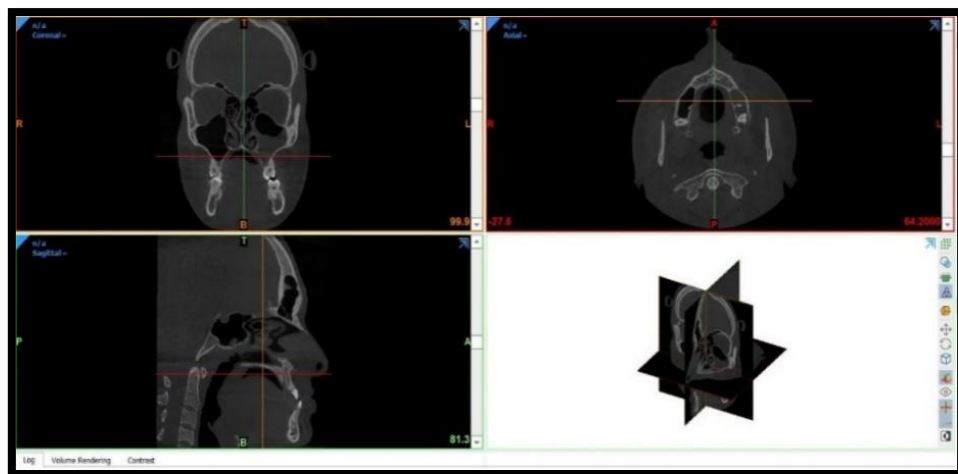


Figure 1: CBCT images of the maxilla used for the study.



Figure 2: a) Passive self ligating brackets, b) buccal tube.

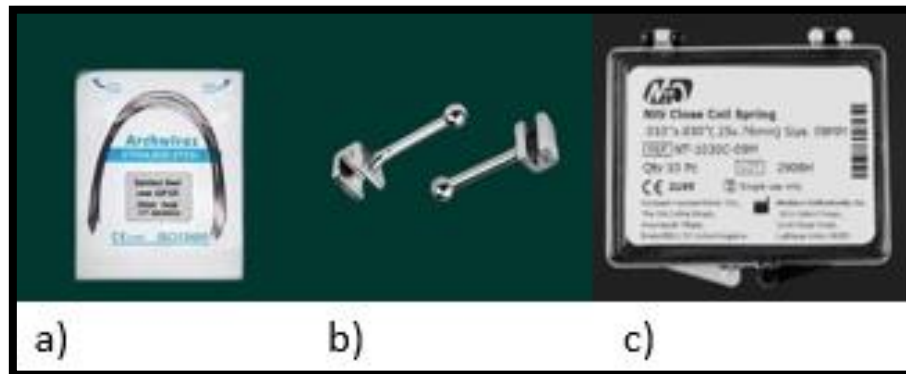


Figure 3: Materials used for sliding mechanics.
a) SS arch wire, b) crimpable hook, c) NiTi closed coil spring.

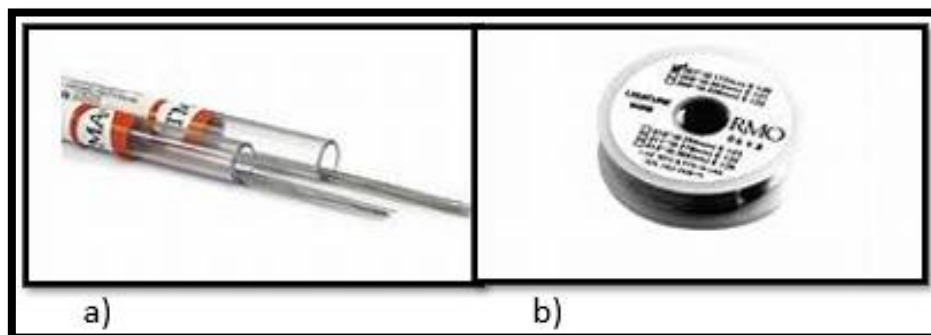


Figure 4: Materials used for loop mechanics.
a) TMA wire used for loop mechanics, b) ligature wire.

4. Materials used for Loop mechanics (Figure 4a)

0.019''X 0.025'' Titanium Molybdenum (TMA) straight length wire to fabricate mushroom loop.

5. Ligature wire (Figure 4b)

Soft stainless steel wire of 0.009'' diameter.

6. Software used for creating and analyzing FEM (Finite Element Method).

a. Fusion 360

- Fusion 360 was used to convert CBCT into STL format.
- Fusion 360 modeling software was used for the construction of geometric model.

b. Solid works.

- 3D scanning of the Damon Q2 brackets, SS arch wire, TMA arch wire with mushroom loop, crimpable hook and NiTi coil spring to make the CAD model was done.

c. HYPERMESH 2019

- It was utilized to generate mesh models and number of nodes and elements count.

d. ANSYS software

- To calculate stress and displacement.
- Application of load and boundary condition.
- To integrate the model of the maxilla with the periodontal ligament (PDL), bone, and other components.
- To carry out the simulation of applied loads after applying boundary conditions.
- To simulate the finite element results, create result images, and extract information about stress and displacement.

Methodology

Construction of Finite Element Model generally involves the following steps:

1. Pre-Processing (Meshing):

- Finite element modelling will be done using suitable element type & size.
- Respective material properties will be assigned.
- Stringent element quality parameters will be followed for the better accuracy of the results
- Boundary Conditions & respective load & constraints will be applied.

2. Finite Element Solution / Solver:

- FE model will be solved for Structural analysis.

3. Post-processing/ Result Interpretation

- Pictorial and/or Tabular representation of the stresses. The stress flow in each component will be plotted.

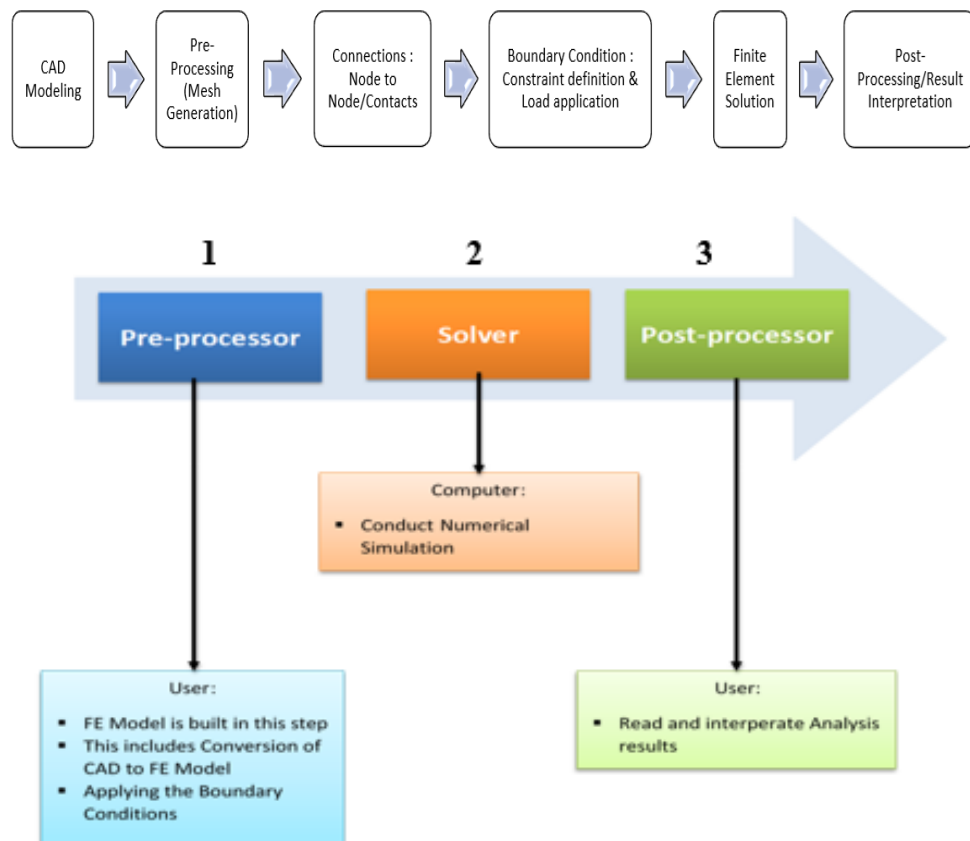


FIGURE 6: Flow chart showing construction of finite element model and processing of results.

In the present study, the following steps were involved for the finite element study:

1. Generation of the CAD Model
2. Construction of the geometric model.
3. Conversion of the geometric models to a finite element model.
4. Incorporation of material properties.
5. Defining boundary condition.
6. Loading configuration.
7. Translation of results and interpretation.

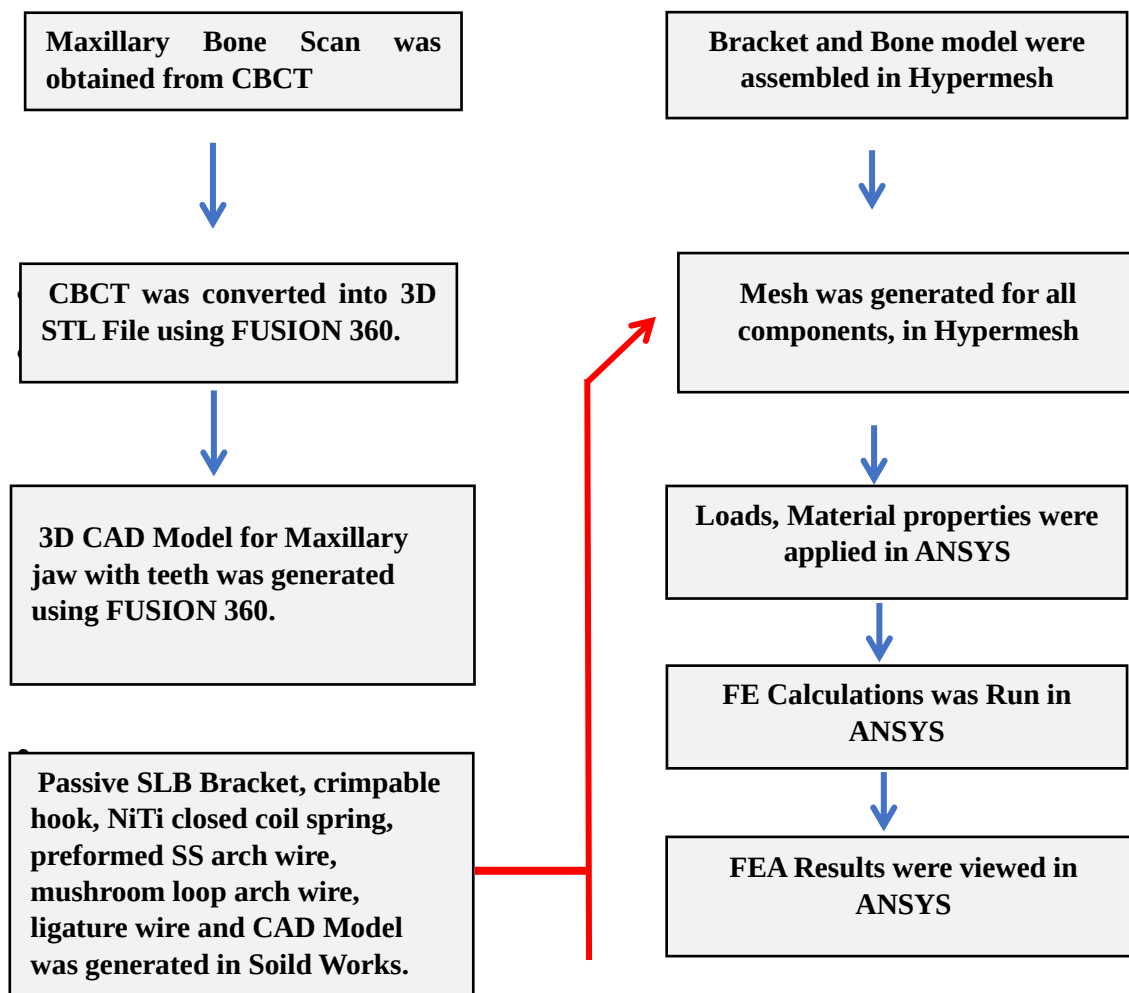


FIGURE 7: Schematic flowchart showing the steps involved in the stu

1. Generation of STL file of maxilla. (Figure 8)

A CBCT scan of normal adolescent skull without any skeletal defects, trauma, lesions, and with all of teeth up to second molars, taken parallel to the Frankfort plane in the axial orientation. were obtained from the archives of a reputed CBCT scan centre. DICOM files were the output of the scan at 0.5 mm intervals. These files were imported into Fusion 360 Software to develop a 3D model (Steriolithography STL file). Different parts like teeth, jawbone etc. were then extracted from fusion 360 Software by separating them based on bone density. This STL file was exported from fusion 360 Software.

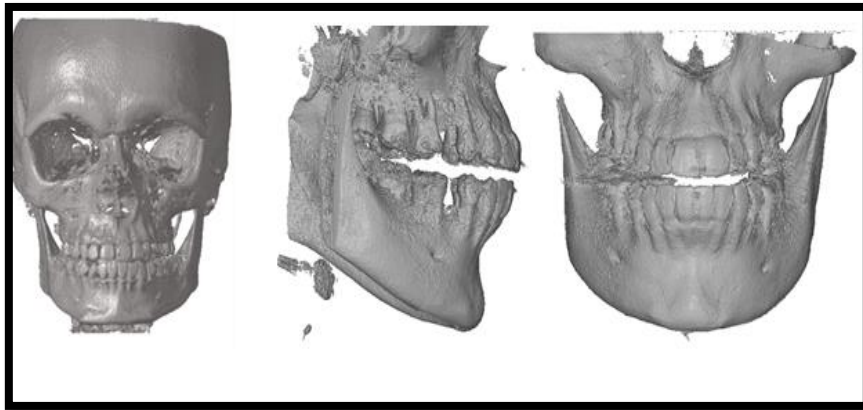


Figure 8: STL Model of maxilla.

2. Construction of the CAD model of the maxillary arch.

Files in stereo-lithography (STL) format were converted into CAD model of maxilla using FUSION 360 software. CAD model was exported to 3D image processing and editing software- 3D-Doctor (Able Software Corp., Lexington, Massachusetts, USA. This bone model was then imported in HyperMesh for incorporation of material properties and creating finite element model (Figure 9).

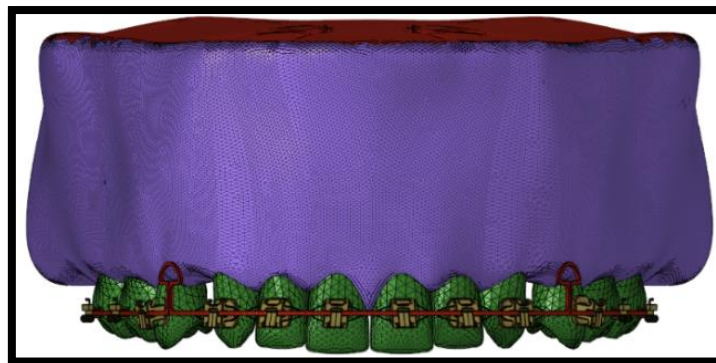


Figure 9: Finite Element model of the maxillary arch

3. Construction of 2 geometric models of maxillary bone with the whole assembly for the study.

Geometric model of individual components i.e. brackets and tubes was made using Fusion 360 software. (Figure 10).

Two geometric models of maxilla along with complete assembly of components were grouped as follows:

GROUP 1 – Maxillary arch with bonded passive self ligating bracket along with placement of 0.019” x 0.025” TMA mushroom loop arch wire was simulated. Enmasse space closure was attempted with frictionless mechanics using a mushroom loop placed between the canine and 2nd premolar bracket.

Before fabrication of CAD model of group 1, fabrication of mushroom loop is explained by following these steps:

1. Start with a straight 0.019” x 0.025” TMA (Titanium Molybdenum Alloy) wire.
2. Used a Dela Rosa plier to give an arch form. (Figure 11b)
3. Mark a point in the middle of the extraction space for loop creation. (Figure 11c)
4. Using a bird beak plier mushroom loop was fabricated on both sides with the dimensions specified in (Figure11d).

Similar steps were performed for construction of the geometric model of the mushroom loop arch wire using the FUSION 360 software. (Figure11 e,f). Complete geometric model for group 1 is shown in Figure 12.



Figure 10 – a) Passive self ligating bracket b) buccal tube.

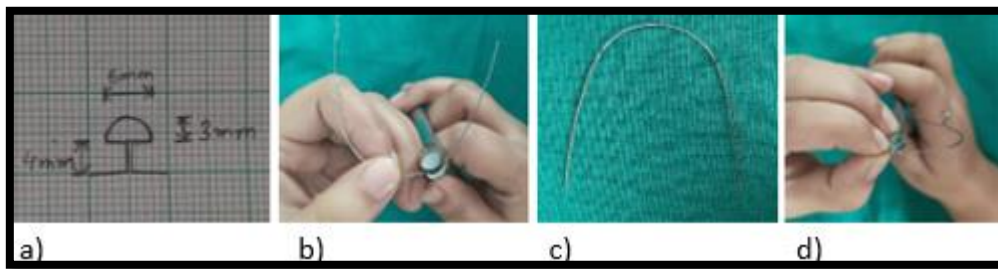


Figure 11 – Fabrication of mushroom loop(a-d).

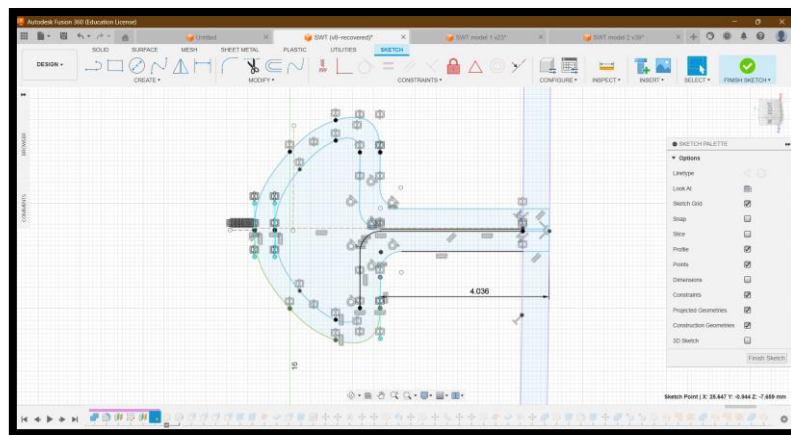


Figure 11 e – construction of Geometric model of mushroom loop using FUSION 360 software.

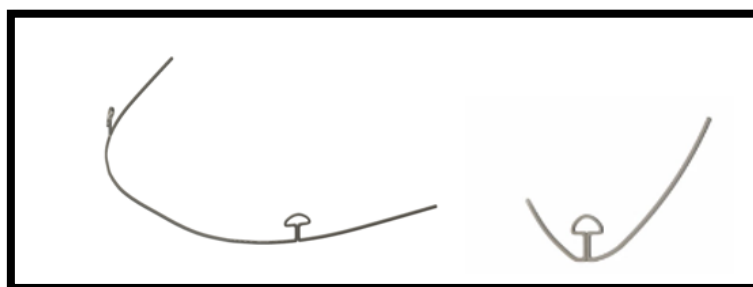


Figure 11 f – Geometric model of mushroom loop.

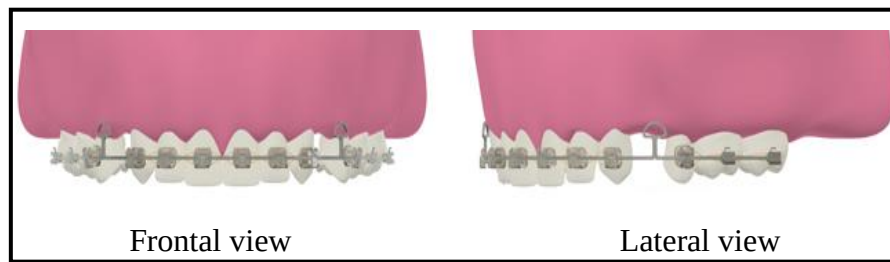


Figure 12: Geometric model of maxilla for retraction of anterior teeth with loop mechanics.

GROUP 2 – Maxillary arch model with bonded passive self ligating bracket along with placement of 0.19x0.25 stainless steel wire with crimpable hook attached between Lateral Incisor and canine bracket was simulated. Enmasse space closure was attempted with frictional mechanics using a using NiTi closed coil spring stretched between crimpable hook and auxiliary hook on molar tube. Complete geometric model for group 2 is shown in (Figure 13).

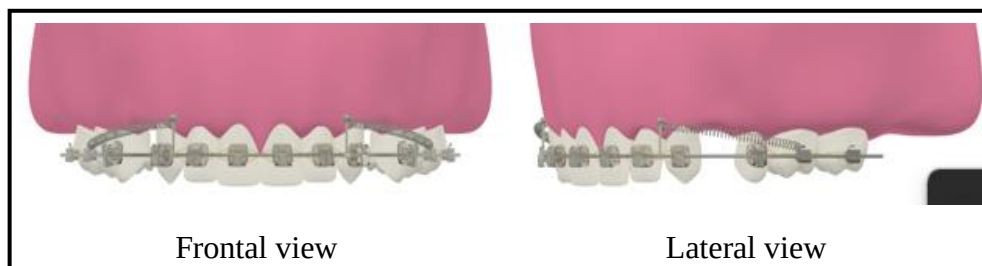


Figure 13: Geometric model of maxilla for retraction of anterior teeth with sliding mechanics.

4. Conversion of the geometric models to a Finite element model

With the help of HyperMesh Software, the geometric models were converted into finite element models and this process is called meshing or mesh generation. Meshing is nothing but to discretize, or divide, the complex geometry into a collection of manageable, smaller "elements" with finite dimensions (2D or 3D). The intersections of two or more distinct components are known as nodes or nodal points. The perimeter nodes are the main primary exterior nodes. The additional nodes that show up on an element's edges are called secondary external nodes. As compared to corner nodes, the secondary nodes have less movement. The finite element model represents geometry in terms of finite elements and the nodes that could be tetrahedron, pyramid, triangular Prism and Hexahedron. This process is called

“discretization.” Number, size and type of element are decided. Practical knowledge and judgement are needed to limit the number of elements to minimum amount conducive to acceptable results. (TABLE 1) represent the number of nodes and elements of the present FEM study. In this study, to model the irregular geometry of the teeth, maxilla, wire, bracket, crimpable hook and NiTi closed coil spring, 4-noded tetrahedral shape was selected as the finite element and for modeling a 3-D Quad mesh was used. (Figure 14, 15 & 16)

Component	No. of Nodes	No. of elements
Teeth	38292	174299
Periodontal Ligament (PDL)	61781	183928
Jaw bone	58195	281737
Brackets	38292	174299
TMA loop Arch Wire	3635	11462
SS Arch Wire	17966	72063
NiTi closed coil spring	43480	129260
Ligature wire	130605	507695

Table 1 – Elements and nodes count for individual component.

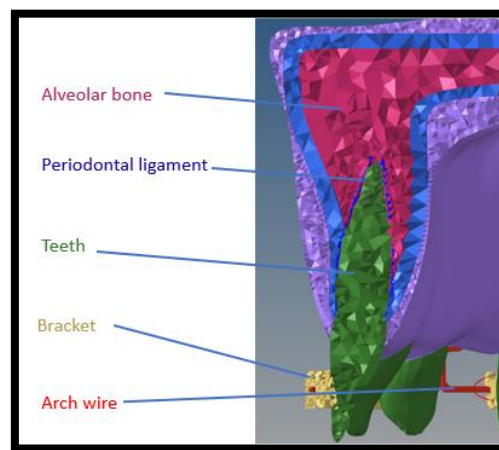


Figure 14: Final finite element model of maxillary arch.

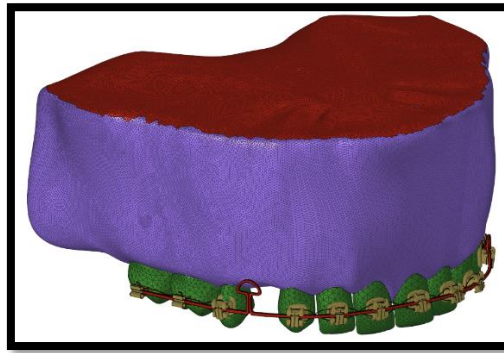


Figure 15: Final finite element model of maxillary arch for retraction of anterior segment with loop mechanics.

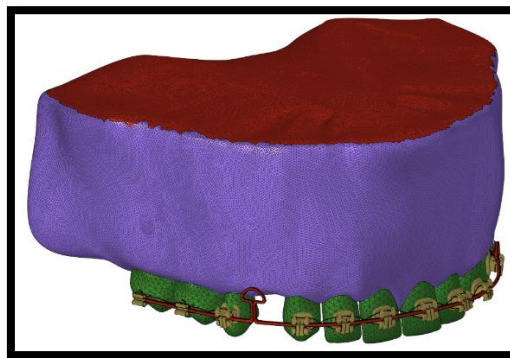


Figure 16: Final finite element model of maxillary arch for retraction of anterior segment with sliding mechanics.

5. Incorporation of material properties

The material properties of teeth, cortical bone, cancellous bone, SS wire, TMA wire, NiTi closed coil spring, crimpable hook, brackets and buccal tube were taken as per the average values reported in literature. All materials employed for the finite element model study were taken to be isotropic, homogenous, and linearly elastic and material properties are shown in (Table 2)

MATERIALS	YOUNG'S MODULUS (Mpa)	POISSON'S RATIO
Teeth	20,000	0.30
Periodontal ligament	0.05	0.30
Alveolar bone	2,000	0.30
Cortical bone	13,700	0.30
Cancellous bone	1,600	0.30

Stainless steel self ligating bracket / molar tube/ arch wire / crimpable hook.	2,00,000	0.30
TMA arch wire	42,840	0.30
NiTi closed coil spring	80000	0.30

Table 2: Material properties as used in present study

6. Defining boundary condition

Validation of Model:

This step served as a FEA trial run. It served as a testing ground for constituent quality. In order to enhance the element quality, the model's Warpage, Aspect Ratio, and tet Collapse element qualities were examined.

The Finite Element Model's general mesh quality might benefit from local re-meshing in some places. All of this was done to make sure the generated mesh/element quality is within the FEA Solver's permissible range. Both Maxilla models underwent this procedure.

Application of Boundary Conditions

Boundary Conditions define the way model is held or fixed in the FE space & the way forces are applied on the model.

Fixing the Model:

Model need to be fixed at a point in FEA. Following image (Figure 17) gives details on how the model was fixed in this study.

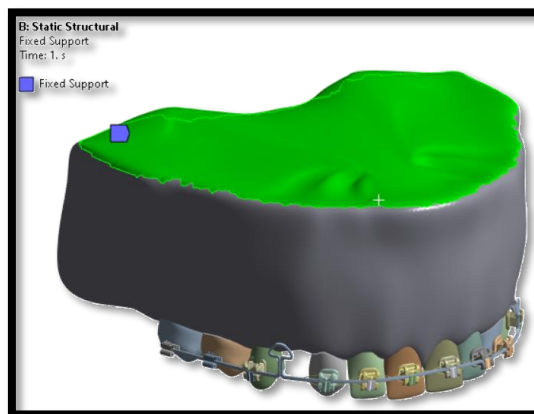


Figure 17: Boundary fixing of maxilla.

As per FEM, nodes on the selected surfaces were locked in all Degrees of Freedom.

This restricted the displacement of these nodes in all direction. This way model was locked / fixed in the FEA space for solving.

Force Application:

A variable sagittal load on the anterior segment to simulate enmasse retraction of the anterior teeth by loop mechanics and sliding mechanics was simulated using ANSYS software.

7. Loading Configuration

Based on loading configuration each given model was subdivided into subgroups as follows.

Group 1 - FEM model where enmasse retraction was attempted using a mushroom loop by applying 200 g (subgroup 1 A) and 250 g (subgroup 1 B) of force.

Group 2 - FEM model where enmasse retraction was attempted using Niti closed coil spring by applying 200 g (subgroup 2 A) and 250 g (subgroup 2 B) of force.

Table 3: Showing group distribution.

		GROUP 1 (Loop)		GROUP 2 (Sliding)	
		Group 1 A (200 g)	Group 1 B (250 g)	Group 2 A (200 g)	Group 2 B (250 g)
Anterior	Stress				
	Displacement				
Posterior	Stress				
	Displacement				

8. Translation of results and interpretation

At this stage the FEA results are checked, tabulated and understood in form of results.

These results are then interpreted and converted into proper discussion of results which resembles clinical significance.

This study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, Babu Banarasi Das College of Dental Sciences in collaboration with ANAMAC with an aim to evaluate and compare the stress and displacement in anterior and posterior segment during enmasse space closure with loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system using FEM.

In this study the FEM models were divided in groups based on retraction mechanics as follows:

Group I - FEM model where enmasse retraction was attempted using a mushroom loop by applying 200 g (subgroup 1 A) and 250 g (subgroup 1 B) of force.

Group II - FEM model where enmasse retraction was attempted using Niti closed coil spring by applying 200 g (subgroup 2 A) and 250 g (subgroup 2 B) of force.

After application of variable forces of 200g and 250g, FEM analysis results were obtained as Von Mises stress and displacement in all the three planes (X-Axis for mesio-distal movement, Y-Axis for occluso-gingival movement and Z-Axis labio-lingual for movement). The stress and displacement in all the three axis for all the tooth were calculated separately after application of force. A colour scale consisting of 9 stress values was used to evaluate the stress value for our present study. This colour scale for the stress distribution (Von Mises stress in MPa) runs from lowest stress values i.e. blue colour to the highest values i.e. red colour.

The results of the study for different situations are discussed below in details.

Table 4: Descriptive data for Maximum displacement in the anterior and posterior segment of the maxillary arch for both the groups.

Overall Maximum Displacement.				
Mechanics	Group I (Loop mechanics)		Group II (Sliding mechanics)	
Force	I a (250g)	Ib (200g)	IIa (250g)	IIb (200g)
Anterior	6.6825 e-5 mm	5.346 e-5 mm	7.6669 e-5 mm	6.1333 e-5 mm
posterior	0.7425 e-5 mm	0.594 e-5 mm	0.85188 e-5 mm	0.68148 e-5 mm

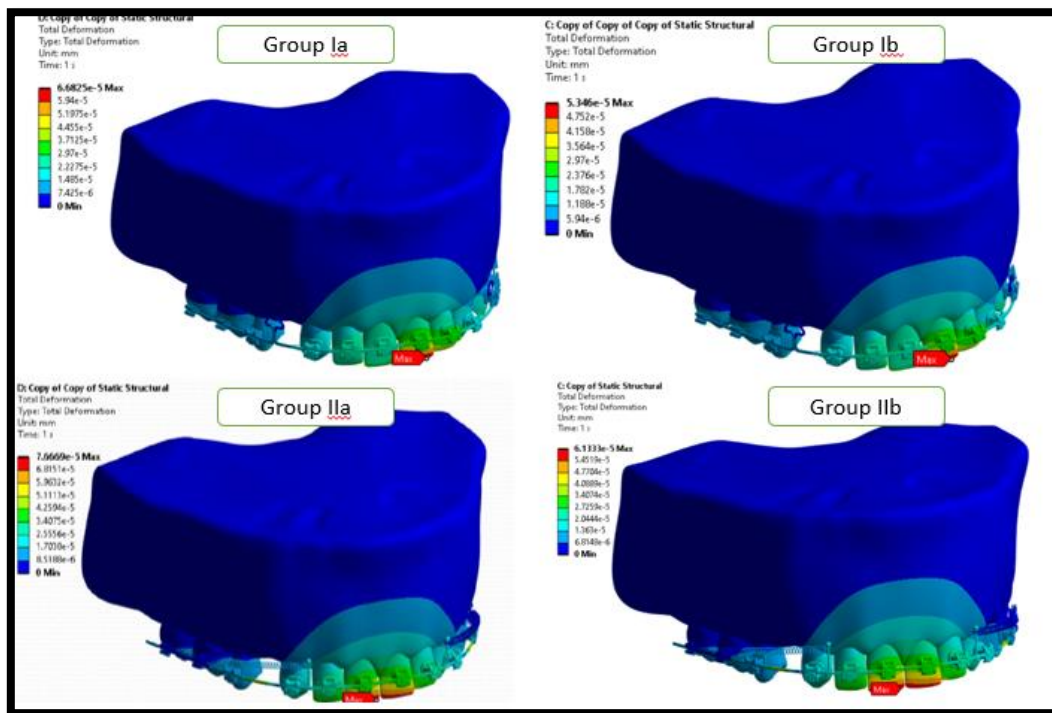


Figure 18: Overall maximum displacement.

Displacement – (Figure 18)

The retraction of **anterior** teeth as expressed by maximum displacement in the anterior segment was maximum in group IIa (7.6669×10^{-5}) than group Ia (6.6825×10^{-5}) for **250 g** of force. The retraction of **anterior** teeth as expressed by maximum displacement in the anterior segment was maximum in group IIb (6.1333×10^{-5}) than group Ib (5.346×10^{-5}) for **200 g** of force. The maximum displacement of **posterior** segment (anchorage) was also maximum in Group IIa (0.85188×10^{-5}) than group I (0.7425×10^{-5}) for **250grams** of force.

The maximum displacement of **posterior** segment (anchorage) was also maximum in Group IIb (0.68148×10^{-5}) than group I (0.7425×10^{-5}) for **200grams** of force.

On comparison of displacement at variable force levels, it was seen in each group that maximum displacement in **anterior** segment was more at 250 g (6.6825×10^{-5}) than at 200 g (5.346×10^{-5}) for **group I**.

Maximum displacement in **anterior** segment was more at 250 g (7.6669×10^{-5}) than at 200 g (6.1333×10^{-5}) for **group II**.

Maximum displacement in **posterior** segment was more at 250 g (0.7425×10^{-5}) than at 200 g (0.594×10^{-5}) for **group I**.

Maximum displacement in **posterior** segment was more at 250 g (0.85188×10^{-5}) than at 200 g (0.68148×10^{-5}) for **group II**.

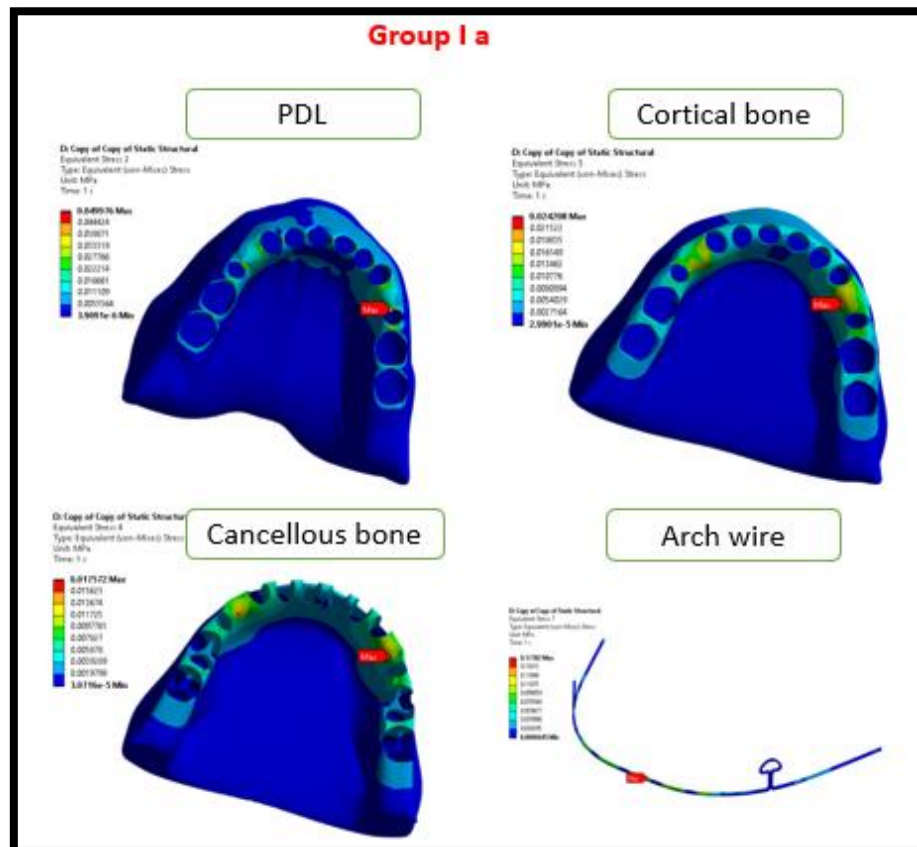


Figure 19: Von. Mises stress on PDL, cortical bone, cancellous bone and arch wire for group Ia.

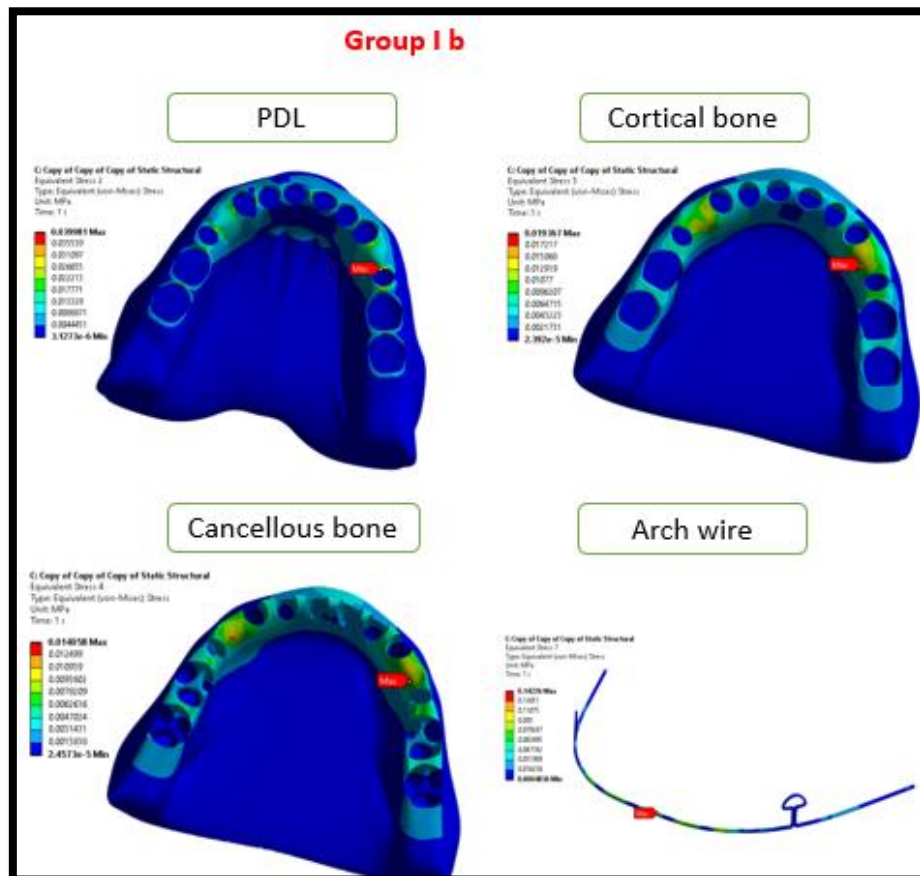


Figure 20: Von. Mises stress on PDL, cortical bone, cancellous bone, arch wire for group Ib.

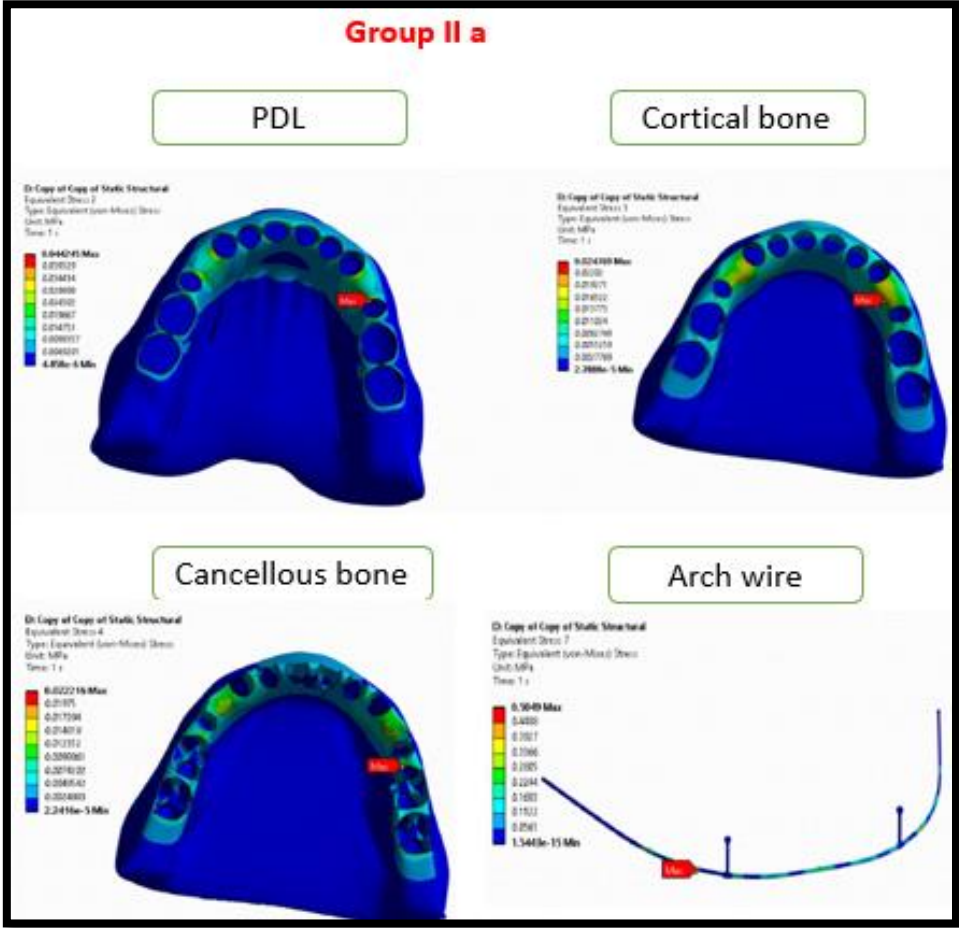


Figure 21: Von. Mises stress on PDL, cortical bone, cancellous bone, arch wire for group II a.

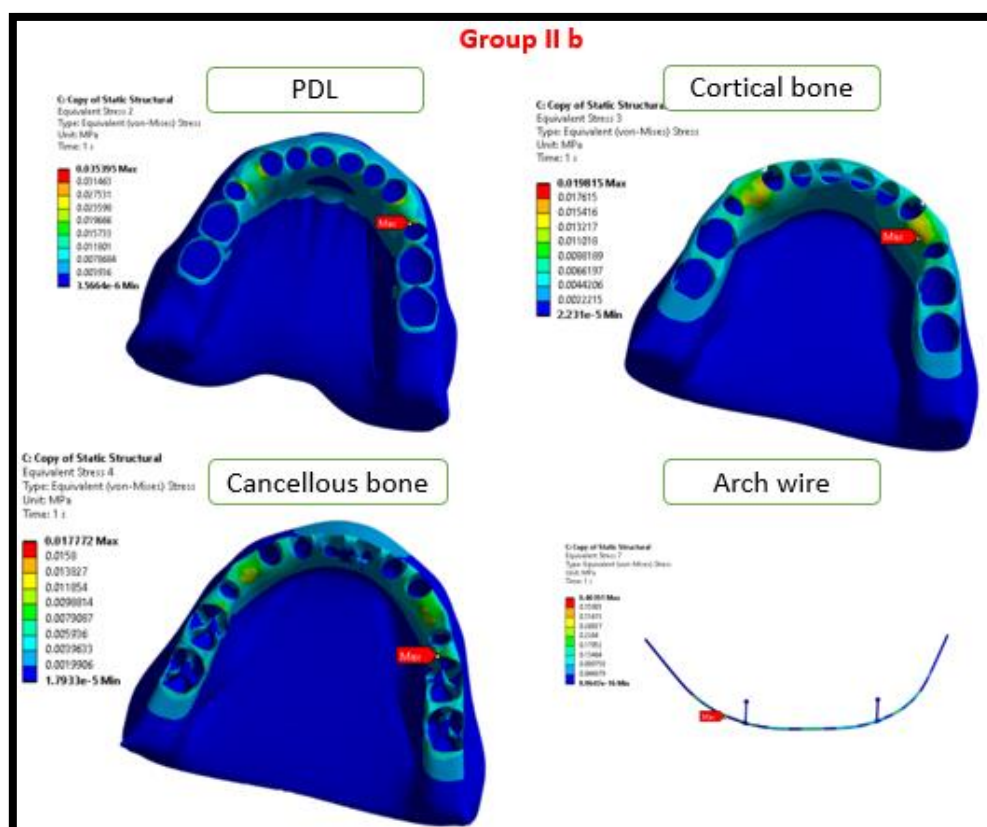


Figure 22: Von. Mises stress on PDL, cortical bone, cancellous bone, arch wire for group II b.

Table 5: Descriptive data for the stress distribution (Von. Mises stress) in MPa in different structures (PDL, cortical bone, cancellous bone, teeth and arch wire) (Figure 19 - 22)

Maximum Stress.				
	Group I (Loop mechanics)		Group II (Sliding mechanics)	
	subgroup I a	subgroup I b	subgroup II a	subgroup II b
PDL	0.049976 MPa	0.039981 MPa	0.044245 MPa	0.035395 MPa
Cortical bone	0.024208 MPa	0.019367 MPa	0.024769 MPa	0.019815 MPa
Cancellous bone	0.017572 MPa	0.014058 MPa	0.022216 MPa	0.017772 MPa
Dental component	0.038013 MPa	0.030411 MPa	0.069054 MPa	0.055242 MPa
Arch wire	0.17782 MPa	0.14226 MPa	0.5049 MPa	0.40391 MPa

- **PDL:** Stresses on PDL in group I (loop mechanics) had higher stress values than group II (sliding mechanics). For 250 grams of force group 1a had the higher stress 0.049976 MPa than 0.039981 MPa in Group IIa. For 200 grams force group 1b (0.044245 MPa) had more stress than Group 2b (0.035395 MPa).
- **CORTICAL BONE:** Stresses on cortical bone in group II (sliding mechanics) had higher stress values than group I (loop mechanics). The stress values are close between group 1 and 2 for the same force value. For 250 grams of force Group IIa (0.024769 MPa) had slightly higher stress than group 1a (0.024208 MPa). For 200 grams of force group 2b (0.019815 MPa) had more stress than Group 1b (0.019367 MPa).
- **CANCELLOUS BONE** Stresses on cancellous bone in group II (sliding mechanics) had higher stress values than group I (loop mechanics). For 250 grams of force group 2a had the higher stress (0.022216 MPa), followed by group 1a (0.017572 MPa). For 200 grams group 2b 0.017772 MPa had more stress than Group 1b (0.014058 MPa).
- **DENTAL COMPONENT:** Stress on the dental component is significantly higher for group II (sliding mechanics) than group I (loop mechanics). For 250 grams of force Group IIa exhibits the higher stress (0.069054 MPa), than group IIb (0.055242 MPa). For 200 grams group 1a had higher force (0.038013 MPa), than group 1b (0.030411 MPa).
- **ARCH WIRE:** Stress on the arch wire is significantly higher for group II (sliding mechanics) than group I (loop mechanics) for 250 g force, group IIa exhibits higher stress (0.5049 MPa), than group 2b (0.40391 MPa). For 200 g force group 1a (0.17782 MPa) had higher force than group Ib (0.14226 MPa).
- Maximum stress in all the four models was found in the cervical area mesial to the 2nd premolar and distal to canine and also in the interdental area of entire anterior segment.

Table 6: Descriptive data for the stress distribution (Von. Mises stress) in MPa for individual tooth considering two points as reference (apex and occlusal).

Stress					
Tooth	Region	Group 1 a	Group 1 b	Group 2 a	Group 2b
Central incisor	Apex	2.2643 e-3	1.9243 e-3	2.4468 e-3	2.0301 e-3
	Occlusal	2.9752 e-3	1.3808 e-3	3.589 e-3	4.5084 e-3
Lateral incisor	Apex	1.2574 e-3	1.0029 e-3	1.728 e-3	1.6156 e-3
	Occlusal	2.7863 e-3	2.7678 e-3	2.9487 e-3	3.253 e-3
Canine	Apex	0.86619 e-3	0.67649 e-3	1.1183 e-3	0.46667 e-3
	Occlusal	2.6353 e-3	1.8996 e-3	3.563 e-3	1.9235 e-3
2 nd premolar	Apex	2.4823 e-3	2.0497 e-3	2.7075 e-3	2.1562 e-3
	Occlusal	3.6377 e-3	1.8223 e-3	8.9296 e-3	4.7943 e-3
1 st molar	Apex	1.6913 e-3	1.3429 e-3	0.01325 e-3	0.01685 e-3
	Occlusal	2.1136 e-3	1.746 e-3	2.1611 e-3	1.7679 e-3
2 nd molar	Apex	1.1598 e-3	0.93343 e-3	0.01197 e-3	0.03697 e-3
	Occlusal	2.9825 e-3	2.2349 e-3	2.3182 e-3	1.8545 e-3

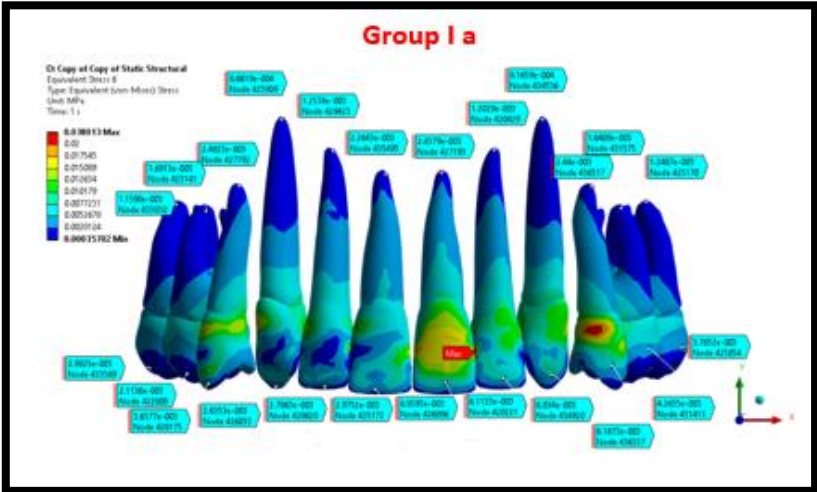


Figure 23: Von Mises Stress in group I a.

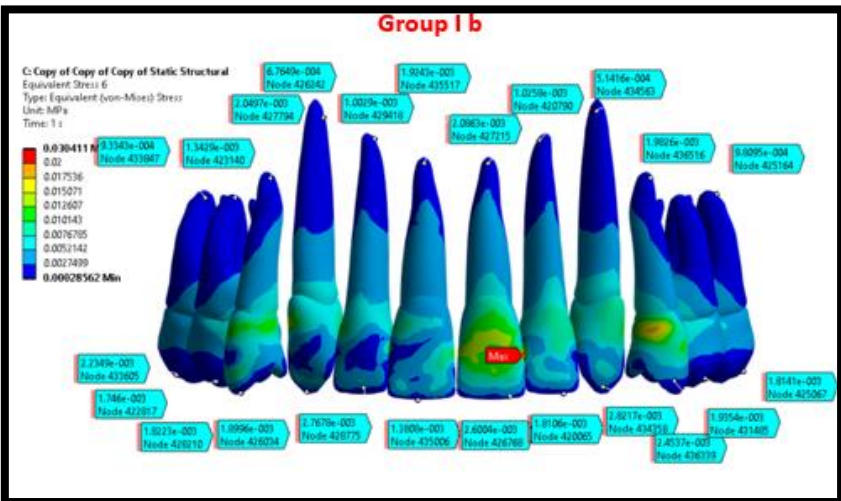


Figure 24: Von Mises Stress in group I b.

Group Ia:

During the retraction of anterior teeth using **loop mechanics** with a force of **250 G**, the stress was maximum at occlusal surface of 2nd premolar ($3.6377e-3$) > 2nd molar ($2.9825e-3$) > Central incisor ($2.9752e-3$) > Lateral incisor ($2.7863e-3$) > Canine ($2.6353e-3$) > 1st molar ($2.1136e-3$). The trend at apex was as follows: 2nd premolar ($2.4823e-3$) > Central incisor ($2.2643e-3$) > 1st molar ($1.6913e-3$) > Lateral incisor ($1.2574e-3$) > 2nd molar ($1.1598e-3$) > Canine ($0.86619e-3$).

Group Ib:

During the retraction of anterior teeth using **loop mechanics** with a force of **200 g**, the stress was maximum at occlusal surface of lateral incisor ($2.7678e-3$) 2nd molar ($2.2349e-3$) > Canine ($1.8996e-3$) > 2nd premolar ($1.8223e-3$) > 1st molar ($1.746e-3$) > Central incisor ($1.3808e-3$). The trend at apex was as follows: 2nd premolar ($2.0497e-3$) > Central incisor ($1.9743e-3$) > 1st molar ($1.3429e-3$) > Lateral incisor ($1.0029e-3$) > 2nd molar ($0.93343e-3$) > Canine ($0.67649e-3$).

Group IIa

During the retraction of anterior teeth using **sliding mechanics** with a force of **250 G**, the stress was maximum at occlusal surface of 2nd premolar ($8.9296 e-3$) > Central incisor ($3.589 e-3$) > Canine ($3.563 e-3$) > Lateral incisor ($2.9487 e-3$) > 2nd molar ($2.3182 e-3$) > 1st molar ($2.1611 e-3$). The trend at apex was as follows: 2nd premolar ($2.7075 e-3$) > Central incisor ($2.4468 e-3$) > Lateral incisor ($1.728 e-3$) > canine ($1.1183 e-3$) > 1st molar ($0.01325 e-3$) > 2nd molar ($0.011973 e-3$).

Group II b

During the retraction of anterior teeth using **sliding mechanics** with a force of **200 G**, the stress was maximum at occlusal surface of 2nd premolar ($4.7943 e-3$) > Central incisor ($4.5084 e-3$) > Lateral incisor ($3.253 e-3$) > Canine ($1.9235 e-3$) > 2nd molar ($1.8545 e-3$) > 1st molar ($1.7679 e-3$). The trend at apex was as follows: 2nd premolar ($2.1562 e-3$) > Central incisor ($2.0301 e-3$) > Lateral incisor ($1.6156 e-3$) > canine ($0.466676 e-3$) > 2nd molar ($0.036971 e-3$) > 1st molar ($0.016859 e-3$).

On analysis of Fem results for stress distribution among different groups, stress (as denoted on apex and occlusal surface) of individual tooth has been noted as follows.

Central Incisor:

In the apex region, the stress was highest in Group 2a (2.4468) > Group 1a (2.2643) > Group 2b (2.0301) > Group 1b (1.9243). On the occlusal surface, the stress is highest in Group 2b (4.5084), > Group 2a (3.589) > Group 1a (2.9752) > Group 1b (1.3808).

Lateral Incisor:

The stress at the apex is highest in Group 2a (1.728), > Group 2b (1.6156), > Group 1a (1.2574), > Group 1b (1.0029). On the occlusal surface, the stress is highest in Group 2b (3.253) > Group 2a (2.9487), > Group 1a (2.7863), > Group 1b (2.7678).

Canine:

The apex stress is highest in Group 2a (1.1183) > Group 1a (0.86619) > Group 1b (0.67649), > Group 2b (0.466676). On the occlusal surface, the stress is highest in Group 1a (2.6353) > Group 2a (3.563), Group 2b (1.9235), > Group 1b (1.8996).

2nd Premolar:

The apex stress is highest in Group 1a (2.4823) > group 2a (2.7075) > Group 1b (2.0497) > Group 2b (2.1562). On the occlusal surface, the stress is highest in Group 2a (8.9296) > Group 2b (4.7943) > Group 1a (3.6377) > Group 1b (1.8223).

1st Molar:

The apex stress is highest in Group 1a (1.6913) > Group 1b (1.3429) > Group 2a (0.01325) > Group 2b (0.016859). On the occlusal surface, the stress is highest in Group 1a (2.1136) > Group 2a (2.1611) > Group 1b (1.746) > and Group 2b (1.7679).

2nd Molar:

The apex stress is highest in Group 1a (1.1598) > Group 1b (0.93343), Group 2a (0.011973) > Group 2b (0.036971). On the occlusal surface, the stress is highest in Group 1a (2.9825) > Group 2a (2.3182) > Group 1b (2.2349) > Group 2b (1.8545).

Table 4: Descriptive data for displacement of individual tooth considering two points as reference (apex and occlusal) in three planes (X, Y and Z).

Maximum Displacement.									
Mechanics		Group 1 (Loop mechanics)				Group 2 (Sliding mechanics)			
Force		250g		200g		250g		200g	
		Apex	Occlusal	Apex	Occlusal	Apex	Occlusal	Apex	Occlusal
CI	X	-1.4855e-7	-2.9291e-6	-1.1884e-7	-2.3749e-6	-1.0034e-7	-3.2631e-6	-8.0269e-8	-2.7801e-6
	Y	-6.0957e-7	-1.5069e-5	-6.4122e-7	-1.1406e-5	-7.8885e-7	-1.6485e-5	-6.4504e-7	-1.3617e-5
	Z	-3.0877e-7	-6.1956e-5	-2.6809e-6	-4.741e-5	-3.809e-6	-6.8869e-5	-2.6644e-6	-5.5291e-5
LI	X	-1.4855e-7	-5.0805e-6	-1.5325e-7	-2.3102e-5	-1.747e-7	-5.7458e-6	-1.2369e-7	-5.4177e-6
	Y	-3.7275e-7	-8.3384e-6	-2.982e-7	-6.6403e-6	-3.194e-7	-8.6542e-6	-3.0743e-7	-7.5747e-6
	Z	-1.4353e-6	2.4977e-5	-1.2344e-6	-2.2075e-5	-1.572e-6	-3.928e-5	-1.0476e-6	-3.1618e-5
Canine	X	9.4615e-9	-2.2343e-6	3.3066e-8	-1.5935e-6	2.742e-8	-2.6423e-6	2.4347e-8	-1.4021e-6
	Y	1.9896e-7	-3.3071e-6	1.7753e-7	-2.0473e-6	1.7172e-7	-1.3655e-6	1.4821e-7	-1.9513e-6
	Z	-1.7106e-7	2.4977e-5	-1.8268e-7	-1.5805e-5	-1.7761e-6	-3.185e-5	-1.42e-7	-2.455e-5
2nd premolar	X	1.592e-6	-4.2332e-6	1.2446e-6	-3.2243e-6	1.6333e-6	-3.4473e-6	1.3395e-6	-1.9511e-6
	Y	1.6041e-6	9.0861e-7	1.2818e-6	1.5405e-6	1.5103e-6	4.6502e-6	1.2082e-6	2.3787e-6
	Z	4.4359e-7	1.488e-5	3.083e-7	1.2188e-5	2.313e-7	1.0717e-5	1.1213e-7	8.9519e-6
1st molar	X	1.2111e-6	-1.617e-6	1.0021e-6	-1.1667e-6	2.1837e-6	-2.2413e-6	1.7561e-6	-1.042e-6
	Y	6.5435e-7	-1.2511e-6	5.6469e-7	-5.3564e-7	8.7513e-7	1.1145e-6	6.9354e-7	5.5384e-7
	Z	1.1096e-6	1.0366e-5	8.3981e-7	8.6925e-6	3.5319e-7	1.0575e-5	3.7255e-7	8.9858e-6
2nd molar	X	3.2652e-7	-2.3438e-6	2.8522e-7	-1.8401e-6	-2.3366e-7	-3.6634e-6	-1.318e-7	-2.5652e-6
	Y	-4.5061e-7	-2.0259e-6	-3.2529e-7	-1.6906e-6	-58619e-7	-3.2462e-7	-3.7085e-7	-2.5594e-8
	Z	1.3689e-6	9.6141e-6	1.0723e-6	7.7592e-6	2.0015e-6	9.587e-6	1.6013e-6	7.6331e-6

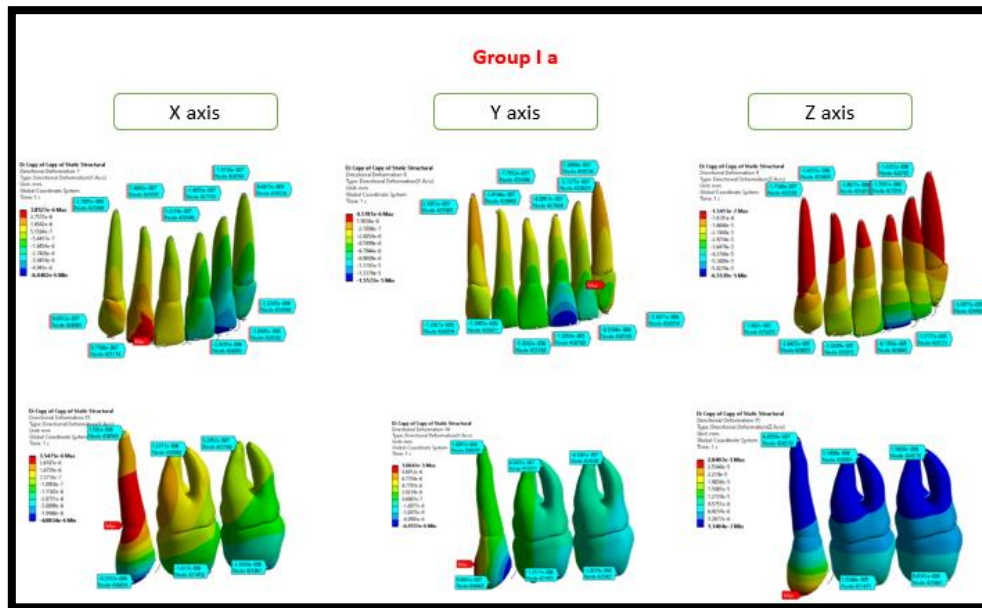


Figure 27: Displacement of individual tooth in group I a.

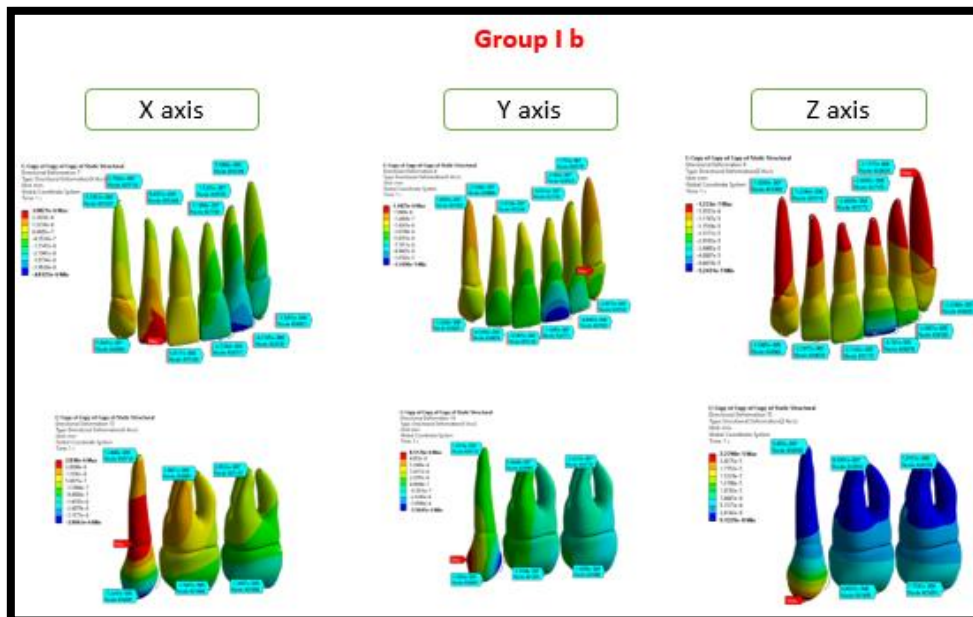


Figure 28: Displacement of individual tooth in group I b.

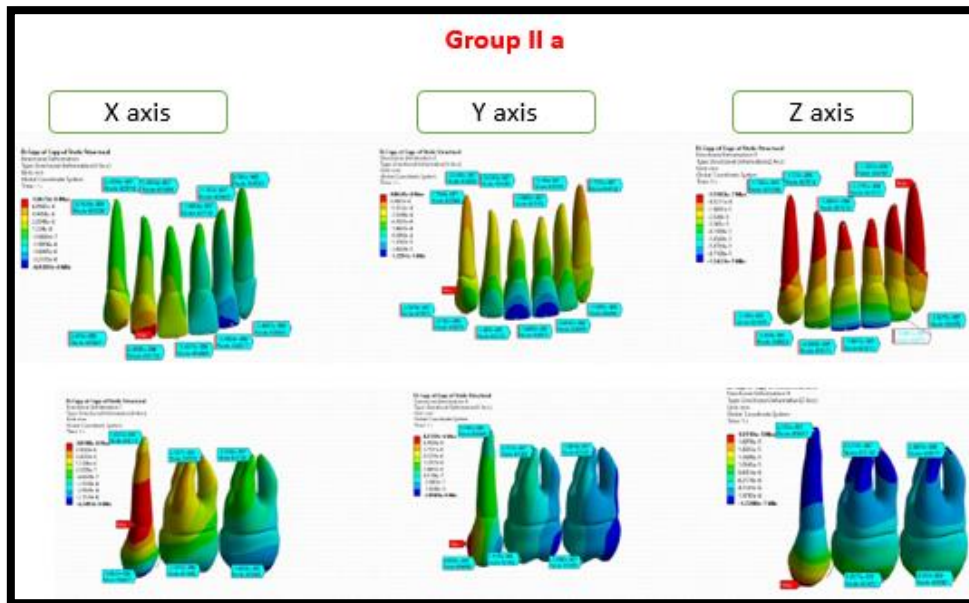


Figure 29: Displacement of individual tooth in group II a.

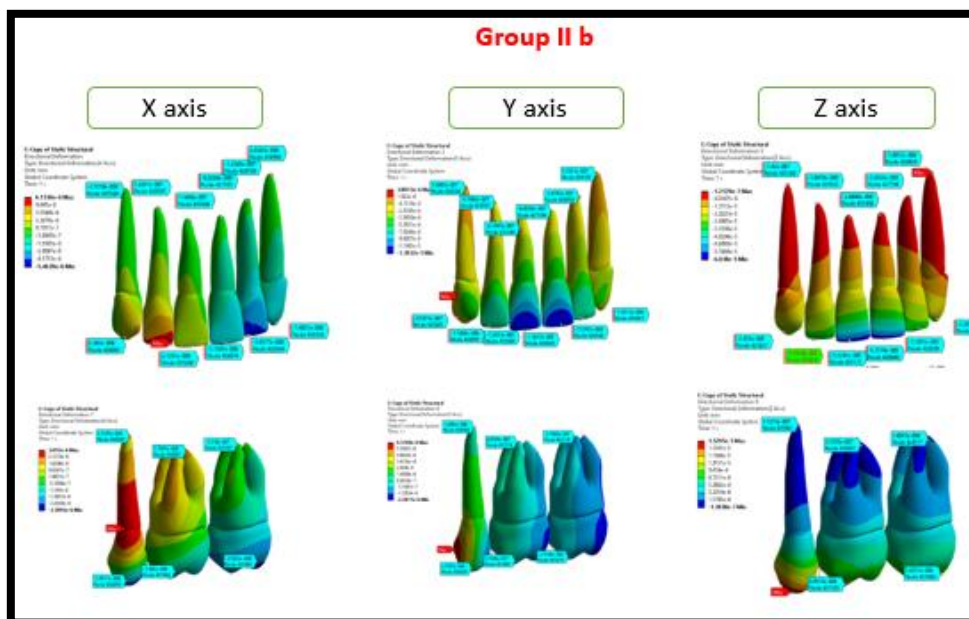


Figure 30: Displacement of individual tooth in group II b.

For central incisor,

Displacement in **X axis** at apex was -1.4855e-7, -1.1884e-7, -1.0034e-7, -8.0269e-8 and at occlusal surface was -2.9291e-6, -2.3749e-6, -3.2631e-6, -2.7801e-6 for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Y axis** at apex was -6.0957e-7, -6.4122e-7, -7.8885e-7, -6.450e-7 and at occlusal surface was -1.5069e-5, -1.1406e-5, -1.6485e-5, -1.3617e-5 for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Z axis** at apex was -3.0877e-7, -2.6809e-6, -3.809e-6, -2.6644e-6 and at occlusal surface was -6.1956e-5, -4.741e-5, -6.8869e-5, -5.5291e-5 for Group Ia, Ib, IIa, IIb respectively.

For lateral incisor,

Displacement in **X axis** at apex was -1.4855e-7, -1.5325e-7, -1.747e-7, -1.2369e-7 and at occlusal surface was -5.0805e-6, -2.3102e-5, -5.7458e-6, -5.4177e-6. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Y axis** at apex was -3.7275e-7, -2.982e-7, -3.194e-7, -3.0743e-7 and at occlusal surface was -8.3384e-6, -6.6403e-6, -8.6542e-6, -7.5747e-6. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Z axis** at apex was -1.4353e-6, -1.2344e-6, -1.572e-6, -1.0476e-6 and at occlusal surface was 2.4977e-5, -2.2075e-5, -3.928e-5, -3.1618e-5. for Group Ia, Ib, IIa, IIb respectively.

For canine,

Displacement in **X axis** at apex was 9.4615e-9, 3.3066e-8, 2.742e-8, 2.4347e-8, and at occlusal surface was -2.2343e-6, -1.5935e-6, -2.6423e-6, -1.4021e-6 for Group Ia, Ib, IIa, IIb respectively.

Displacement at apex in **Y axis** at apex was 1.9896e-7, 1.7753e-7, 1.7172e-7, 1.4821e-7, and at occlusal surface was -3.3071e-6, -2.0473e-6, -1.3655e-6, -1.9513e-6. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Z axis** at apex was -1.7106e-7, -1.8268e-7, -1.7761e-6, -1.42e-7 and at occlusal surface was 2.4977e-5, -1.5805e-5, -3.185e-5, -2.455e-5. for Group Ia, Ib, IIa, IIb respectively.

For second premolar,

Displacement in **X axis** at apex was 1.592e-6, 1.2446e-6, 1.6333e-6, 1.3395e-6 and at occlusal surface was -4.2332e-6, -3.2243e-6, -3.4473e-6, -1.9511e-6. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Y axis** at apex was 1.6041e-6, 1.2818e-6, 1.5103e-6, 1.2082e-6 and at occlusal surface was 9.0861e-7, 1.5405e-6, 4.6502e-6, 2.3787e-6. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Z axis** at apex was 4.4359e-7, 3.083e-7, 2.313e-7, 1.1213e-7 and at occlusal surface was 1.488e-5, 1.2188e-5, 1,0717e-5, 8.9519e-6. for Group Ia, Ib, IIa, IIb respectively.

For first molar,

Displacement in **X axis** at apex was 1.211e-6, 1.0021e-6, 2.1837e-6, 1.7561e-6 and at occlusal surface was -1.617e-6, -1.1667e-6, -2.2413e-6, -1.042e-6. for Group Ia, Ib, IIa, IIb respectively.

Displacement apex in **Y axis** at apex was 6.5435e-7, 5.6469e-7, 8.7513e-7, 6.9354e-7 and at occlusal surface was -1.2511e-6, -5.3564e-7, 1.1145e-6, 5.5384e-7. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Z axis** at apex was 1.1096e-6, 8.3981e-7, 3.5319e-7, 3.7255e-7 and at occlusal surface was 1.0366e-5, 8.6925e-6, 1.0575e-5, 8.9858e-6. for Group Ia, Ib, IIa, IIb respectively.

For second molar,

Displacement in **X axis** at apex was 3.2652e-7, 2.8522e-7, -2.3366e-7, -1.318e-7 and at occlusal surface was -2.3438e-6, -1.8401e-6, -3.6634e-6, -2.5652e-6. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Y axis** at apex was -4.5061e-7, -3.2529e-7, -5.8619e-7, -3.7085e-7 and at occlusal surface was -2.0259e-6, -1.6906e-6, -3.2462e-7, -2.5594e-8. for Group Ia, Ib, IIa, IIb respectively.

Displacement in **Z axis** at apex was 1.3689e-6, 1.0723e-6, 2.0015e-6, 1.6013e-6 and at occlusal surface was 9.6141e-6, 7.7592e-6, 9.587e-6, 7.6331e-6, for Group Ia, Ib, IIa, IIb respectively.

Orthodontic tooth movement occurs when applied force overcome the friction between the bracket and archwire. Enmasse retraction of anterior teeth during space closure can be achieved through two types of mechanics i.e., frictionless (loop) mechanics or friction (sliding) mechanics.

Loop mechanics involve the activation of loop placed in the extraction space, eliminating sliding of the wire within brackets. Various loops, contribute to accomplishing space closure. The Mushroom loop advocated by Nanda is an adaptation of T loop where length of the horizontal arm was reduced and was more curved. It produces increased moment to force ratio and lower force levels, thus providing faster and more controlled space closure thereby increasing its popularity for space closure using loop mechanics. Hence it was decided to evaluate space closure using mushroom loop in present study.

In sliding mechanics as a continuous arch wire moves through posterior brackets during the retraction of anterior teeth, friction arises from direct contact among the bracket, arch wire, and ligature. Retraction is accomplished using elastics, active tie backs, elastomeric links, NiTi closed coil springs etc. Previous studies showed faster rate of space closure with NiTi closed coil springs making them a preferred treatment option. Hence it was decided to evaluate space closure using sliding mechanics with NiTi closed coil spring in the present study.

Friction during orthodontic sliding mechanics represents a clinical challenge to the Orthodontists because high level of friction may require the application of higher amount of orthodontic forces which may compromise the amount of tooth movement and anchorage control there by reducing the effectiveness of mechanics.

Several factors influence friction, includes wire size, material, and ligation technique. Smaller-sized wires and round wires generally encounter less friction, but for effective three-dimensional control during space closure, higher dimension wires with less play are essential. Thus, in brackets with 0.022x0.028 slot arch wire with 0.019''X 0.025''inch dimension is preferred. As stainless steel has least amount of friction hence it is a preferred material for frictional or sliding mechanics. TMA wire is preferred for loop mechanics despite of high friction as it is a frictionless mechanics and has more spring back and less load deflection rate that is favourable for loop

mechanics. Hence 0.019''X 0.025''inch SS arch wire for sliding mechanics and 0.019''X 0.025''inch TMA wire for loop mechanics was considered for this study.

In conventional orthodontics, arch wire is tied to brackets and ligation is considered as an established parameter affecting the resistance to applied forces. Ligation is accomplished using ligature wire or elastic ligature ties. Elastic ligature ties provide more friction than SS ligature wire. The advent of self-ligating brackets was based on the fact that, elimination of ligating wire to tie the wire to bracket slot would reduce friction. They come with accessories like clips or lock gates, which keep the arch wire in the slot.

The efficacy of SLB in reducing friction in comparison to conventional brackets has been evaluated in various studies. These studies consistently shown lower frictional resistance, reduced chairside time, and improved infection control with self-ligating bracket systems. It was also seen that reduced friction with self-ligating brackets was only in initial stages where play was more between the wire and the bracket slot, however on engaging full dimension wire, reduction in friction was not evident. Other studies showed frictional resistance was similar between self-ligating bracket and conventional bracket, however stress was much lesser in passive self-ligating bracket system. The efficacy of SLB during space closure using sliding and frictionless mechanics has not been widely evaluated in previous studies, hence it was decided to evaluate the same in present study.

Self ligating bracket (SLB) system have two main designs, based on the mechanism of lid closure i.e. active and passive. Active SLBs can apply force on the arch wire, owing to the spring clip, whereas Passive SLBs do not exert any active force, has lesser friction than active SLB and have minimal interference which allows for a clearer understanding of the biomechanics involved, making it easier to analyse and model in finite element simulations, hance it was decided to use passive SLB in present study.

Several clinical studies have shown efficacy of SLB however little information regarding pattern of mechanical stresses in tissue around teeth during space closure is available. As quantification of stress is difficult in clinical studies, various in vitro methods have been proposed like photoelastic strain analysis, mathematical models, laser holography, strain gauges, FEM etc. FEM is a mathematical method where in the shape of complex geometric objects and their physical properties are computer

constructed and, stress and displacement can be predicted with significant accuracy. Finite Element Method (FEM) allows for a detailed analysis of biomechanical factors involved in tooth movement and treatment outcome in terms of stress and displacement.

As self ligating brackets have lower frictional resistance hence it is anticipated that amount of stress during space closure would also be lesser. Hence, forces for enmasse space closure might be lesser than those needed conventionally for similar displacement of anterior segment hence it was decided to employ two forces i.e. 250 g (regularly recommended for space closure using conventional brackets) and a lesser value of 200 g of force, so as to see amount of stress and displacement generated using sliding or loop mechanics for space closure in self ligating brackets.

Considering this, the aim of the present study was to evaluate and compare the stresses and displacement in anterior and posterior segment during enmasse space closure with loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system using FEM.

This comparative in-vitro study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, Babu Banarasi Das College of Dental Sciences, Lucknow in collaboration with ANAMAC.

A maxillary arch was modeled on the basis of CBCT images. FUSION 360 software was used to convert CBCT into STL format to CAD model of maxillary arch. Geometric model of Passive self ligating bracket prescription with 0.022'' X 0.028''inch bracket slot, molar tube, NiTi closed coil spring, crimpable hook, stainless-steel archwire of 0.019''X 0.025''inch and a TMA arch wire with mushroom loop was modelled using SOLIDWORKS modeling software was used for the construction of geometric model from CAD models. HYPERMESH software was used to create mesh models and also was used to fuse the model of maxilla with PDL, bone and complete assembly of brackets, molar tube, arch wire, NiTi closed coil spring, crimpable hook, stainless-steel archwire of 0.019''X 0.025''inch and a TMA arch wire with mushroom loop etc. to make FEM models. A total of 2 finite element model with 4 load cases were generated and boundary conditions was applied. Material properties were incorporated for teeth, PDL, bone, stainless steel and TMA. FEM models were divided into two groups (Group I and Group II) based on mechanics. Group I included FEM model where loop (frictionless mechanics) was

used for enmasse retraction and Group II included FEM model for sliding (frictional mechanics). Each group was subdivided into two groups (A and B) based on the amount of force applied (A – 200 g and B – 250 g).

The finite element model was submitted to HYPERMESH Finite Element (FE) solver to perform the simulation. Finally, HYPERVIEW software was used to read finite element results, generate result images and extract stress data from simulation. Von Mises stress and displacement in three axis (X-Axis for labio-lingual movement, Y-Axis for occluso-gingival movement and Z-Axis for mesio-distal movement) was measured. Data was tabulated to understand stress and displacement during sliding and loop mechanics using two different force levels.

The result of present study suggested that retraction of anterior teeth was more in sliding mechanics than loop mechanics. The maximum displacement was observed for sliding mechanics at 250 g > loop mechanics at 250 g > sliding mechanics at 200g > loop mechanics at 200 g for anterior segment. Also, displacement increased as force increased in each group at each force levels. Anchorage taxation of the posterior segment was found to be more in sliding mechanics than loop mechanics at each force level. Considering the amount of force, 200 g of force showed less movement of the posterior segment in both the mechanics.

Maximum stress in the PDL was seen for loop mechanics (250 g of force) > sliding mechanics (250 g force) > loop (200 g force) > sliding mechanics (200 g force). For cortical and cancellous bone stress was more in sliding mechanics (250 g of force) > loop mechanics (250 g of force) > sliding (200 g of force) > loop mechanics (200 g of force).

In all the models stress was more at occlusal region than apex of all teeth suggestive of tipping of teeth in lingual direction. As tipping was more in sliding mechanics hence more displacement was seen in sliding mechanics. However, uniform stress distribution was seen for loop mechanics in 200 g because of lesser difference in stress at apex and occlusal surface in comparison to other models. This is suggestive of more of bodily movement in anterior posterior direction for loop mechanics on applying 200 G of force.

Displacement in X axis (Transverse plane).

Displacement in Central and Lateral Incisor showed lingual crown tipping in all models which is in accordance to general biomechanical principles of orthodontics where maxillary anterior teeth have clockwise moment and tip lingually.

Canine showed controlled lingual crown tipping with negligible movement of root of canine in opposite direction in loop mechanics of 250 grams. However, canine in other models showed large crown tipping like in incisors, both for sliding and loop mechanics.

The second premolar, first molar and second molar did not show appreciable difference between displacement of crown and root apex in x axis of each tooth suggestive of better anchorage control for loop mechanics.

On comparing loop mechanics at different force levels, difference of displacement between crown and apex of posterior teeth was more at 250 g of force than 200 g of force. This is also evident in less mesial movement of posterior segment at 200 g then 250 g of force. Similar results were seen for posterior segment using sliding mechanics.

Displacement in Z axis (Antero-posterior plane).

In Z axis more displacement was seen at crown level of canine and Lateral Incisor than roots for all models.

Controlled distal tipping was seen in canine of all models. For second premolar and first molar controlled mesial tipping was seen in all models. Sliding mechanics 200 g had least difference in displacement of crown and root apex of second premolar suggestive of minimal mesial tipping of posterior segment in comparison to other models. Sliding mechanics at 250 grams had maximum difference in displacement of crown and root apex of maxillary first molar suggestive of maximal mesial tipping of tooth as also evident by maximal mesial displacement of posterior segment (0.85188e-5) in this model.

Displacement in Y axis. (Occluso-gingival plane)

In y axis no appreciable extrusion was observed for any tooth in both the segments in all the models. This could be due to the fact that power arm of sliding mechanics had a length of 7 mm and mushroom loop used in loop mechanics had a height of 7 mm that would be closer to the centre of resistance of maxillary anterior teeth.

The results will be discussed with respect to other studies that evaluated displacement using FEM. (Zhang et al, Bohara et al, Chetan et al, Tominaga et al)

Zhang et al ^[14] compared two FEM models during retraction of anterior teeth with conventional bracket using sliding mechanics at power arm height of 2 mm and 4 mm respectively. Second model with powerarm height of 4 mm had retraction from Mini screw placed between 2nd premolar and first molar. Similar to present study they found greater displacement of crown than roots for Lateral Incisor for model 1 whereas crown and root showed equal displacement for Lateral Incisor in model 2. Stress at apex of upper canine was maximum 0.068 3 MPa for model 1 where as it was maximum at apex of Central Incisor at 0.0736 MPa.

Bohara et al ^[37] conducted a FEM study to evaluate displacement of maxillary anterior teeth with conventional bracket during enmasse intrusion and retraction on force application with different combinations of mini-implants and retraction hooks. Model with retraction hook of height 6 mm was compared to present study. In X axis distal crown movement of lateral incisor (-0.001mm in crown and 0mm in root) was seen while canine crown moved lingually (0.002mm in crown -0.001mm in root) and canine root moved buccally. In y axis central and lateral incisor (0.004 in crown and 0.003 in root) showed almost bodily movement and distal tipping of canine (0.006 in crown and 0.002 in root) was observed. Along the z axis central and lateral incisor showed extrusion (≈ 0.001).

Chetan S et al ^[31] conducted a FEM study for enmasse retraction of anterior teeth with conventional bracket at different levels of force application. When force was applied at the level of molar hook with a hook of 2 mm in between lateral incisor and canine displacement in Y axis (sagittal plane) showed lingual tipping of anterior teeth. Most tipping was seen in canine > lateral incisor > central incisor. In Z axis (vertical plane) extrusion of all anterior teeth was seen.

Tominaga et al ^[16] conducted a FEM study to determine the optimum height and position of power arm for sliding mechanics with conventional bracket. It was found that significant amount of tipping was seen when the power arm was placed distal to the canine irrespective of the power arm height. When the power arm was placed between the lateral incisor and canine and the height of power arm kept at 5.5 mm, bodily movement was seen.

The conclusion drawn from the above mentioned studies is that friction mechanics was more effective than frictionless mechanics for enmasse retraction of anterior teeth using self ligating bracket, as seen in present study was also evident in previous studies both for individual canine retraction and enmasse retraction using conventional brackets. However the variation in values of displacement in different brackets in these studies could be due to difference in bracket prescription that is conventional bracket were used in the above mentioned studies whereas self ligating bracket were used in the present study. Also more lingual tipping as observed in sliding mechanics than loop mechanics in present study was also seen in previous FEM studies. More lingual tipping of anterior teeth as observed in sliding mechanics could be due to the fact that friction though anticipated to be lesser in ligating brackets couldn't be eliminated. However, loop mechanics being frictionless mechanics had lesser lingual tipping of incisors. Gabel bend of 30° for anterior and posterior segment of loop also controlled tipping in anterior and posterior segment as evident by lesser retraction of anterior teeth and lesser taxation of anchorage of posterior segment. For sliding mechanics as crimpable hook was at a height of 7 mm in present study and was more closer to centre of resistance of anterior teeth, hence lingual tipping and extrusion of anterior teeth was lesser than those achieved for lesser power arm of height of 2, 4 mm of previous studies.

Von Mises Stress observed for different groups.

Maximum stress in the PDL was seen for loop mechanics with 250 g of force > sliding mechanics with 250 g force > loop with 200 g force > sliding mechanics with 200 g force. For cortical bone stress was more in sliding mechanics 250 > loop mechanics 250 g > sliding 200 g > loop mechanics 200 g. The maximum stress for cancellous bone, teeth and arch wire showed a similar pattern with highest stress seen in sliding mechanics at 250 G of force > sliding mechanics with 200 g of force > loop mechanics with 250 g force > loop mechanics with 200 g of force. Maximum stress in PDL in all the four models, was found in the cervical area mesial to the premolar and distal to the canine. Similar stress pattern was noted for teeth adjacent to extraction space. This is in accordance with principles of orthodontic tooth movement where forces are concentrated on either sides of the extraction space. The force level in the cortical and cancellous bone around the extraction space was found to be greater and was is in accordance to the pattern shown in the cervical zone of the distal aspect of

canine and mesial aspect of premolar in our study. The current study showed that the stress values in the cortical bones are greater than in the cancellous bones. The explanation for this might be cortical bones having a higher Young's modulus than cancellous bones which sustain more loads and resists more deformation than soft bones as suggested by Ali et al.

The result of the present study will be discussed with respect to previous FEM studies that evaluated stress during retraction of anterior teeth using self ligating bracket. (Gomez et al) and conventional brackets (Prem et al, Lombardo et al, Patel et al, Bohara et al, Kojima et al.)

Gomez et al ^[39] compared the frictional force between passive self-ligating brackets and conventionally ligated brackets, during the space closure. Closure of space resulting from the FEM simulation was 1.47 mm for the passive self-ligating system and 1.3 mm for the conventionally ligated system. Stress resulting from conventional bracket was 4.69 MPa on the apical surface of teeth 21, 22, 23, and 13 and cervical, palatal, and distal surfaces of tooth 15. Maximum stress for self ligating bracket was 2.98 MPa on the palatal, mesial, and distal surfaces of central incisors, and on cervical and palatal surface of canines. Maximum stress on the bone was 0.8319 MPa for SLB and 1.266 MPa for conventional bracket. Stress on PDL was similar to that of bone for both the groups. Maximum stress on tooth was 1.3 MPa for passive SLB and 1.22 MPa in conventional bracket. As per the authors displacement of anterior teeth was more in SLB than conventional brackets with lesser stress on bone and greater stress on tooth with SLB.

Prem et al ^[36] conducted a FEM study to compare sliding and loop mechanics for canine retraction for conventional bracket with Niti closed coil spring and T loop and tear drop loop. Sliding mechanics showed bodily movement of canine at a force of 210g whereas bodily Movement in loop mechanics was seen at 200 g. Maximum tensile stress (0.054239 N/mm²) was observed on the cervical third of the mesial surface and maximum compressive stress (−0.084013 N/mm²) was observed on the cervical third of the distal surface for sliding mechanics. For loop mechanics maximum tensile stress (0.0014 N/mm²) and compressive stress (−0.0015 N/mm²) on the cervical area of the mesial and distal surfaces of the maxillary canine. They found lesser stress for loop mechanics than sliding mechanics the similar to results of present study for enmass retraction of anterior teeth in self ligating bracket.

Lombardo et al^[27] compared stress and displacement during retraction of anterior teeth using conventional bracket in the mandibular arch with lingual and labial mechanics. In labial mechanics lingual (+x) and mesial (+y) tipping with extrusion (-z) was seen for incisors, for canine lingual and distal tipping with intrusion, for second premolar lingual and mesial tipping of crown with extrusion, first molar showed lingual movement of crown with mesiolingual rotation, intrusion. Second molar showed mesiolingual rotation, mesial tipping and extrusion was seen. The trend as observed in their study was almost similar to present study. They found minimal stress in lingual surface of root of incisor as 0.002192 N followed by canine (0.001256 N) in labial mechanics.

Patel et al^[1] compared four different loops T-loop, mushroom loop, keyhole loop and teardrop loop using conventional bracket. However, they excluded teeth and adjoining structures after fabrication of loop and measured moment to force ratio for different loops. They found a moment to force ratio at molar as (5.83) for mushroom loop (5.87) for teardrop loop that lesser than K-loop (5.45) and key hole loop (6.10) but had comparable moment to force ratio of 9.15 - 9.16 for all loops at central incisor suggestive of bodily movement of anterior segment in all loops.

Bohara et al^[37] conducted a FEM study to evaluate stress of maxillary anterior teeth during enmasse intrusion and retraction using conventional bracket. The maximum stress in the PDL was found in the cervical area with a changing pattern from tensile to compressive from cervical area to root apex.

Kojima et al^[17] utilized finite element simulation to analyze tooth movements in enmasse retraction with sliding mechanics in conventional bracket. Immediately after force application of 1 N tipping of the anterior teeth (0.2 degree) was observed and root moved mesially and the crown moved distally with a mean stress in the PDL of 13kPa.

The overall conclusion of above mentioned studies was that stress concentration at pdf cortical bone and cancel the sport was adjacent to the extraction spaces and was similar to the present study. However, stresses at PDL, cortical and cancellous bone for both the mechanics at two force levels differed from previous studies, but values were within yield strength of respective anatomical structures (PDL, cancellous and

cortical bone) as used during incorporation of material properties for making FEM model.

The results of the present study will be discussed with respect to clinical studies. (Shilb et al, Rhee et al, Kumar S et al, Machibaya et al, Shivapuja et al)

Shibl et al^[47] compared friction (power chain with 0.017" x 0.025" SS archwire and 9 mm crimpable hook) and frictionless mechanics (T loop 0.017" x 0.025" TMA) during enmasse retraction using conventional bracket. The rate of retraction of anterior segment was seen to be more for friction mechanics than frictionless mechanics. For the friction group, the rate of retraction was 0.63 ± 0.18 mm per month, with a total retraction of 4.04 ± 1.41 mm spanning over 6.42 ± 1.08 months. The frictionless group was 0.75 ± 0.23 mm per month with a total retraction of 4.13 ± 1.44 mm, over 5.67 ± 1.5 months. Anchorage loss was seen for both the mechanics but was comparatively higher for frictionless mechanics ($p < 0.001$). Molar rotation (7.58-degree) was seen for friction mechanics. In the frictionless group, there was a 14.9 - degree rotation seen. Slight amount of intrusion and lingual crown torque was also seen for both the groups by 15.46 and 13 degrees in the friction and the frictionless group.

Rhee et al^[7] compared friction (NiTi closed coil spring) and frictionless (poulgjessing spring) mechanics to evaluate the tipping, rotation, extrusion, intrusion, amount of retraction and anchorage loss for maxillary canine retraction. Canine retraction was more in friction mechanics (5.97 mm) than frictionless mechanics (5.74 mm). The amount of anchorage loss was more in frictionless mechanics (3.01mm) than friction mechanics (2.92mm). The friction or sliding mechanics showed more tipping than frictionless or loop mechanics. ($P < 0.0001$). The extrusion of canine and second premolar was observed to be more for sliding or friction mechanics. ($P = 0.20$).

Kumar S et al^[29] evaluated friction in various types of brackets and arch wires. It was seen that self ligating bracket (Damon 3 SLTM) had the lowest friction for all dimensions of wire in comparison to conventional and active SLB bracket. For 19 x 25 stainless steel wire, passive SLB had the lowest friction (0.1) > active SLB (0.56) > conventional bracket (2.8).

Machibaya et al^[25] compared the treatment time, outcome, and anchorage loss for conventional and self ligating brackets. Self ligating bracket showed more amount of

displacement in comparison to conventional bracket. The maxillary central incisor was displaced by 11.13 mm in SLB and 1.04 in conventional bracket.

Shivapuja et al^[3] compared conventional bracket and self ligating bracket. It was observed that self-ligating bracket systems displayed a significantly lower level of frictional resistance for passive self ligating bracket (10 g) > active self ligating bracket (25 g) > standard twin bracket (40 g).

As sliding mechanics showed greater rate of space closure than loop mechanics in previous clinical studies for different bracket prescriptions, sliding mechanics in the present FEM study showed more lingual tipping than loop mechanics; however, the difference was negligible.

Within limitations of the present study, it can be stated that loop mechanics is equally effective for retraction of anterior teeth using self-ligating brackets. The main clinical implication is that loop mechanics should be preferred when bodily tooth movement is desired. Also, at lesser force levels, stresses were lesser during en masse retraction of anterior teeth using both mechanics, with negligible difference in displacement (250 g > 200 g), hence retraction of anterior teeth can be accomplished at 200 G of force with either mechanics. Also, anchorage taxation was lesser at 200 g of force.

As desired M/F ratio needed for bodily tooth movement can easily be achieved by avoiding frequent activations. As force used during retraction of teeth over a period of time, thereby increasing M/F ratio needed for accomplishing translatory as well as root movement.

The major limitation is that the complex and dynamic oral environment cannot be simulated using FEM. Analytical results of FEM are highly dependent on the models developed. In FEM studies, the PDL was modeled as a layer of uniform thickness and was treated as linear elastic and isotropic even though the PDL exhibits anisotropy and nonlinear viscoelastic behavior because of tissue fluid. Another limitation of this study is the inability to directly predict long-term tooth movement quantitatively through simulation. Finite element model can only calculate initial tooth displacement and stress distribution after force application. Hence results of any FEM study must be validated with clinical studies.

Future scope includes evaluation of stress and displacement for enmasse retraction of anterior teeth using different loops, different powerarm heights in sliding and loop mechanics in self ligating brackets. Also, retraction can be evaluated when accomplishing sliding mechanics with anchorage reinforcement using mini screw. Clinical studies on larger sample size can validate results of FEM studies.

Following conclusion were drawn from the present study conducted with an aim to evaluate and compare the stresses and displacement in anterior and posterior segment during enmasse space closure with loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system using FEM.

- Enmasse retraction of anterior teeth was more in sliding mechanics than loop mechanics at each force level.
- For either of the mechanics displacement increased as force increased both for anterior and posterior segment.
- In all models stress was more at occlusal surface than at apex of all teeth suggestive of lingual tipping of teeth in the anterior segment. Loop mechanics at 200 g had least difference between stresses at apex and occlusal surface, suggestive of minimal tipping than other models.
- During enmasse retraction of anterior teeth anchorage taxation was more in sliding mechanics than loop mechanics at each force level.
- In all models – for both mechanics different – displacement between – and apex of posterior teeth would more at 250 grams than 200 g of force suggesting of less mesial tipping of posterior segment in at 200 g of force.
- For cortical and cancellous bone stress was more in sliding mechanics (250 g of force) > loop mechanics (250 g of force) > sliding (200 g of force) > loop mechanics (200 g of force).

The overall conclusion drawn from results of the present study is that loop mechanics is equally effective for retraction of anterior teeth using self ligating brackets and type of mechanics must be decided as pre individual case requirement.

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- 56.

Orthodontic tooth movement occurs when applied force overcome the friction between the bracket and archwire. Enmasse retraction of anterior teeth during space closure can be achieved through two types of mechanics i.e., frictionless (loop) mechanics or friction (sliding) mechanics.

The Mushroom loop advocated by Nanda was used to evaluate space closure in present study. In sliding mechanics, NiTi closed coil spring was used for the present study.

Several factors influence friction, which includes wire size, material, and ligation technique. Smaller-sized wires and round wires generally encounter less friction, but for effective three-dimensional control during space closure, higher dimension wires with less play are essential. Thus, in brackets with 0.022x0.028 slot arch wire with 0.019''X 0.025''inch dimension is preferred. 0.019''X 0.025''inch SS arch wire for sliding mechanics and 0.019''X 0.025''inch TMA wire for loop mechanics was considered for this study.

In conventional orthodontics, arch wire is tied to brackets and ligation is considered as an established parameter affecting the resistance to applied forces. The advent of self-ligating brackets was based on the fact that, elimination of ligating wire to tie the wire to bracket slot would reduce friction. They come with accessories like clips or lock gates, which keep the arch wire in the slot.

The efficacy of SLB in reducing friction in comparison to conventional brackets has been evaluated in various studies. These studies showed lower frictional resistance with self-ligating bracket systems. It was also seen that reduced friction with self-ligating brackets was only in initial stages, however on engaging full dimension wire, reduction in friction was not evident. In other studies frictional resistance was similar between self-ligating bracket and conventional bracket, however stress was much lesser in passive self-ligating bracket system. The efficacy of SLB during space closure using sliding and frictionless mechanics has not been widely evaluated in previous studies, hence it was decided to evaluate the same in present study.

Self ligating bracket (SLB) system have two main designs, based on the mechanism of lid closure i.e. active and passive. Passive SLBs do not exert any active force, has lesser friction than active SLB and have minimal interference which allows for a clearer understanding of the biomechanics involved, making it easier to analyse and model in finite element simulations, hence it was decided to use passive SLB in present study.

Several clinical studies have shown efficacy of SLB however little information regarding pattern of mechanical stresses in tissue around teeth during space closure is available. As quantification of stress is difficult in clinical studies, FEM has been chosen for the present study.

As self ligating brackets have lower frictional resistance hence it is anticipated that amount of stress during space closure would also be lesser. Hence, forces for enmasse space closure might be lesser than those needed conventionally for similar displacement of anterior segment hence it was decided to employ two forces i.e. 250 g (regularly recommended for space closure using conventional brackets) and a lesser value of 200 g of force, so as to see amount of stress and displacement generated using sliding or loop mechanics for space closure in self ligating brackets.

Considering this, the aim of the present study was to evaluate and compare the stresses and displacement in anterior and posterior segment during enmasse space closure with loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system using FEM.

This comparative in-vitro study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, Babu Banarasi Das College of Dental Sciences, Lucknow in collaboration with ANAMAC (Gurugram).

A maxillary arch was modeled on the basis of CBCT images. FUSION 360 software was used to convert CBCT into STL format to CAD model of maxillary arch. Geometric model of Passive self ligating bracket prescription with 0.022'' X 0.028'' inch bracket slot, molar tube, NiTi closed coil spring, crimpable hook, stainless-steel archwire of 0.019''X 0.025'' inch and a TMA arch wire with mushroom loop was modelled using SOLIDWORKS modeling software was used for the construction of geometric model from CAD models. HYPERMESH software was used to create mesh models and also was used to fuse the model of maxilla with PDL, bone and complete assembly of brackets, molar tube, arch wire, NiTi closed coil spring, crimpable hook, stainless-steel archwire of 0.019''X 0.025'' inch and a TMA arch wire with mushroom loop etc. to make FEM models. A total of 2 finite element model with 4 load cases were generated and boundary conditions was applied. Material properties were incorporated for teeth, PDL, bone, stainless steel and TMA. FEM models were divided into two groups (Group I and Group II) based on mechanics. Group I included FEM model where loop (frictionless mechanics) was used for enmasse retraction and Group II

included FEM model for sliding (frictional mechanics). Each group was subdivided into two groups (A and B) based on the amount of force applied (A – 200 g and B – 250 g).

The finite element model was submitted to HYPERMESH Finite Element (FE) solver to perform the simulation. Finally, HYPERVIEW software was used to read finite element results, generate result images and extract stress data from simulation. Von Mises stress and displacement in three axis (X-Axis for labio-lingual movement, Y-Axis for occluso-gingival movement and Z-Axis for mesio-distal movement) was measured. Data was tabulated to understand stress and displacement during sliding and loop mechanics using two different force levels.

Following results could be drawn from the results of the present study-

- Enmasse retraction of anterior teeth was more in sliding mechanics than loop mechanics at each force level.
- For either of the mechanics displacement increased as force increased both for anterior and posterior segment.
- In all models stress was more at occlusal surface than at apex of all teeth suggestive of lingual tipping of teeth in the anterior segment. Loop mechanics at 200 g had least difference between stresses at apex and occlusal surface, suggestive of minimal tipping than other models.
- During enmasse retraction of anterior teeth anchorage taxation was more in sliding mechanics than loop mechanics at each force level.
- In all models – for both mechanics different – displacement between – and apex of posterior teeth would be more at 250 grams than 200 g of force suggesting of less mesial tipping of posterior segment in at 200 g of force.
- For cortical and cancellous bone stress was more in sliding mechanics (250 g of force) > loop mechanics (250 g of force) > sliding (200 g of force) > loop mechanics (200 g of force).

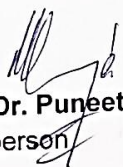
The overall conclusion drawn from results of the present study is that loop mechanics is equally effective for retraction of anterior teeth using self ligating brackets and type of mechanics must be decided as per individual case requirement.

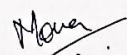
ANNEXURE-I

**BABU BANARASI DAS UNIVERSITY**
BBD COLLEGE OF DENTAL SCIENCES, LUCKNOW**INSTITUTIONAL RESEARCH COMMITTEE APPROVAL**

The project titled “Comparative Evaluation Of Friction And Frictionless Mechanics In Self-Ligating System – Fem Study” submitted by Dr Sweety Gupta Postgraduate student in the Department of Orthodontics & Dentofacial Orthopaedics for the Thesis Dissertation as part of MDS Curriculum for the academic year 2021-2024 with the accompanying proforma was reviewed by the Institutional Research Committee in its meeting held on 14th September, 2022 at BBDCODS.

The Committee has granted approval on the scientific content of the project. The proposal may now be reviewed by the Institutional Ethics Committee for granting ethical approval.


Prof. Dr. Puneet Ahuja
Chairperson


Dr. Mona Sharma
Co-Chairperson

ANNEXURE-II



BABU BANARASI DAS UNIVERSITY

BBD COLLEGE OF DENTAL SCIENCES, LUCKNOW

BBDCODS/IEC/09/2022

Dated: 16th September, 2022Communication of the Decision of the Xth Institutional Ethics Sub-Committee Meeting

IEC Code: 18

Title of the Project: Comparative Evaluation Of Friction And Frictionless Mechanics In Self-Ligating System – Fem Study.

Principal Investigator: Dr Sweety Gupta **Department:** Orthodontics & Dentofacial Orthopaedics

Name and Address of the Institution: BBD College of Dental Sciences Lucknow.

Type of Submission: New, MDS Project Protocol

Dear Dr Sweety Gupta,

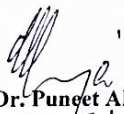
The Institutional Ethics Sub-Committee meeting comprising following members was held on 15th September, 2022.

- | | |
|---|--|
| 1. Dr. Lakshmi Bala
Member Secretary | Prof. and Head, Department of Biochemistry |
| 2. Dr. Praveen Singh Samant
Member | Prof. & Head, Department of Conservative Dentistry & Endodontics |
| 3. Dr. Jiji George
Member | Prof. & Head, Department of Oral Pathology & Microbiology |
| 4. Dr. Amrit Tandan
Member | Professor, Department of Prosthodontics and Crown & Bridge |
| 5. Dr. Rana Pratap Maurya
Member | Reader, Department of Orthodontics & Dentofacial Orthopaedics |

The submitted documents of the current MDS Project Protocol is exempted for review in the meeting.

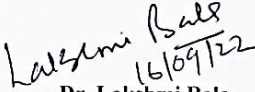
Decision: The MDS Protocol is exempted for review by the Institutional Ethics Sub-Committee.

Forwarded by:


Prof. Dr. Pooja Ahuja
 Principal
 BBD College of Dental Sciences
 BBD University, Lucknow

PRINCIPAL

Babu Banarasi Das College of Dental Sciences
 (Babu Banarasi Das University)
 BBD City, Faizabad Road, Lucknow-226028


Dr. Lakshmi Bala
 Member-Secretary
 Institutional Ethics Sub-Committee (IEC)
 BBD College of Dental Sciences
 BBD University, Lucknow
Member-Secretary
 Institutional Ethics Committee
 BBD College of Dental Sciences
 BBD University
 Faizabad Road, Lucknow-226028

ANNEXURE -III

Babu Banarasi Das College of Dental Sciences

(Babu Banarasi Das University)

BBD City, Faizabad Road, Lucknow – 227105 (INDIA)

Guidelines for Devising a Participant / Legally Acceptable Representative Information Document (PID) in English

1. Study Title

Comparative evaluation of friction and frictionless mechanics in self-ligating system – FEM study.

2. Invitation Paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research/study is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives and your treating physician/family doctor if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3. What is the purpose of the study?

The purpose of the study is to evaluate and compare loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system during enmass space closure using FEM at two force levels (250, 200 gms).

4. Why have I been chosen?

No patient is required as it is an in vitro study

5. Do I have to take part?

Not applicable.

6. What will happen to me if I take part?

Not applicable.

7. What do I have to do?

Not applicable

8. What is the procedure that is being tested?

The procedure will involve comparative evaluation of loop (frictionless) and sliding (frictional) mechanics in passive self ligating bracket system.
FEM study

What are the interventions for the study?

1. To evaluate the stress and displacement in the anterior segment (incisors and canine) during enmass space closure with sliding mechanics in self-ligating bracket system.
2. To evaluate the stress and displacement in the posterior segment (second premolar, first and second molar) during enmass space closure with sliding mechanics in self-ligating bracket system.
3. To evaluate the stress and displacement in the anterior segment (incisors and canine) during enmass space closure with loop mechanics in self-ligating bracket system.
4. To evaluate the stress and displacement in the posterior segment (second premolar, first and second molar) during enmass space closure with loop mechanics in self-ligating bracket system.
5. To make intra and inter group comparison of stress and displacement for anterior and posterior segment during enmass space closure with friction (sliding) and frictionless (loop) mechanics in self-ligating bracket system.

9. What are the side effects of taking part?

Not applicable

10. What are the possible disadvantages and risks of taking part?

Not applicable

11. What are the possible benefits of taking part?

Not applicable

12. What if new information becomes available?

Sometimes during the course of a research project, new information becomes available about the research being studied. If this happens, your researcher will tell you about it and discuss with you whether you want to continue in the study. If you decide to withdraw, your researcher/investigator will make arrangements for your withdrawal. If you decide to continue in the study, you may be asked to sign an updated consent form.

13. What happens when the research study stops?

If the study stops/finishes before the stipulated time, this will be explained to the patient/volunteer.

14. What if something goes wrong?

If any severe adverse event occurs, or something goes wrong during the study, the complaints will be handled by reporting to the institution (s), and Institutional ethical community.

15. Will my taking part in this study be kept confidential?

Not applicable as it is an in vitro study.

16. What will happen to the results of the research study?

The results of the study will be used to be compare stress distribution on alveolar bone.

17. Who is organizing the research?

This research study is organized by the academic institution (BBDCODS).

18. Will the results of the study be made available after study is over?

Yes

19. Who has reviewed the study?

The study has been reviewed and approved by the Head of the Dept,
and the IEC/IRC of the institution.

20. Contact for further information

Dr. Sweety Gupta

Department of Orthodontics and Dentofacial Orthopaedics

Babu Banarasi College of Dental Sciences.

Lucknow-227105

Mob- 8597633433

Dr. Tripti Tikku (Professor)

Department of Orthodontics and Dentofacial Orthopaedics

Babu Banarasi College of Dental Sciences.

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Mob-9554832799

Dr. Sneh Lata Verma (Professor)

Department of Orthodontics and Dentofacial Orthopaedics

Babu Banarasi College of Dental Sciences.

Lucknow-227105

Mob-8960943326

Dr. Rohit Khanna (HOD)

Department of Orthodontics and Dentofacial Orthopedics

Babu Banarasi College of Dental Sciences.

Lucknow-227105

Mob-9415037011

Signature of PI.....

Name.....

Date.....

ANNEXURE -IV

Babu Banarasi Das College of Dental Sciences

(Babu Banarasi Das University, Lucknow)

BBD City, Faizabad Road, Lucknow – 227105 (INDIA)

प्रतिभागी के लिए सूचना पत्र

1. अध्ययन शीर्षक?

स्वयं बंधन प्रणाली में घर्षण और घर्षणरहित यांत्रिकी का तुलनात्मक मूल्यांकन - एफईएम अध्ययन

2. निमंत्रण अनुच्छेद?

मान्य नहीं।

3. अध्ययन का उद्देश्य क्या है?

अध्ययन का उद्देश्य है स्वतंत्र सेल्फ लिगेटिंग ब्रैकेट सिस्टम में लूप (फ्रिक्शनलेस) और स्लाइडिंग (फ्रिक्शनल) मैकेनिक्स का मूल्यांकन करना और तंतुमात्रा में दो बलों के स्तरों (250, 200 ग्राम) पर एंमैस स्पेस क्लोजर के दौरान उपयुक्तता और तुलना करना है, एफईएम का उपयोग करके।

4. मुझे इस अध्ययन के लिए क्यों चुना गया है?

किसी रोगी की आवश्यकता नहीं है।

5. क्या इसमें मुझे भाग लेना चाहिए?

मान्य नहीं।

6. मुझे क्या होगा यदि मैं इस अध्ययन में भाग लेता हूँ।

मान्य नहीं।

7. मुझे क्या करना है?

मान्य नहीं।

8. किस प्रक्रिया का अध्ययन किया जा रहा है?

1. स्व-लाइगेटिंग ब्रैकेट सिस्टम में स्लाइडिंग मैकेनिक्स के साथ एंमैस स्पेस क्लोजर के दौरान अंतःक्रिया (इंसाइजर्स और कैनाइन) में तनाव और स्थानांतरण का मूल्यांकन करना।
2. स्व-लाइगेटिंग ब्रैकेट सिस्टम में स्लाइडिंग मैकेनिक्स के साथ एंमैस स्पेस क्लोजर के दौरान पश्चिमी सेगमेंट (दूसरा प्रीमोलर, पहला और दूसरा मोलर) में तनाव और स्थानांतरण का मूल्यांकन करना।
3. स्व-लाइगेटिंग ब्रैकेट सिस्टम में लूप मैकेनिक्स के साथ एंमैस स्पेस क्लोजर के दौरान अंतःक्रिया (इंसाइजर्स और कैनाइन) में तनाव और स्थानांतरण का मूल्यांकन करना।
4. स्व-लाइगेटिंग ब्रैकेट सिस्टम में लूप मैकेनिक्स के साथ एंमैस स्पेस क्लोजर के दौरान पश्चिमी सेगमेंट (दूसरा प्रीमोलर, पहला और दूसरा मोलर) में तनाव और स्थानांतरण का मूल्यांकन करना।
5. स्व-लाइगेटिंग ब्रैकेट सिस्टम में फ्रिक्शन (स्लाइडिंग) और फ्रिक्शनलेस (लूप) मैकेनिक्स के साथ एंमैस स्पेस क्लोजर के दौरान अंतः और अंतर समूह तुलना करना के लिए तनाव और स्थानांतरण का मूल्यांकन करना।

9. इस शोध में कौन से हस्तक्षेप दिए जाएंगे?

मान्य नहीं।

10. इस अध्ययन में भाग लेने के क्या दुष्प्रभाव हैं?

मान्य नहीं।

11. इस अध्ययन में भाग लेने के संभावित जोखिम और नुकसान क्या हैं?

मान्य नहीं।

12. अध्ययन में भाग लेने के संभावित लाभ क्या हैं?

मान्य नहीं।

13. क्या होगा यदि कोई नई जानकारी उपलब्ध हो जाती है?

मान्य नहीं।

14. क्या होता है जब अध्ययन / शोध परीक्षण बंद हो जाता है?

मान्य नहीं।

15. क्या होगा अगर कुछ गलत हो जाता है?

मान्य नहीं।

16. क्या इस अध्ययन में मेरा हिस्सा गोपनीय रखा जाएगा?

मान्य नहीं।

17. अध्ययन / शोध परीक्षण के परिमाण का क्या होगा?

मैक्सिलरी के चार सामने के दांतों को अंदर ले जाने के लिए कौन सा मैकेनिक बेहतर है।

18. इस अध्ययन को कौन आयोजित कर रहा है और इस परीक्षण के लिए धन कहां से आएगा?

यह शोध अध्ययन शैक्षणिक संस्थान (बीबीडीसीओडीएस) द्वारा आयोजित किया जाता है।

19. क्या सेवाएं शोध खत्म हो जाने के बाद उपलब्ध रहेगी या नहीं?

हां।

20. अध्ययन की समीक्षा किसने की है?

अध्ययन की समीक्षा की गई है और विभाग के प्रमुख, और आईईसी/आईआरसी के द्वारा अनुमोदित किया गया है। निम्न

लोगों से संपर्क करें

21.अधिक जानकारी के लिए संपर्क करें ।

डॉ स्वीटी गुप्ता

ऑर्थोडॉन्टिक्स और डेंटोफेशियल ऑर्थोपेडिक्स विभाग

बाबू बनारसी कॉलेज ऑफ डेंटल साइंसेज।

लखनऊ-227105

मोब- 8597633433

डॉ तृप्ति टिक्कू (प्रोफेसर)

ऑर्थोडॉन्टिक्स और डेंटोफेशियल ऑर्थोपेडिक्स विभाग

बाबू बनारसी कॉलेज ऑफ डेंटल साइंसेज।

लखनऊ-227105

मोब-9554832799

डॉ. स्नेह लता वर्मा (प्रोफेसर)

ऑर्थोडॉन्टिक्स और डेंटोफेशियल ऑर्थोपेडिक्स विभाग

बाबू बनारसी कॉलेज ऑफ डेंटल साइंसेज।

लखनऊ-227105

मोब-8960943326

डॉ रोहित खन्ना (एचओडी)

ऑर्थोडॉन्टिक्स और डेंटोफेशियल ऑर्थोपेडिक्स विभाग

बाबू बनारसी कॉलेज ऑफ डेंटल साइंसेज।

लखनऊ-227105

मोब-9415037011

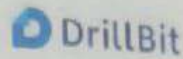
bdbcods.iec@gmail.com

पीआईकाहस्ताक्षर

नाम

दिनांक.....

ANNEXURE -V



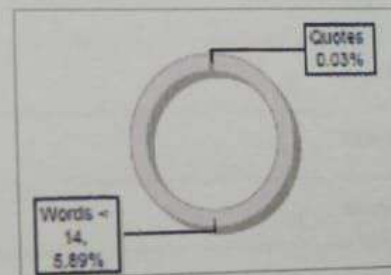
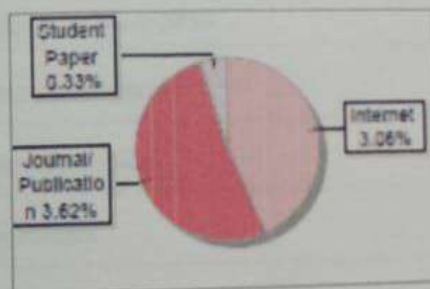
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Submission Information

Author Name	Sweety Gupta
Title	COMPARATIVE EVALUATION OF FRICTION AND FRICTIONLESS MECHANICS IN SELF-LIGATING BRACKETS - A FEM STUDY
Paper/Submission ID	1450656
Submitted by	anuragpal.singh0016@bbedu.ac.in
Submission Date	2024-02-20 15:17:11
Total Pages	37
Document type	Dissertation

Result Information

Similarity 7.9%



Exclude Information

Quotes	Excluded
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Sources: Less than 14 Words: %	Excluded
Excluded Source	0.9%
Excluded Phrases	Not Excluded

Database Selection

Language	English
Student Papers	Yes
Journals & publishers	Yes
Internet or Web	Yes
Institution Repository	Yes



Tripti Tripathi

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SIMILARITY %		MATCHED SOURCES	GRADE	
LOCATION	MATCHED DOMAIN		%	SOURCE TYPE
1	worldwidescience.org		1	Internet Data
2	www.freepatentsonline.com		1	Internet Data
3	asianssr.org		1	Publication
4	Optimal loading conditions for controlled movement of anterior teeth in sliding by Jun-y-2010		1	Publication
5	www.slideshare.net		1	Internet Data
6	www.ijmdcr.com		<1	Publication
7	moam.info		<1	Internet Data
8	www.jpbums.info		<1	Publication
9	www.jpbums.info		<1	Publication
10	vdocuments.mx		<1	Internet Data
11	asianssr.org		<1	Publication
12	REPOSITORY - Submitted to Dr Y.S.R. UNIVERSITY OF HEALTH SCIENCES VIJAYAWADA on 2023-06-28 08-57		<1	Student Paper
13	Polarized Apical Targeting Directed by the SignalAnchor Region of Simian Virus by Huang-1997		<1	Publication