EVALUATION OF MOMENT-FORCE RATIO OF TWO DIFFERENT LOOPS – A FINITE ELEMENT STUDY

Dissertation submitted to

THE TAMILNADU DR. M.G.R.MEDICAL UNIVERSITY

In partial fulfillment for the degree of

MASTER OF DENTAL SURGERY

BRANCH V

ORTHODONTICS AND DENTOFACIAL ORTHOPAEDICS

APRIL - 2013

CERTIFICATE

This is to certify that this dissertation titled **"EVALUATION OF MOMENT-FORCE RATIO OF TWO DIFFERENT LOOPS – A FINITE ELEMENT STUDY""** is a bonafide record of work done by **Dr.G.NUPUR ARATHI** under my guidance during her postgraduate study period 2010–2013.

This dissertation is submitted to **THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of **Master of Dental Surgery** in Branch V – Orthodontics and Dentofacial Orthopaedics. It has not been submitted (partially or fully) for the award of any other degree or diploma.

Guided by

Dr. Rekha Bharadwaj M.D.S.,
Reader
Department of Orthodontics and
Dentofacial Orthopedics,
Ragas Dental College and Hospital,
Chennai.

Head of Department

N.R.
22/12/12

Dr.N.R.Krishnaswamy M.D.S.,
M.Ortho R.C.S.(Edin), Dip.N.B.(Ortho)
Diplomate of Indian Board of Orthodontics
Professor and Head
Department of Orthodontics and Dentofacial Orthopedics,
Ragas Dental College & Hospital, Chennai.

Principal

Dr. S.Ramachandran, M.D.S.,
Ragas Dental College & Hospital,
Chennai

PRINCIPAL
RAGAS DENTAL COLLEGE & HOSPITAL
CHENNAI

ACKNOWLEDGEMENTS

At this juncture I am honour bound to express my immense gratitude to everyone who have helped me through this journey.

Firstly I extend my gratefulness to my very respected and beloved professor, ***Dr.N.R.Krishnaswamy, M.D.S., M.Ortho RCS.(Edin),*** *Diplomat of Indian National of Orthodontics, Professor and Head, Department of Orthodontics, Ragas Dental College and Hospital, Chennai. It is indeed my good fortune to have had the opportunity to do my post graduation under his able guidance. Besides being a constant source of encouragement, he has inspired me to perform better not only in academics but also in life. I thank him for having taken interest in my study and providing his valuable insight.*

I am indebted to express my solemn gratitude to my respected professor ***Dr.S.Venkateswaran, M.D.S.,D.N.B*** *(Ortho), for being a pillar of support all through my academics.*

I would like to thank my professor, ***Dr. Ashwin George, M.D.S.,D.N.B*** *(Ortho) to have helped me tune myself to the changing environment in our profession.*

Words seem insignificant to express my deep sense of gratitude to my post graduate teacher and guide, ***Dr.Rekha Bharadwaj,*** *M.D.S.,(Reader), Department of Orthodontics, Ragas Dental College and Hospital, Chennai, for her valuable guidance, suggestions, tireless pursuit for perfection and her* *immense patience towards my amateur mistakes. I thank her for the keen surveillance of the minute details throughout this dissertation. Without the help that she has conferred upon me this dissertation would not have come true.*

My sincere thanks to ***Prof.Mr.KANAGARAJ,*** *Chairman &* ***Dr.S.RAMACHANDRAN,*** *Principal, Ragas Dental College for providing me with an opportunity to utilize the facilities available in this institution in order to conduct this study.*

I greatly acknowledge ***Dr. SHAHUL*** *(Professor),* ***Dr. ANAND*** *(Reader)* ***Dr. JAYAKUMAR*** *(Reader),* ***Dr. SHAKEEL*** *(Reader),* ***Dr. SHOBANA, Dr. PRABHU,*** *and* ***Dr. BIJU TOM, Dr. KAVITHA. S.IYER*** *(senior lecturers) for their support, enthusiasm & professional assistance throughout my post graduate course.*

My heartfelt thanks to my wonderful batch mates ***Dr. Ashwin, Dr. Manikandan, Dr. Deepak, Dr. Siva Subramanian, Dr. Sakthi, Dr. Ravanth,*** *who were cheerfully available at all times to help me. I wish them a successful career ahead.*

I also extend my gratitude to my juniors ***Dr.Femin, Dr.Murali, Dr.Vishal, Dr.Gayathri, Dr.Manali, Dr.Vikram, Dr.Regina*** *and* ***Dr.Saptharishi, Dr.Anselm, Dr.Avdesh, Dr.Divya, Dr.Jayakrishna, Dr.Karthik, Dr.Mercy, Dr.Piradhiba, Dr.Shrabani,*** *for all their support.*

*I thank Mr.Ravanan***,** *for helping me with the statistical analysis for the study. I am extremely thankful to* ***Versetia Technologies*** *for conducting the finite element analysis for my study.*

I extend my gratitude to ***Mr.Ashok and Mr.Rajendran*** *for helping with the photographs of the study.*

I would like to thank Sisters ***Lakshmi, Rathi, Kanaka, & Azeena, Ms. Banupriya, Ms.Divya,*** *and attender* ***Mr. Baskar, Mr. Mani*** *for their co-operation and help during my Post-Graduate course.*

My heartfelt thanks to my wonderful grandparents, ***Prof. Dr.C.A.Perumal and Mrs.Jayalakshmi Perumal,*** *who have been my pillar of support and an eternal source of energy in every endeavour of mine.*

I would also like to thank my parents, ***Dr.K.Gurunath and Dr.Vimala Gurunath,*** *and my sister,* ***G.Rohini*** *for their love, understanding and support.*

Above all, I am thankful to God almighty, to have given me the strength to pursue this course and also to have given all these wonderful people in my life.

CONTENTS

ABSTRACT

Biomechanics of space closure is an integral stage of orthodontic treatment wherein, the understanding of the mechanical system utilized for closing extraction space is critical. Loop mechanics is a more convenient method of space closure in that a known force system is delivered to the teeth and no friction involved. Two popular loops used for en-masse space closure are Double Keyhole loop and Continuous T-loop. However, they are biomechanical properties and their retraction efficiency has not been studied previously in literature.

Therefore, the present study aimed to involve the moment-force ratio of Double Keyhole loop and Continuous T-loop for en-masse space closure with two different methods of activation using a finite element method. The resultant stress, displacement and moment-force ratio was calculated for two loops at 0, 15 and 30 degree gable bends at 1 mm activation using cinch back and ligature tie.

Results show that there was no significant difference in the overall stress distribution and displacement of the teeth with both the loops. Nevertheless, the moment-force ratio achieved a desirable ratio of 8-10 and increased with increase in gable bend with both Double Keyhole loop and Continuous T-loop. Therefore the study conclusively proves that both the loops, though different in design and morphology was equally efficient for en-masse space closure producing bodily or translatory tooth movement without anchor loss in maximum anchorage cases.

Keywords :- Finite element analysis, Double keyhole loop (DKHL), Continuous T-loop (T-loop), moment-force ratio.

INTRODUCTION

Biomechanics of Space Closure poses a great challenge to an orthodontist and is the integral stage of orthodontic treatment wherein, the understanding of the mechanical system utilized for closing extraction space is critical. This can be done depending on the type of tooth movement needed and the anchorage requirements. Anchorage control is delivery of differential force system to the anchor tooth and is determined by applying unequal moment – force ratios to each unit.

Tooth movement can be accomplished with optimum forces and the rate of tooth movement increases with force upto a point after which the tooth movement decreases or ceases with increased force levels due to undermining resorption and necrosis of the supporting periodontal tissues as suggested by Storey and Smith[65,74].

Schwartz et al stated that optimal force levels are required to achieve predictable tooth movement because forces below this level cause no tissue response in the periodontal ligament whereas excessive force leads to tissue necrosis, preventing tooth movement[57, 74].

The current concept of optimal force is based on the hypothesis that a force of certain magnitude and temporal characteristics (continuous Vs intermittent, constant Vs declining etc) would be capable of producing a maximum rate of tooth movement without tissue damage[74]. Therefore, the preferred space closure mechanism must be the one that is easy to fabricate with minimal activation, cause least discomfort to the patient and finally produce a predictable space closure[43].

Hence, treatment mechanics should produce an dentition that are in ideal positions with roots uprighted and stable on the basal bone. In majority of cases, this can be accomplished with bodily/translatory type of tooth movement.

Space closure can be accomplished using either friction or frictionless/loop mechanics. Friction mechanics causes binding of the archwire, thereby taxing the anchorage, increasing the force levels, resulting in unwanted tooth movement[25].

In this regard, loop mechanics is more beneficial in that a known force system is delivered to the teeth and spaces are closed with the help of loops with forces and couples built into it. Moreover, the loops incorporated in the arch wire increases the flexibility and springiness thereby producing optimal force for different types of tooth movement[8, 10].

Space closure can be done either as two step retraction where the canines are distalized first followed by anterior retraction that is supposed to be less detrimental to anchorage. However, the treatment time is prolonged. On the contrary, an en-mass /one step retraction is more beneficial in terms of duration of treatment. Nevertheless it is still debated if a two-step retraction is more beneficial compared to en-masse retraction for preserving anchorage.

There are several loops in the literature that can be used for space closure.T-loop is one of the most common loop for producing predictable space closure. It was developed by Burstone et al for individual canine retraction using TMA wires[10]. The literature is replete for segmental T-loop biomechanics when compared to continuous T-loop biomechanics.

Double keyhole loop was introduced by John Parker[55] and has the following specific advantages:-

1. Allows the luxurious use of one set of arch wire for entire space closure.
2. Allows a reasonably happy medium between severe tipping and sliding mechanics.
3. Allows the operator to select how the space will be closed depending on anchorage consideration.
4. Control of canine position.

Incorporation of two loops makes the arch wire more flexible for optimum force delivery. It acts like a stress braker in the canine region. To satisfy the principles of gnathology, the in-built canine tip in Roth prescription is 13° and if the force levels are not at an optimum, this can alter the moment–force ratio, cause the canine root to be displaced into the cortical plate, thereby taxing the anchorage. In this regard Roth suggested that double keyhole loop particularly works well with his prescription, aiding in excellent control of canine position and rotation. There is no existing literature available on the biomechanics of Double key hole loop.

Some of the important factors governing the loop mechanics are the moment-force ratio and the load deflection rate. The moment-force ratio determines the center of rotation of a tooth or segment of teeth, thus allowing translation, tipping or root movement[46].

A preactivation or gable bends is frequently incorporated into the loop configuration to control the centers of rotation through an appropriate moment-force (M/F) ratio, thereby preventing uncontrolled tipping of the teeth[64].

Conveniently most of the loops are activated by cinching the wire distal of the first or second molar, there by activating the loop. As the loops close, the teeth come together, closing the space. However, the disadvantage includes difficulty in accessibility and patient discomfort. A different activation method was suggested by Suzuki wherein the loops are opened for activation and then a stainless steel ligature is used to ligate the distal loop to the hook of the first or second molar tube, with sufficient tension to keep the loops open. As the loops tend to close, the ligature will exert force on the molar tube and the teeth will come together[3]. Nevertheless, this method of activation can vary the point of force application and center of resistance hence the moment-force ratio. Therefore, the response of the teeth and assessing the type of stress distribution in the supporting tissue and moment-force ratio with different methods of activation is essential for assessing the 3D control of teeth during space closure.

Various methods have been used to study the force generated and stress distribution in the periodontium. However, the finite element analysis is a non-invasive technique, in which the object of various shapes of materials of non homogenous nature can be studied three dimensionally. It provides a quantitative data that increases the understanding of the physiologic reactions that occur after force application and may yield an improved understanding of the reaction and interactions of individual tissues. Thus the actual stress experienced can be measured at any point of force application[71].

To the best of our knowledge, there has been no study that has evaluated the biomechanical response of Double keyhole loop and T-loop on a continuous wire with different methods of activation.

Aim :- The present study was done to evaluate the stress distribution and moment-force ratio of Double Keyhole loop and T-loop with two different methods of activation (Cinching and Ligature-tie) at different degrees of gable bend using Finite Element Analysis.

REVIEW OF LITERATURE

Categorized as follows:

- Biomechanics
- Loop mechanics.
- Finite element analysis.

BIOMECHANICS

Burstone & Pryputniewicz (1980)[9] used laser holography to study the three dimensional tooth displacements as it offers an accurate, noninvasive approach to determine tooth movement and designed an in-vitro study to establish the force system required on the crown of maxillary incisor which would produce different centers of rotation for lingual tipping, translation, and root movement and found that when force is applied at bracket level the center of resistance was at a point one-third of the distance from the alveolar crest to the apex.

Smith & Burstone (1984)[52] studied the relationships between forces systems and center of rotation in relation to center of resistance to produce desired tooth movement and their clinical relevance thus determining the moment-force ratios which produces translation (bodily movement), rotation, tipping and root movement. Since most forces are applied at the bracket, it is necessary to compute equivalent force at the center of resistance in order to predict tooth movement.

Kusy and Tulloch (1986)[53] compared the Force systems at the center of resistance for the conventional fixed appliance and for two special clinical situations in which force systems were delivered at the tooth crown - a single lateral force and a lateral force complemented by a counteracting couple and determined that although the force systems that result at the bracket and at the center of resistance are equivalent, the concept of moment/force ratios at the bracket can only be reestablished by considering the net moment/net force ratios at the center of resistance.

Vanden Bulcke , Burstone et al (1986)[70] studied the location of the centers of resistance for various symmetryic units of the anterior maxillary dentition for a lingually directed force in two dry human skulls using a laser reflection technique and determined that the center of resistance location shifted apically as the number of dental units (2, 4 & 6) increased. The greatest shift occurred in the six- tooth unit, but increasing the magnitude offeree applied to the units had little effect on the location of center of resistance.

Kazuo Tanne, Koeing & Burstone et al (1988)[27] investigated the relationship between moment to force (M/F) ratios and the centers of rotation using finite element method for an upper central incisor and found that the center of resistance was located at 0.24 times the root length measured apical to the level of alveolar crest.

Pedersen E, Isidor.F, Gjessing.P et al (1991)[41] using human autopsy material studied the location of center of resistance of various consolidated units of maxillary anterior teethand found that when horizontal forces were applied the CR for the two- and six-tooth units was located approximately 6.5 mm apical to the bracket position compared to four-tooth unit 5.0 mm. Applying vertical forces CR was located about 13.0 mm posterior to the bracket position for the two- and four-tooth unit and incorporation of the canines into the incisor segment resulted in a distal shift of CR of 6 mm. CR for the six anterior teeth was, thus, located on a line 3 mm behind the distal surface of the canines.

Demetrios. J (1998)[15] studied the forces and moments produced by a straight portion of an archwire and were transferred from the brackets to the center of resistance to compare the force system at the brackets to the force system at the center of resistance and to assess whether bracket geometry can be applied to predict initial tooth movement. Concluded that the force systems developed by an ideal arch cannot be used directly to estimate tooth movement they should be first transferred to the center of resistance of the teeth and the force systems at the center of resistance may differ significantly from the force systems at the brackets.

Kobayashi&Yoshida et al (2001)[34] this study was designed to locate the centres of restistance of two, four and six anterior teeth during retraction in two human subjects by measuring the retraction forces applied at different levels by means of a device for displacement measurement using magnetic sensors and magnets. Clinically this finding indicates that translation can be achieved with a smaller amount of moment-to-force ratio in en mass retraction and also indicate thai the location of the centre of resistance of the anterior segment during retraction may depend on the palatal alveolar bone height, rather than on the labial alveolar bone height. correlation exists between the palatal alveolar bone height and the moment-to-force ratio needed for any orthodontically programmed tooth movement such as controlled tipping, translation, and root movement during anterior retraction.

Heo , Nalim & Back (2007)[69] compared theamount of anchorage loss of the maxillary posterior teeth and amount of retraction of the maxillary anterior teeth between en masse retraction and two-step retraction of the anterior teeth. No significant differences existed in the degree of anchorage loss of the upper posterior teeth and the amount of retraction of the upper anterior teeth associated with en masse retraction and two-step retraction of the anterior teeth.When choosing retraction mechanics, it is necessary to consider additional aspects such as the inclination and vertical position of the anterior teeth rather than anchorage loss.

Yoshiyuki Koga, Noriaki Yoshida et al (2007)[58] determined the location of center of resistance and compared the relationship between height of retraction force on power arm and movement of anterior teeth during sliding mechanics retraction and found that controlled crown-lingual tipping and controlled crown-labial movement can be achieved by attaching a power-arm length that is lower or higher than the level of center of resistance, respectively and bodily movement is achieved by attaching a power-arm length which is at the same level of the center of resistance.

Jeong GM, Sung SJ et al (2009)[19] found the center of resistance of the 4 maxillary anterior teeth, 6 maxillary anterior teeth, and the full maxillary dentition at 13.5 mm apical and 12.0 mrn posterior, 13.5 mm apical and 14.0 mm posterior, and 11.0 mm apical and 26.5 mm posterior to the incisal edge of the upper central incisor, respectively using 3-dimensional finite element analysis.

Masaru Kobayashi, Noriaki Yoshida et al (2009)[34] determined the optimal loading conditions such as height of retraction force on the power arm and its position on the archwire in sliding mechanics during en-masse space closure. They concluded that the power arm at the level of 0 mm (bracket slot level), uncontrolled lingual crown tipping of the incisor occurred. At a 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. Thus both the biomechanical principles associated with the tooth's center of resistance and the deformation of the archwire should be taken into consideration for predicting and planning orthodontic tooth movement.

Zhang et al (2010)[66] in this study a three-dimensional finite element model of premaxillary bone and anterior teeth was established in ANSYS 8.1 software. Anterior teeth were fixed with stainless archwire of 2 mm x 2 mm. A horizontal retraction force of 150 g was applied bilaterally to the segment through hooks of 2 to 14 mm. Concluded that Displacement and stress distribution of anterior teeth varied according to the increase of height of horizontal retraction force. Labiolingual displacement of incisors varied from crown lingual tipping to lingual translation and lingual controlling root movement, while canine mainly showed lingual crown tipping. The displacements of teeth increased with the length of hook but their moving tendency remained unchanged. Stress distribution in PDL was in accordance with direction and magnitude of teeth displacement.

LOOP MECHANICS

Burstone and lawless (1961)[7] determined load deflection rate, load at which permanent deformation occurs and range of action as the major spring characteristics required for the utilization of the loops in orthodontics. The other factors considered in spring design are mechanical properties (modulus of elasticity), cross section of the wire, its configuration and spring activation. Thus the springs with low load force deflection rate and high working range of action delivers more constant force during unloading and can produce an uniform physiologic tooth movement.

Booth (1971)[4] studied the effects on the spring characteristics of a steel closing loop depending on the wire size, design of the loop, inter-bracket span and concluded that changing the size of the wire produces the largest changes in characteristics but the amount of wire incorporated in loop is also important.

Spiro J. Chaconas & Angelo A. Caputo et al (1974)[61] compared closed vertical loop , closed vertical loop with helix , double closed vertical loops with helix sectional and squashed loop determining the effects of wire size, loop configuration and gabling on canine-retraction springs and concluded that increased activation forces were produced when wire size was increased, whereas gable angle had varying effects upon activation force, depending on the loop configuration.

Burstone & Koenig et al (1976)[8] studied the factors influencing the moment force ratio in a spring design used for canine and anterior tooth retraction to optimize spring design and avoid undesirable side effects. They concluded that increasing loop length, additional length of wire incorporated at loop apex and angulation of loop legs (if the legs is bent facing towards the apex) the m/f ratio increases, where as increasing the horizontal length of loop decreases the moment-force ratio. Placement of the loop: a centered loop produces equal moment force ratio on either side of the loop, an off centered placement would generate unequal moments.

Burstone et al (1982)[10] has incorporated certain design features into retraction springs to optimize the force system depending on the material used (beta-titanium), incorporation of additional wire that is placed into a loop, centricity of the loop which affects the rate of change of moment-force ratio in alpha and beta positions and large inter-attachment distance between the auxiliary tube on the first molar and the vertical tube of the canine allows sufficient space for the large activations required. In addition, it adds to the accuracy of determining the force system, since small errors in the shape or geometry of the spring will not radically change the forces produced.

S.J.Chaconas, A. A. Caupto et al (1989)[62] compared three contraction archwires double delta , contraction torquing arch and contraction torquing utility archwire and the activation studied were intrusion, retraction and torque. They indicated that in cases of deepening of bite the double delta archwire would produce a lingual crown tipping and possibly extrusion of the incisors during retraction. However if a deep overbite exists prior to anterior tooth consolidation, the contraction torquing or contraction torquing utility archwires should be used since they show to produce the most effective lingual root torquing during incisor retraction.

Faulkner & Lipsett et al (1991)[36] studied the limitation of a standard vertical loop and redesigned it by drastically increasing the use of wire, which allows larger total activation and considerable preactivation of the appliance. Thus , incorporating helices to the apex and lateral sides of the loop can effectively increase the amount of wire being bent and if proper gabling (preactivation) is coupled to the design with the helices, it will produce considerably higher moments and M/F ratios compared to the standard loop.

Roth. H. Ronald (1991)[55] discussed about double key hole loop retraction wire in the chapter treatment mechanics for the straight wire appliance. Double key-hole loop, introduced by John Parker has the following specific advantages.

1. Allows the operator the luxury of complete space closure with one set of arch wire.
2. Allows a reasonably happy medium between severe tipping and sliding mechanics.
3. Allows the operator to select how the space will be closed depending on anchorage considerations.
4. Good control of canine rotation during space closure.

Staggers.A.J, Germane.N et al (1991)[63] Described the importance of gable bend in the retraction mechanics, site of gable bend placement and the degree of gable bend is main governing factor in different anchorage pattern. In group A anchorage consideration the gable bend is placed distal to the loop and increasing the moment in the posterior segment, which is helpful in anchorage preservation. He also quoted that anchorage as being taxed twice with a two-step retraction, as opposed to once with en masse retraction, pointing out that the posterior segment is unaware of knowing how many teeth are being retracted and merely responds according to the force system involved.

Poul Gjessing (1992)[44] analysed the force characteristics inherent in the prefabricated PG retraction spring for controlled movement of canines and concluded that it can be used as a module for controlled retraction of both canines and incisors. Reduced M/F ratio as a result of larger interbracket distance by incisor retraction as compared with canine retraction is compensated by placement of the points of force application and interbracket distance had no significant influence on the magnitude of intrusion force produced by the spring.

Kuhlberg AJ, Burstone CJ et al (1997)[2] studied and examined the effect of off-center placement of T-loops with a standard shape at a standardized activation and interbracket distance.

- A centered T-loop produces equal and opposite moments with negligible vertical forces.
- Off-center positioning of a T-loop produces differential moments. More posterior positioning produces an increased beta moment while more anterior positioning produces an increased alpha moment.
- A standard shaped T-loop can be used for differential anchorage requirements by altering the activation and mesial-distal position of the spring.

Ravindra Nanda (1997)[46] described the biomechanical basis for extraction space closure in group A, B & C anchorage situation using both segmental T-loop (0.017x0.025 TMA) and continuous T-loop archwire (0.017x0.025 TMA and 0.016x0.022 SS). Increasing posterior. For group A ,B & C anchorage the loop is positioned distally, in center and anterior to the extraction space respectively. But in group A anchorage high pull headgear is used commonly to control posterior tooth position.

Raymond E. Siatkowski, (1997)[48] systematic approach to closing loop design for use in continuous arch wires is presented in Part-1. The design process uses Castigliano's theorem to derive equations for moment-to-force ratio (M/F) in terms of loop geometry. The equations are used to optimize designs by optimizing

M/F to produce tooth movement via translation.

The result of this process is a new design, the Opus loop, which is capable of delivering a nonvarying target M/F within the range of 8.0 to 9.1 mm inherently, without adding residual moments via twist or bends (commonly gable bends) anywhere in the arch wire or loop before insertion. The resulting precise force systems delivered with nonvarying M/F can move groups of teeth more accurately to achieve predetermined anteroposterior treatment goals for esthetics and/or stability.

In Part II the experimental results show that the loops must be bent accurately to achieve their design potential.

Christoph Bourauel, Dieter Drescher et al (1997)[11] The present study shows that orthodontic devices made of superelastic NiTi alloys provide mechanical characteristics that may not be reached with conventional alloys. The investigated superelastic T-Ioops generated nearly constant force systems over broad ranges of activation. However, the NiTi alloy used to construct the loops has a decisive influence on the measured force systems. Even a change in the batch of the same orthodontic NiTi wire results in extreme changes in the force system of the retraction spring.

Marcelo do Amaral Ferreira et al (1999)[32] This study tested the wire material and cross-section effect of orthodontic spring retraction with double delta design in relation to the average load and spring rate achieved after several activations. The following conclusions were reached that the TMA (0.017x0.025 in) springs displayed the lowest average load for each tested 0.5 mm of activation and also the lowest spring rate where as stainless steel 0.019x0.025 inch springs showed a higher average load for each tested 0.5 mm activation and the highest spring rate as well. The cobalt-chromium 0.016x0.016 inch and titanium-molybdenum 0.019x0.025 inch springs did not show any significant difference between each other. Thus, the spring rate is dependent on wire material, crosssection,and spring design.

Jie Chen, David L. Markham et al (2000)[22] studied the Effects of T-Loop Geometry on Its Forces and Moments. the results demonstrate that the moments and forces generated by a T-loop spring are functions of its geometry and gable angle combined with heat treatment. In general, increasing its vertical or horizontal dimension reduces the load-deflection rate and the moment-to-force ratio. Gable preactivation and stress relieving heat treatment has the opposite effect.

Domenico Mazza, Michele Mazza et al (2000)[16] The purpose of this study was to further assess the reliability of the software in 4 tests using T-loop springs. A numerical simulation of a determined experimental condition relative to a T-loop spring was carried out in each test. Numerical and experimental results were compared, and the precision of the analytical tool was assessed relative to a variety of parameters of the spring. Since the comparison between numerical and experimental results showed good agreement along the entire range of activation of the spring, the reliability of the software is sufficient for the clinical purposes of the segmented arch technique.

Faulkner, Bill Lipsett et al (2001)[17] This numerical study evaluated several appliances (rectangular loops and L-loops) used to vertically align teeth. Consideration was given to how these designs might be modified to produce the appropriate force system to allow both movements to occur simultaneously. It was found that the rectangular loop was the most appropriate choice for first-order corrections. For the rectangular loops studied, the in-plane force system was shown to be essentially independent of the out-of-plane effects, which allowed the two corrections to be controlled separately.

One disadvantage of these force systems is that the intrusive/extrusive forces are nearly linearly related to the amount of vertical activation, which suggests that the force level will decrease as vertical movement occurs.

Stanley Braun et al (2002)[64] Gable bends are frequently incorporated into a variety of loop configurations to provide appropriate moment-to-force (M/F) ratios in the controlled closure of space between individual teeth or groups of teeth.Appropriate magnitudes and occlusogingival locations of the Gable bends are shown to be vital to maintain the neutral position of the closing loop. Concluded that Gable bends should be distributed occlusogingivally in all loop configurations to achieve forecastable M/F ratios at the active and reactive teeth.

Guilherme Thiesen et al (2005)[18] this study was done to determine the mechanical characteristics of beta titanium T-loops with and without 0 and 180 degree gable bends and constructed from 0.017x0.025 inch and 0.019x0.025 inch wire. The results showed that the transverse section of wire had the greatest effect on the horizontal force produced by the loops. Significantly lower levels of horizontal force where obtained with smaller 0.017x0.025 inch wire. Loops with gable bend yielded high moment force ratios, where as loops without gable bends had lower moment force ratios and T-loops with helices yielded lower magnitudes of horizontal force and moment force ratios than plain T-loop.

Mohammad Reza Safavi et al (2006)[37] compared the M/F ratios of four different closing loops: 3D analysis using the finite element method (FEM)Adding preactivation bends to the VHC, T- and L-loops increased the M/F ratios to acceptable levels at 1 mm activation, but there was a dramatic increase in the M/F ratio as the loops deactivated to 0.1 mm. The results indicate that loop activation should be maintained to avoid applying high M/F ratios.

Thomas R. Katona, Jie Chen et al (2006)[67] It has been demonstrated that first-order (anti-rotation) bends have the intended effect of increasing the My/Fx ratio without changing the Mz/Fx ratio. Similarly, second-order (anti-tipping) bends have the desired increasing effect on the Mz/Fx ratio without affecting the My/Fx ratio. Thus, it is concluded that first- and second-order gable bends in 0.016 x 0.022-in stainless steel triangular (8 x 8 x 8 mm) loops have uncoupled effects on the clinically critical M/F.

Rodrigo F. Viecilli et al (2006)[54] An optimal beta-titanium alloy 0.017 x 0.025-in T-loop spring was designed by using a simulation performed with LOOP software (dHAL Orthodontic Software, Athens, Greece) to allow compensation for anterior unit-position effect on the final force system. The force systems produced by this T-loop spring with and without geometric correction of the brackets have significant differences that should be considered in the segmented arch approach to space closure and concluded the effects of steps, angles, and vertical forces were combined to produce an ideal T-loop design that would provide a more determinate force system. The effects and force systems are estimates based on simplified locations of the centers of resistance, assuming relatively constant behavior of the centers of rotation.

Proffit (2007)[43] mentioned that the performance of closing loop is determined by the amount of force it delivers, moment it generates and its relative position to the bracket. The location of the loop is an important factor in determining space closure and the gable bend incorporated. The gable bends in the closing loop functions as a V bend in the archwire is sensitive to its position. Only if it is in the center of the span does a V bend produce equal forces and couples on the adjacent teeth.

Renato Parsekian Martins,Peter H. Buschang et al (2008)[50] Using the Loop software program they systematically modified a .017x.025-in TTLS (10.6 mm) that was preactivated with a 45° gable bend distal to the loop, and simulated the effects. As the gable bend was moved posteriorly, the moment increased at the posterior bracket more than it decreased at the anterior bracket. As the loop was brought closer to the anterior bracket, the posterior moment decreased at the same rate that it increased anteriorly. As the loop was increased in size, the moments increased both posteriorly and anteriorly. As the interbracket distance increased, the posterior moment decreased, and the anterior moment remained constant and concluded that the size of the loop should be slightly increased, to 10.7 mm, and it should be placed 2 mm from the anterior bracket, with a preactivation bend of 45°, 4 to 5 mm from the posterior bracket (after 4 mm of activation).

Y. Mahesh Kumar,N.S. Ravindran et al (2008)[72] The magnitude and direction of the initial displacement of the canine were studied by means of double-exposure interferometry using four different canine retraction springs, that is, closed coil spring, open coil spring,PG spring, and T-loop retraction spring and concluded that the T-loop may be preferred whenever minimal tipping is performed. The PG spring may be preferred over other springs whenever a higher magnitude of displacement is desired. Closed coil springs may be preferred whenever a reasonable magnitude of displacement is required and reasonable tipping is allowed.

Michael Swain; Peter Herbison et al (2008)[73] the temperature effects on the forces, moments and moment to force ratio of nickel-titanium and TMA symmetrical T-loops were studied and concluded that temperature significantly influenced the forces and moments produced by NiTi closing loops, with values increasing as the temperature increased. The M:F ratios of NiTi loops were less affected, with no significant changes with temperature for the 15º and 30º preactivation loops, although some change was noted for the non-preactivated loops. TMA wires showed significance for some force measurements, but were generally not influenced by temperature.

Renato Parsekian Martins; Peter H. Buschang et al (2008)[49] in this study the force acting on curvature and preactivated bends in titanium T-loop springs were compared for 7 mm of activation and forces and moments were registered after each 0.5 mm of deactivation and concluded that although both loops show symmetrical moments in their anterior and posterior extremities and can be used for group B anchorage, the curvature preactivated TTLS delivers lower horizontal forces and higher MF ratios than the acute preactivated V-bend TTLS.

Renato Parsekian Martins, Peter H. Buschang et al (2009)[51] The purpose of this study was to evaluate the distal tipping of partially retracted canines and the mesial movement of the molars. In eleven patients T-loop springs with 45° gable bends distal to the loops preactivated for group A (maximum anchorage) and metallic bone markers served as references. The canines were retracted until enough space was available for alignment of the incisors without proclination. Oblique (45°) radiographs were taken immediately before the initial activation and after partial retraction and concluded that the T-loop spring used in this investigation produced controlled tipping of the maxillary canines, but it did not produce controlled tipping of the mandibular canines or translation of the molar as expected.

Michael Swain, Peter Herbison et al (2009)[13] This in-vitro study investigated the loads (forces), moments, and moment-to-force ratios (M:F) generated during the activation and deactivation of T closing loops made of rectangular nickel-titanium (NiTi) and titanium-molybdenum alloy (TMA) wires incorporating either 0°, 15° or 30° of preactivation and concluded that;

1. TMA generally produced a higher mean force over its activation range compared with the equivalent NiTi closing-loop specimens.
2. The nonpreactivated closing loops failed to produce an optimum M:F for theoretical tooth movement via translation.
3. All preactivated TMA and NiTi closing-loop specimens produced an M:F ≥10:1 at some point in their deactivation range, irrespective of the force delivered.
4. In the assumed optimal biologic force range for tooth movement investigated (50-150 g), the NiTi preactivated closing loops produced an M:F of ≥10:1 over a greater deactivation range than did their TMA counterparts.
5. With increasing degrees of preactivation, the M:F also increased over the deactivation range for all closing-loop specimens of both materials.

Jie Chen, Serkis C. Isikbay et al (2010)[24] compared three T-loop closing archwires of 0.016x0.022-inch stainless steel with interloop distance of 38mm, 42mm and 46mm to quantify the 3D force system with a continuous closing loop archwire will allow the clinician to make an informed decision when selecting the archwires. The 42-mm T-loop closing archwire (TL42) positioned the T-loop in the middle of the interbracket distance of the lateral incisor and canine brackets. The 38-mm (TL38) and the 46-mm (TL46) archwires positioned the T-loop 2 mm anterior and 2 mm posterior to the middle of the interbracket distance, respectively. Concluded that the intrusion/extrusion force, would also occur depending on the loop locations. Placing the loop mesially (TL38) would extrude the incisor and intrude the canine, while placing the loop in the middle (TL42) or distally (TL46) showed an opposite effect. Thus, when a T-loop is placed eccentrically in the space to be closed, the moment will be higher on the tooth closer to the loop.

Renato Parsekian Martins et al (2011)[49] in this study the effect of preactivation on the force system of symmetrical beta-titanium T-loop springs were compared and concluded that :

1. The concentrated bend preactivation produced higher horizontal forces and lower LD ratios than did the curvature preactivation.
2. Preactivation by concentrated bends produced more overlap of the vertical extensions of the TLSs than did preactivation by curvature.
3. Both preactivations produced similar moments during deactivation.
4. Preactivation by curvature produced higher MF ratios than did preactivation by concentrated bends.

Sergei Godeiro Fernandes Rabelo Caldas,a Renato Parsekian Martins et al (AJO 2011) this study was done to evaluate the load decay on the force system of TLSs preactivated by concentrated bends over time. The TLSs had dimensions of 6 mm in height by 10 mm in length 0.017 x 0.025 inch TMA wire and were preactivated with concentrated bends. The result showed that the TLSs preactivated by concentrated bends suffered progressive deformation over time. This effect was critical on the first 24 hours on the moment reduction, the decrease in the rate of moment reduction, and the decrease in the overlap of the vertical extension of approximately 1 mm, causing a horizontal force reduction at a given activation.

Luiz Gonzaga Gandini et al (2011)[31] The purpose of this study was to use photoelastic analysis to compare the system of forces generated by retraction T-loop springs made with stainless steel and titanium-molybdenum alloy with photoelastic analysis and concluded that The force system released by the springs showed an M/F ratio that was similar in both sides independent of the type of the alloy used to construct the springs. Considering the force magnitude, the T-loop made of TMA showed a lower force magnitude when compared with the T-loop spring made of SS.

FINITE ELEMENT METHOD

Melvin L. Moss et al (1985)[35] The application of the concepts of continuous mechanics and of the numerical techniques of the finite element method permits the development of a new and potentially clinically useful method of describing craniofacial skeletal growth. This new method differs from those associated with customary roentgenographic cephalometry in that its descriptions and analyses are invariant; that is, they are independent of any method of registration and super-imposition. Such invariance avoids the principal geometric constraint explicit in all analytical methods associated with conventional roentgenographic cephalometry. They proved that the FEM permits analysis of the skull at a scale significantly finer than previously possible , by considering cranial structure as consisting of a relatively large number of contiguous finite elements.

Kazuo Tanne, Charles J. Burstone et al (1987)[28] The three-dimensional finite element model of the lower first premolar was constructed on the basis of average anatomic morphology and consisted of 240 isoparametric elements. Principal stresses were determined at the root, alveolar bone, and periodontal ligament (PDL). Concluded that the pattern and magnitude of stresses in the periodontium from a given magnitude of force were markedly different, depending on the center of rotation of the tooth.

Haskell (1990)[20] modeled loops as 2-D beam elements, and one end of the loop was completely restrained. The finite element analysis was carried out in two steps: the first one was to apply the required forces and moments till the other end spring became horizontal, the second step involved the known activations in the horizontal direction. The M/F ratios of these springs could then be deduced from the analysis.

Kazuo Tanne et al (1991)[26] in this study a three dimensional finite element analysis , investigated the pattern of initial tooth displacement associated with varying root lengths and alveolar bone height affect the patterns of initial tooth displacement. The center of resistance and center of rotation shifted towards alveolar crest in the short root lengths and more of alveolar bone loss. They concluded that the forces applied during orthodontic treatment should take into consideration, factors such as to produce optimal and desired tooth movement.

Wilson et al (1991)[68] studied the action of removable appliance to retract maxillary canine into a first premolar extraction space and concluded that the obliquely directed tipping forces applied to a finite element model of a maxillary canine tooth resulted in a lower maximal prinicipal stress at the cervical margin compared to a mesio-distal directed force. This may be due to increased bone bending in the buccopalatal dimension as opposed to the mesio-distal dimension.

Tanne et al (1993)[29] investigated stress distributions in the maxillary complex from head gear forces by means of three dimensional finite element analysis. The stress distributions in the maxillary complex from headgear forces by means of three dimensional finite element analysis. The stress distributions in the sutures varied according to their anatomic locations relative to force directions. The maxillary complex exhibits postero-inferior displacement with clockwise rotation from the horizontal headgear.

Melsen et al (1999)[12] used a two dimensional finite element model to describe the force systems developed by cantilever different configurations during incisor intrusion. The cantilevers with a curvature pi combined retraction and intrusion forces. All other configurations resulted in combined protrusion and intrusion, which reversed into retraction and according to the variations in deactivations.

Schneider J.et al (2002)[56] determined the optimal force system for bodily movement of a single-root tooth, with an orthodontic bracket attached using the numerical finite element method. It determined that optimal F/M ratio for translation depends strongly on tooth geometry and the knowledge of root geometry is important in defining an optimal force system.

Chang Yi et al (2004)[6] compared the effects of a multiloop edgewise archwire on distal enmass movement with a continuous arch wire. The stress distribution and displacement of the maxillary dentition were analyzed when class one intermaxillary elastics (300 g/side) and 5 degree tip-back bends were applied to the ideal archwire. The MEAW seems to have advantages for distal enmass movement of the maxillary dentition.

P.M. Cattaneo, M. Dalstra, and B. Melsen et al (2005)[5] this study was sought to determine the impact of the modeling process on the outcome from FE analyses and to relate these findings to the current theories on orthodontic tooth movement.in a series of FE analysis stimulating teeth subjected to orthodontic loading, the influence of geometry/morphology, material properties and boundry conditions were evaluated. The accurate description of alveolar bone morphology and the assignment of nonlinear mechanical properties for the PDF elements demonstrate that loading of the periodontium cannot be explained in simple terms of compression and tensionalong the loading direction. Tension in the alveolar bone was far more predominant than compression.

Maria Elisa Rodrigues Coimbra et al (2008)[33] The purpose of this study was to evaluate the use of computer simulation to predict the force and the torsion obtained after the activation of teardrop loops of 3 heights (6, 7, and 8 mm). The loops were subjected to tensile load through displacements of 0.5, 1.0, 1.5, and 2.0 mm, and the resulting forces and torques were recorded. The loops were designed in AutoCAD software, and finite element analysis was performed with Ansys software this computer simulation accurately predicted the experimentally determined mechanical behavior of teardrop loops of different heights and should be considered an alternative for designing orthodontic appliances before treatment.

Yue Huang, Ludger Keilig et al (2009)[75] compared torque angle/torque moment characteristics in three types of brackets self-ligating Hanson Speed, Damon MX and conventionally ligated Discovery using finite element analysis with 0.018x0.025 in and 0.019x0.025 in archwires. Of three different alloys stainless steel, titanium molybdenum, and nickel titanium for torque of 20 deg and concluded that the adaptation of torque movements to the biomechanical reactions of the periodontium is best done by proper selection of both wire dimension and wire alloy. The effect of the bracket system is of minor importance, with the exception of brackets with an active clip (eg, Speed), which had the least play and the lowest torquing moments of all the wires.

Issa Fathima Jasmine et al (2011)[21] studied the proper angle of microimplant insertion in cortical anchorage. The microimplants were inserted at 30, 45, 60, and 90° to the bone surface. A simulated horizontal orthodontic force of 200 g was applied to the center of the microimplant head, and stress distribution and its magnitude were analyzed with a 3-dimensional finite element analysis program. Analysis of the stress distribution in the cortical and cancellous bones showed that the stress was absorbed mostly in the cortical bone, and little was transmitted to the cancellous bone.

Hussein H. Amrnar, Peter Ngan et al (2011)[1] in this study they have demonstrated the potential of 3-dimensional modeling and finite element analysis as clinical tools in treatment planning for orthodontic tooth movement. An anatomically accurate 3-dimensional models reconstructed from cone-beam computed tomography scans were used to simulate the retraction of a single-rooted mandibular canine with a miniscrew placed as skeletal anchorage. Concluded that CBCT reconstruction and FE simulation can provide reliable information on the stress pattern around the miniscrew implant and the PDL of the loaded tooth there by using fully 3D, patient-specific approach, multi-tooth orthodontic systems can be modeled and proper multiple miniscrew placement points can be virtually tested preoperatively to determine the optimal treatment plan. Interference with roots can be predicted, and patient-specific cortical bone thicknesses are preserved. This study demonstrates the potential of our method as an effective clinical tool for optimizing miniscrew anchorage stability and minimizing patient risk.

Yukio Kojima et al (2012)[76] The purpose of this article was to clarify the relationship between force directions and movement patterns. They concluded that when the power arm was lengthened, rotation of the entire dentition decreased. The posterior teeth were effective in preventing rotation of the anterior teeth. In cases of the high-position miniscrew, bodily tooth movement was almost achieved and vertical component of the force produced intrusion or extrusion of the entire dentition was observed.

MATERIALS AND METHODS

A 3-dimensional finite element model of a maxillary arch and intact dentition with first premolar extracted, brackets and archwires are created **(Figure 1).**

The materials used are three dimensional models of the following components;

1) The maxillary arch in dentition and first premolar extracted are obtained from the computed tomography scan with a slice thickness of 0.5 mm.
2) The periodontal ligament
3) The alveolar bone
4) A standard conventional preadjusted edgewise brackets of 0.022 slot Roth prescription are used.
5) Double keyhole loop archwires of 0.019x0.025 inch stainless steel with mild reverse Curve of Spee.
6) T-loop archwires of 0.019x0.025 inch stainless steel with mild reverse Curve of Spee.

MODELING:

The first step involved in construction of three dimensional finite element model is modeling. The modeling will be done using a software called Pro/Engineer. Pro/E is a 3D software which is a product of Parametric Technology Corporation. Using the software models can be created and edited with ease. These models represent geometry in terms of points, lines, area and volume. The constructed complicated smooth object can be represented geometrically as simple pieces called Elements.

Three Dimensional Modeling of Maxillary Dentition:

Computerized tomography (CT) image acquisitions in the DICOM (digital imaging communications in medicine) format of an adult dry human skull was obtained using 120 kV, 150 mA, 512 x 512 matrix, field of view 14 x 14 cm and slice thickness of 0.5 mm.

These CT images consisted of 165 sections along the axial axis and 123 sections along the coronal axis, was then imported into the software program Pro Engineer Wildfire version 4.0 and a geometric model was generated that could be manually adjusted to get the exact shape and curves in different sketch planes. Then the geometric model is discreted into several small elements, connected with nodes.

All elements and nodes were numbered so that a setup of matrix connectivity was established. This greatly affects the computing time. The elements could be one, two or three-dimensional and in various shapes and should not overlap each other but are connected only at the key points termed as ***nodes*****.** The joining of elements at the nodes and eliminating duplicate nodes was termed as **‘*Meshing*’ (Figure 2)**. Equations were developed for each element in the FEM mesh and assembled into a set of global equations that modeled the properties of the entire system. Once meshing was done then the lateral curves were created to ensure lateral connectivity of the geometric model. From the curves, surfaces were created using a command called Boundaries **(Figure 3).** Boundaries means that suppose an element is constructed on the computer and a force is applied to it, it will act like a free-floating rigid body and will undergo a translatory or rotatory motion or a combination of the two without experiencing deformation. To study its deformation, some degrees of freedom must be restricted (movement of the node in each direction x, y, and z) for some of the nodes. Such constraints were termed boundary conditions.

From these surfaces a solid was generated. The condition to define a solid will be that the envelope of surfaces should be closed and non intersecting. Once the tooth was developed in similar fashion other parts such as the periodontal ligament and alveolar bone were created and assembled.

Construction of arch wires:

- A 0.019x0.025 inch stainless steel archwire was chosen.
- In the archwire two double keyhole loops of dimension 7mm in height were constructed one distal of lateral incisor and other distal of canine., bilaterally
- A symmetrical T-loop measuring 7mm in height and 10mm wide using 0.019 x 0.025 stainless steel was constructed bilaterally in the centre of extraction space.

- Mild reverse Curve of Spee was incorporated for both the loops.

Archwires with the loops were prepared using measuring instruments like Vernier calipers and screw gauge. These measurements were build into models , feature by feature using PRO – E software. Wire bends were then created by a command called **sweep** where the trajectory and cross section were defined to create the model. A separate analysis was done on the curved wire model to incorporate the reverse Curve of Spee and reaction were calculated. These reactions are incorporated in the actual model for analysis.

All the modeled images were then assembled together in the assembly module. Once the assemblage was completed it was then exported to an analysis package. The export was through a bidirectionally understandable translator called IGES (initial graphics exchange specification).

FINITE ELEMENT ANALYSIS:

This study was done using Ansys Workbench 11 a recent version of Ansys which can import models with 100% data Transfer or with 0% data loss. Once imported the software can do an automatic meshing with defined material properties. The software establishes contacts automatically and defines them as bonded contact. This is of great use as less time is required in selecting surfaces to define contacts especially when there are lots of components between which contact need to be defined.

The constructed modeled images of maxillary arch with dentition, brackets and archwire was imported to work bench ANSYS software and relevant material properties were assigned. The material properties required are *Poissons ratio and Young's modulus* of each component as given in below table. Then the periodontal ligament is extracted as surface from the root of the tooth and thickness is assigned.

Materials	Young's modulus (Mpa)	Poisson's ratio
Tooth	20,000	0.30
Periodontal ligament	0.059	0.49
Alveolar bone	2,000	0.30
Bracket	200,000	0.30
Archwire	200,000	0.30

Table 1: Material properties of various components used in the study.

All these components were individually modeled and then assembled to create 3D finite element models of the maxilla and the mandible depicting en-masse retraction of six anterior teeth with

ANSYS Workbench (version 11.0; ANSYS, Canonsburg, Pa). Once all the images were imported the software can do an automatic meshing with defined material properties. Then the models were converted to elements and nodes. Therefore, the type of Element used in our study was mid noded Tetrahedron and the total number of elements and nodes established were

1,15,3876 and 1,57,233 respectively. Once Meshing and contacts are defined the next process is to define boundary conditions. Boundary condition means defining loads and restraints. Once the loads are defined then the problem is solved and the results can be reviewed. **(Figure 4)**.

A three dimensional finite element model of maxilla with Double keyhole loop and continuous T-loop archwire was finally obtained (**Figure 5**). The stress distribution and moment-force ratio was calculated for different methods of activation :

Cinching – 1mm of activation was done by pulling and bending the archwire distal to molar.

Ligature-tie - activation done with ligature by opening the loop for 1mm.

The assigned study groups were:

Group 1 :- Double Keyhole Loop

DKHL-C - activated by cinching with gable bend (0,15&30°) placed mesial of Second Loop (**Figure 6**).

DKHL-L - activated with ligature-tie to the 2nd loop and gable bend (0,15&30°) placed mesial of second loop (**Figure 7**).

Group 2 :- Continuous T-loop

T-loop-C - activated by cinching with gable bend (0,15&30°) placed mesial to the loop (**Figure 10**).

T-loop-L - activated using ligature tie to the loop and gable bend (0,15&30°) placed mesial to the loop (**Figure 11).**

Group 3: DKHL-V1: Activated using ligature tie to the first loop and gable bend (0,15&30°) placed mesial of the second loop. (**Figure 8).**

Group 4 :- DKHL-V2 :- activated with ligature-tie to the first loop and gable bend (0,15&30°) placed mesial of the first loop **(Figure 9).**

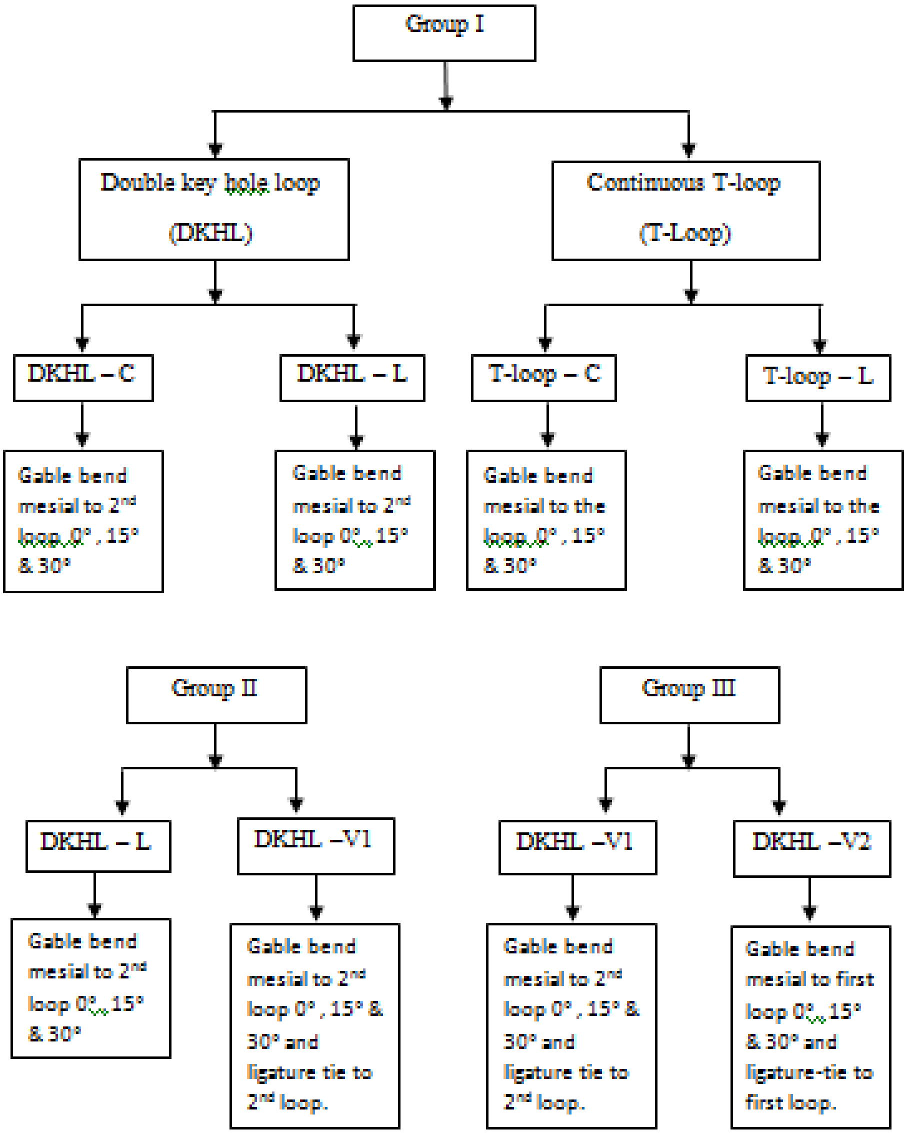
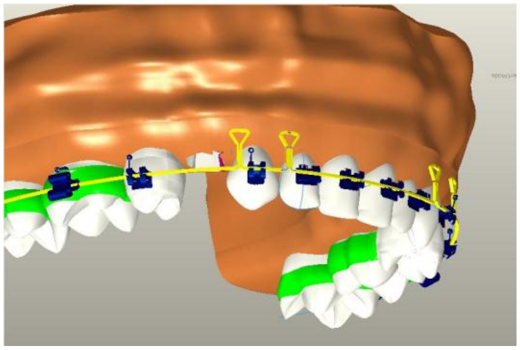


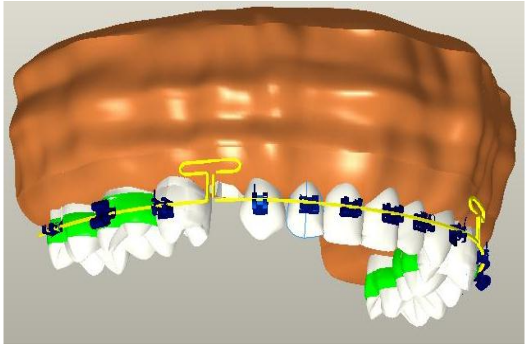
Table 2 : Flowchart representation of designed Groups.

Statistics :

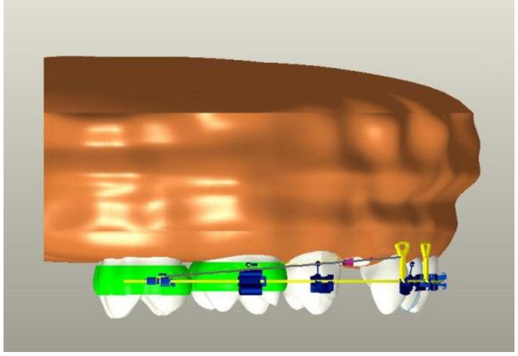
All statistical analysis was performed by using SPSS software package (SPSS for windows XP, version 17.0). A Kruskal-Wallis Test was performed to evaluate the stress distribution and overall displacement of the dentition for en-masse space closure for group A anchorage in both the groups. A P-value of ≤ 0.05 was considered statistically significant.



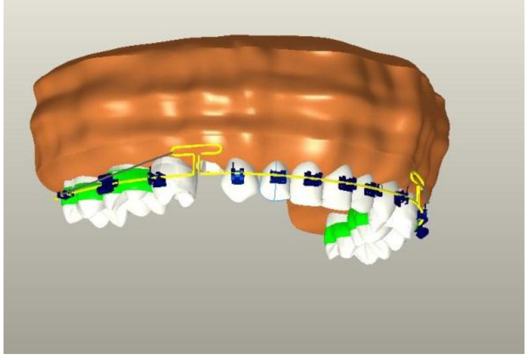
DKHL Cinching



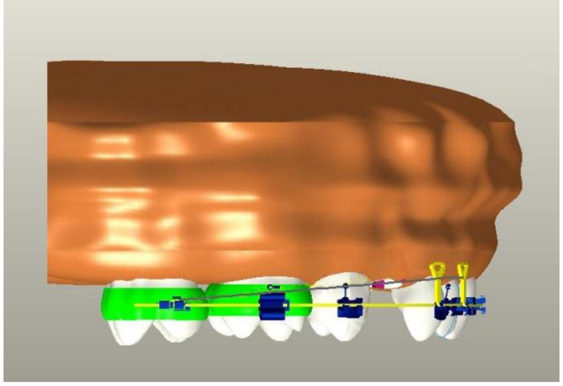
T-Loop Cinching



DKHL Ligature-Tie to 2nd loop

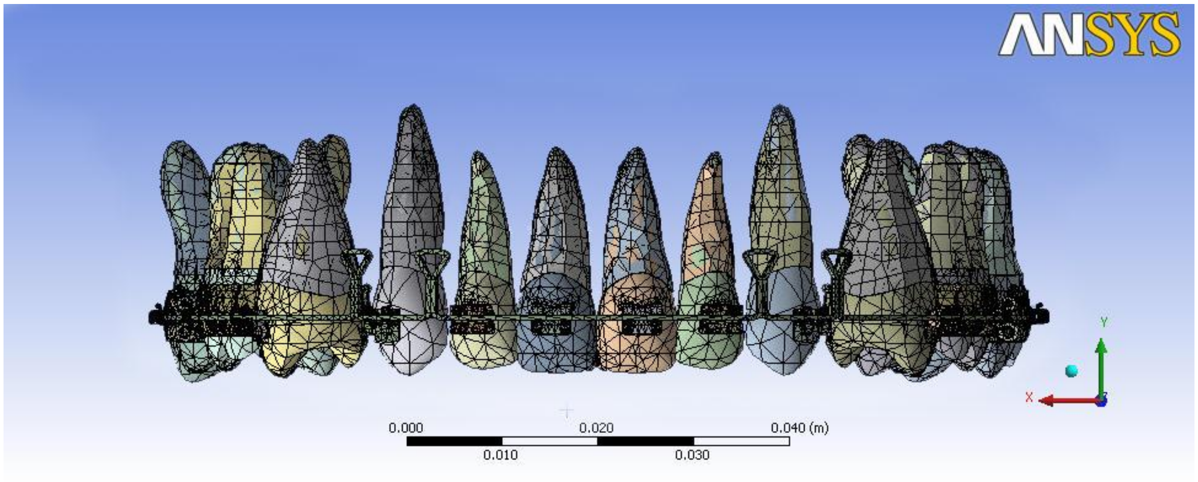


T- Loop Ligature-Tie

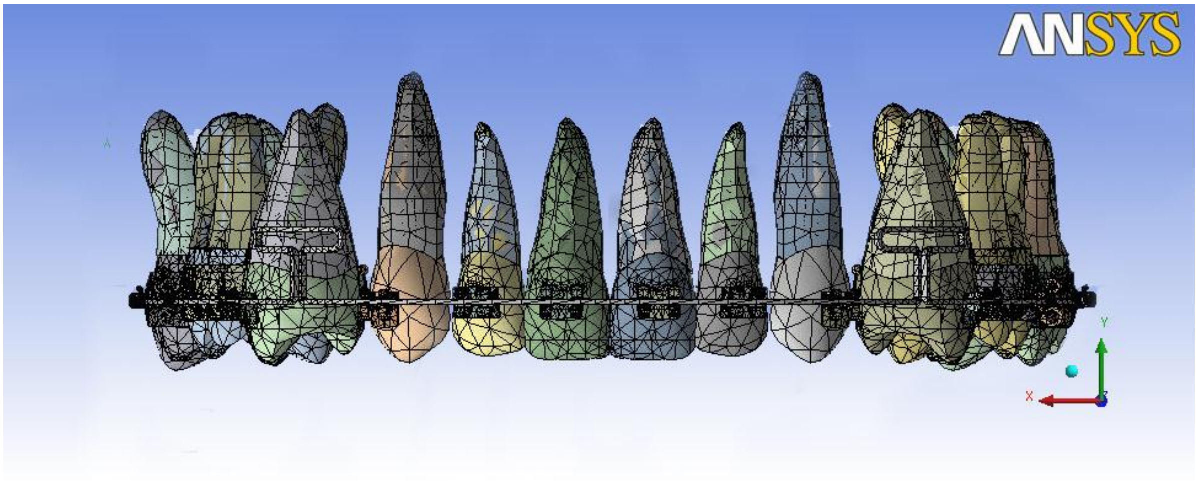


DKHL Ligature-Tie to 1st loop

Figure 1: 3D model of Double key holeloop& T Loop

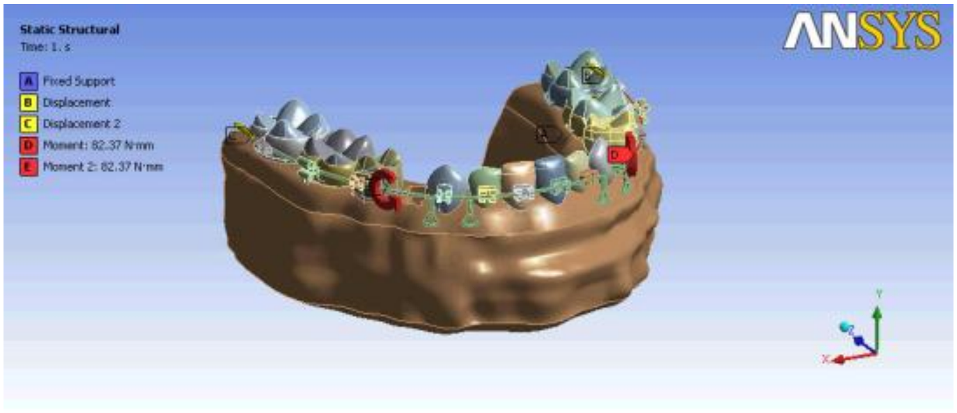


Mesh Image DKHL

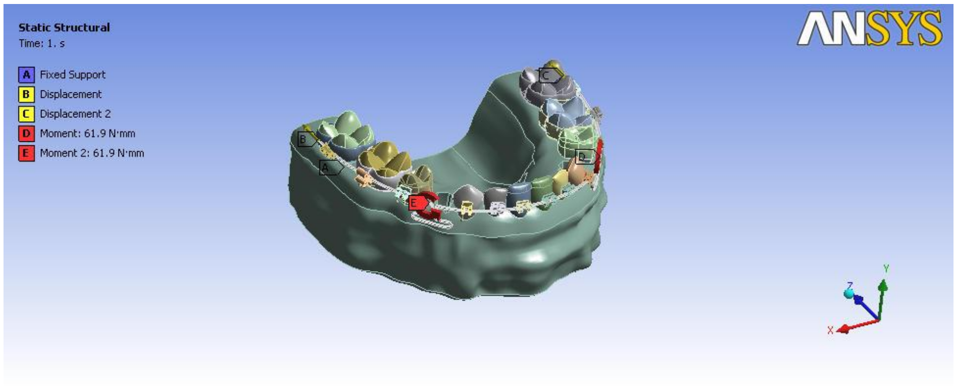


Mesh Image of T-Loop

Figure 2: Pre-processing stage – MESH MODELS

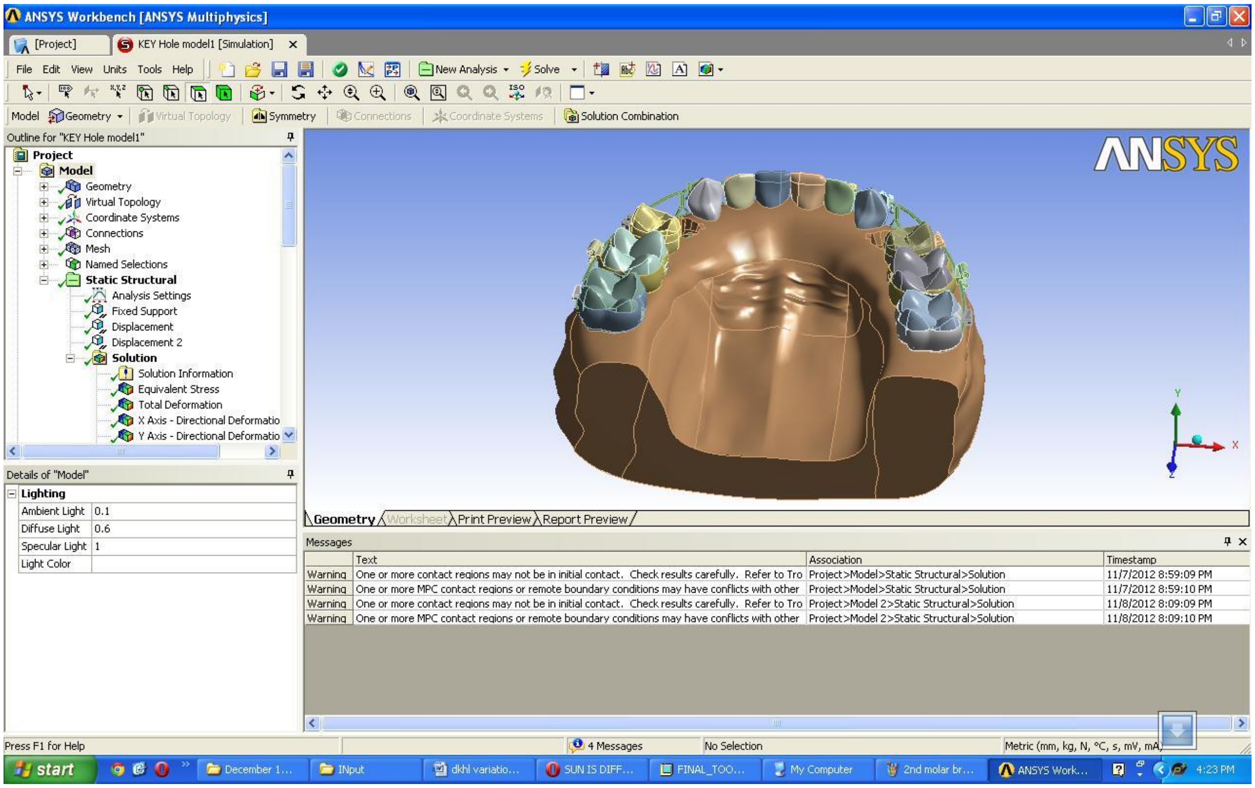


Boundary images of DKHL



Boundary Image T-Loop

Figure 3: Boundary images



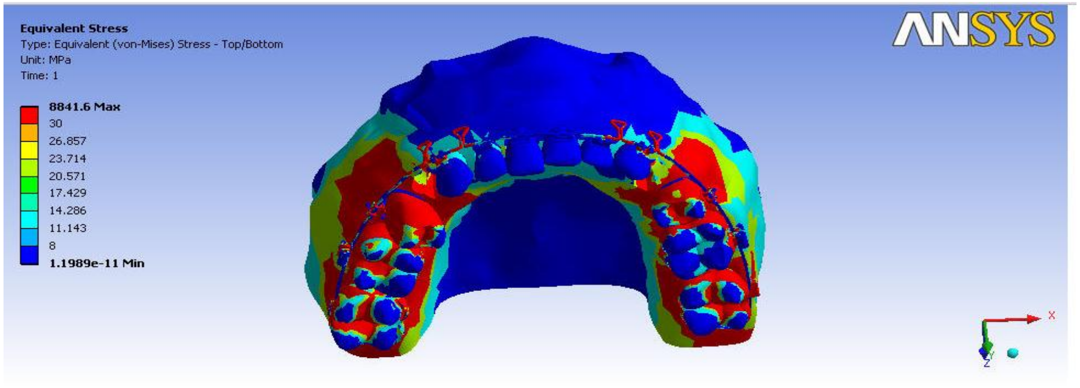
Details of "Model"

Lighting	
Ambient Light	0.1
Diffuse Light	0.6
Specular Light	1
Light Color	

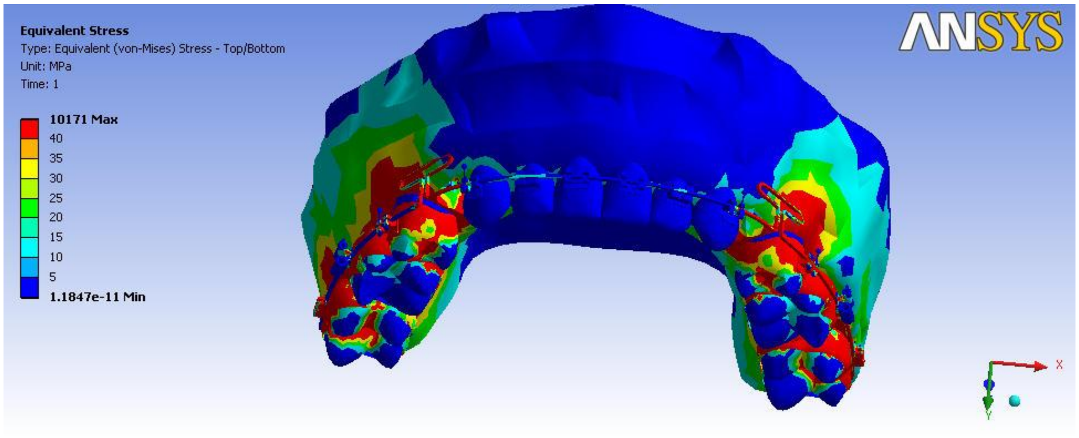
Messages

	Text	Association	Timestamp
Warning	One or more contact regions may not be in initial contact. Check results carefully. Refer to Tro	Project>Model>Static Structural>Solution	11/7/2012 8:59:09 PM
Warning	One or more MPC contact regions or remote boundary conditions may have conflicts with other	Project>Model>Static Structural>Solution	11/7/2012 8:59:10 PM
Warning	One or more contact regions may not be in initial contact. Check results carefully. Refer to Tro	Project>Model 2>Static Structural>Solution	11/8/2012 8:09:09 PM
Warning	One or more MPC contact regions or remote boundary conditions may have conflicts with other	Project>Model 2>Static Structural>Solution	11/8/2012 8:09:10 PM

Figure 4: FEM image generated by ANSYS software

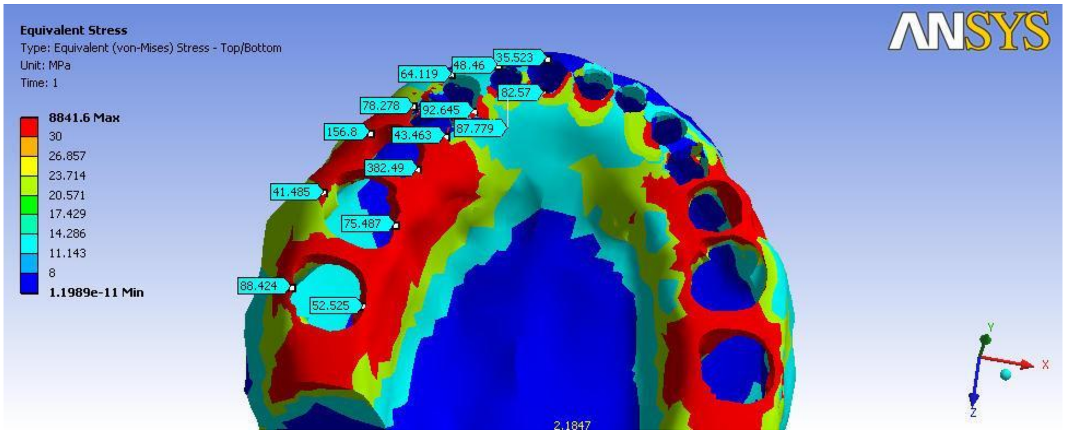


DKHL

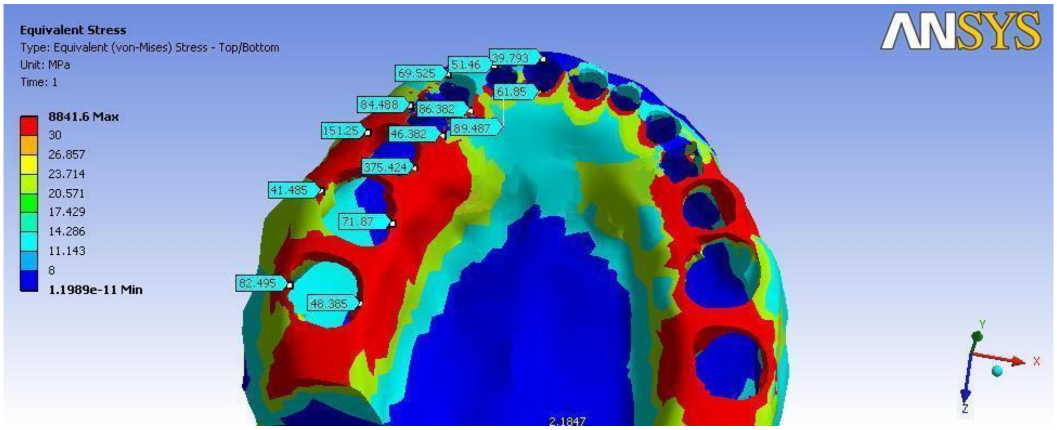


T Loop

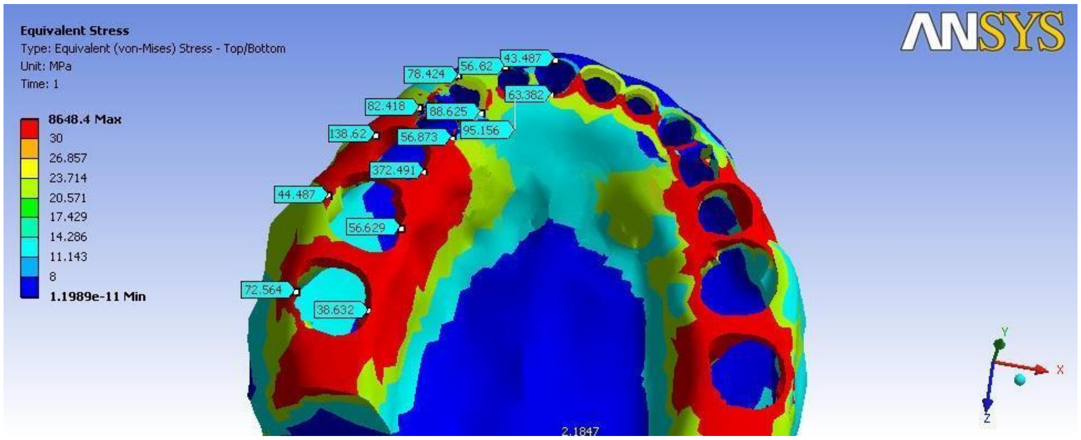
Figure 5: Analysis Image – Post Processing stage: Representation of the results in a colour coded manner



0 degree

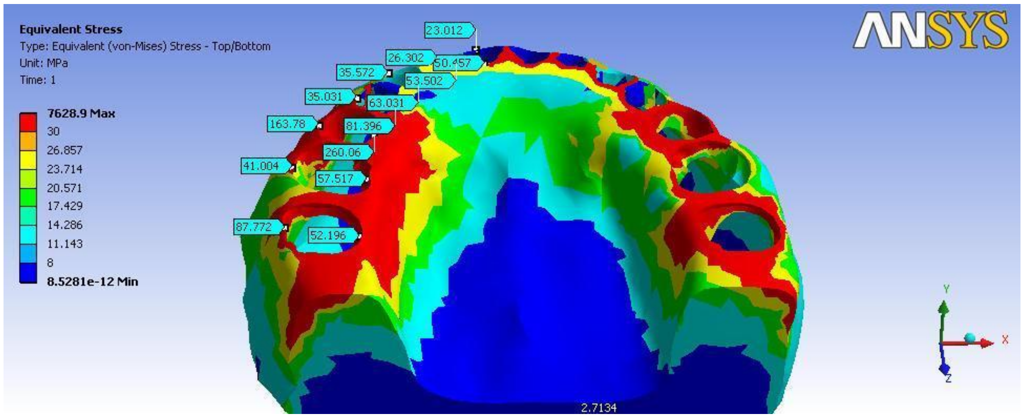


15 degree

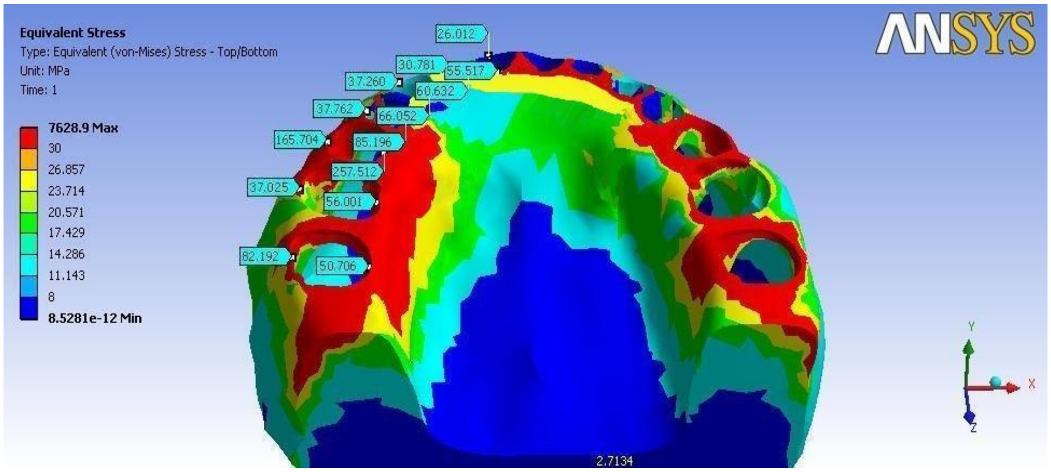


30 degree

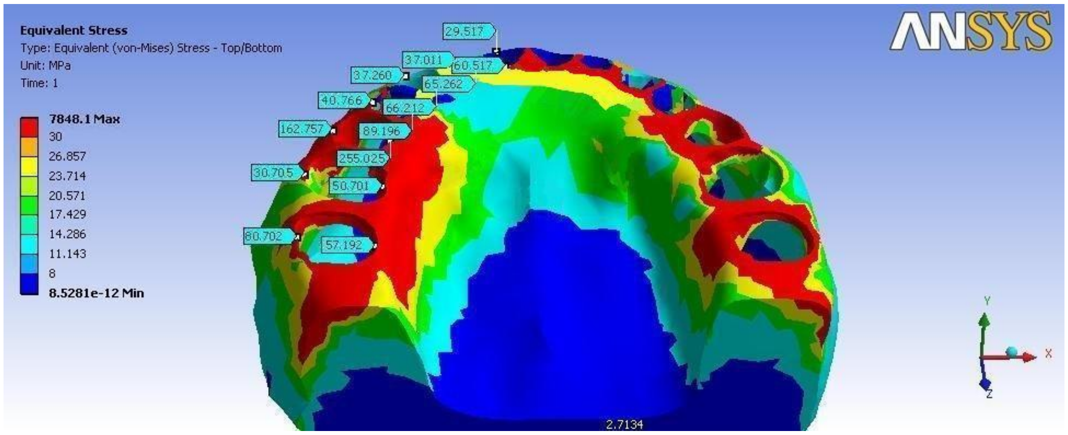
Figure 6: Stress values – Double Keyhole Loop – Cinching.



0 degree

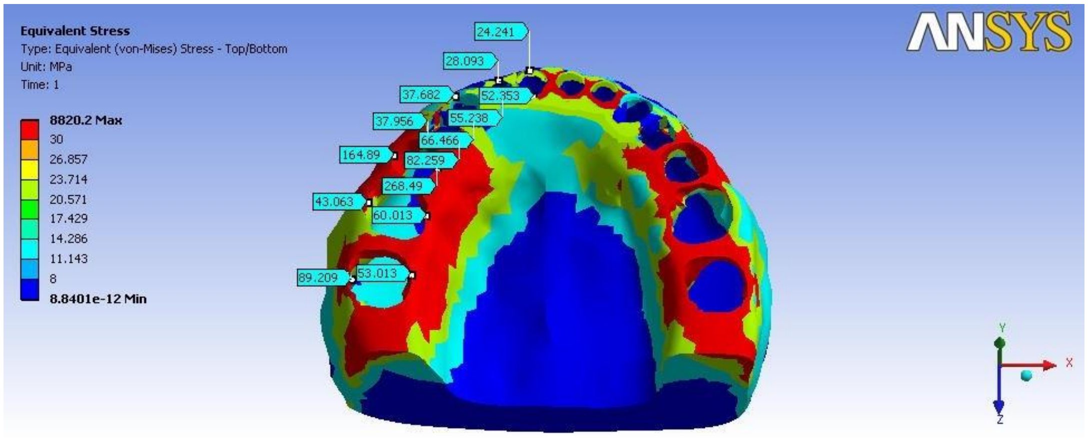


15 Degree

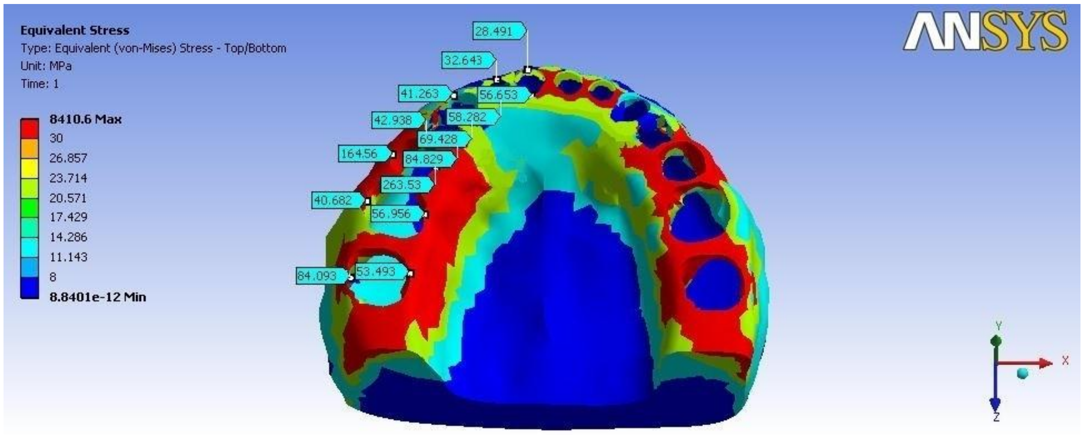


30 degree

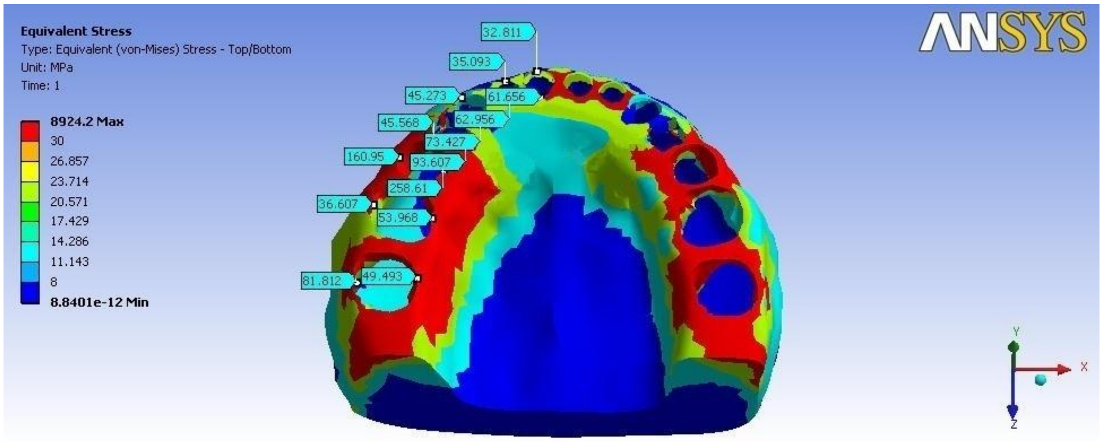
Figure 7: Stress Values: Double keyhole loop - Ligature - tie



0 Degree

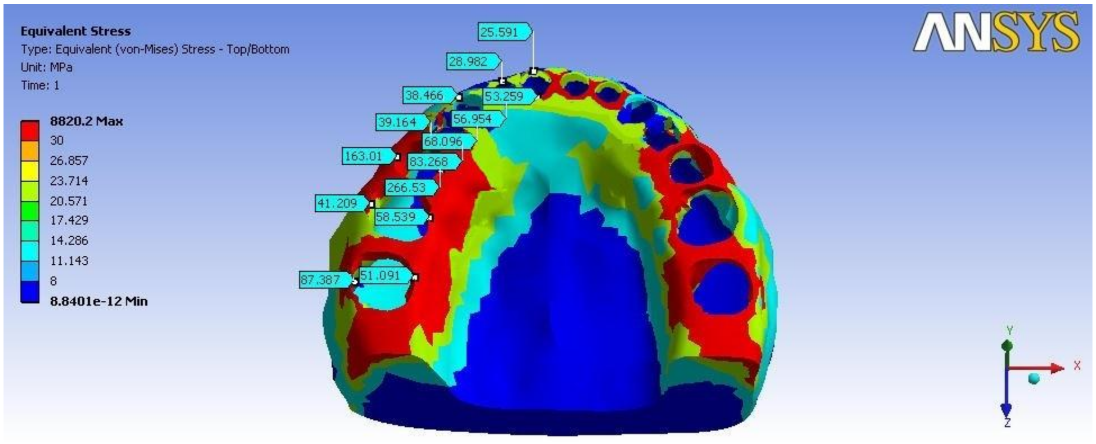


15 Degree

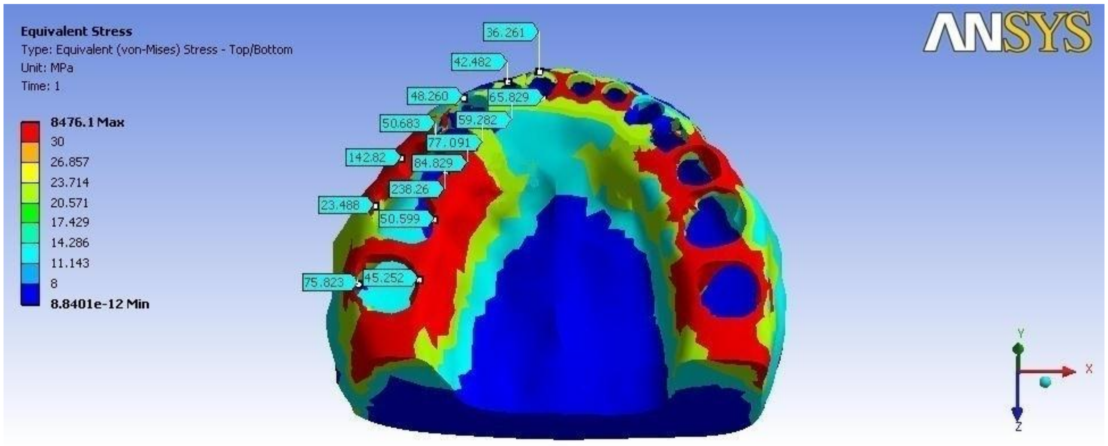


30 Degree

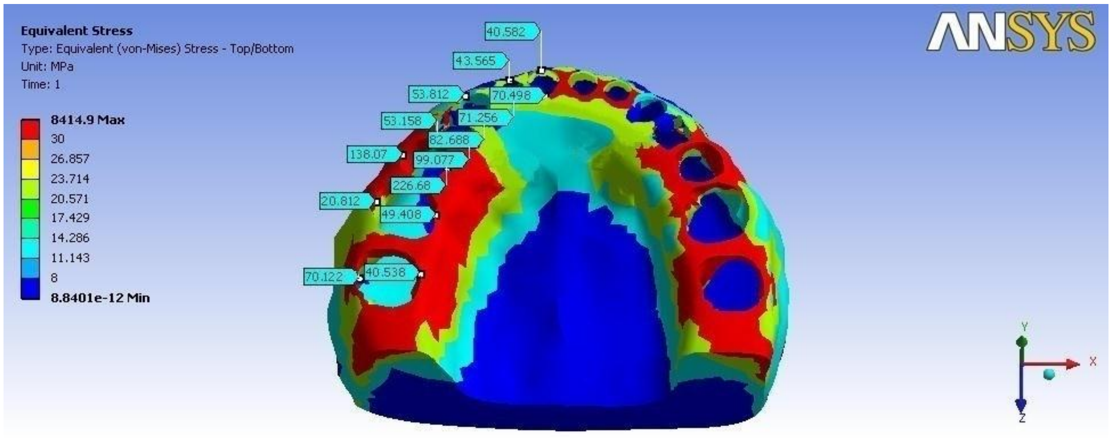
Figure 8: Double keyhole- V1 – ligature tie to 1st Loop



0degrees

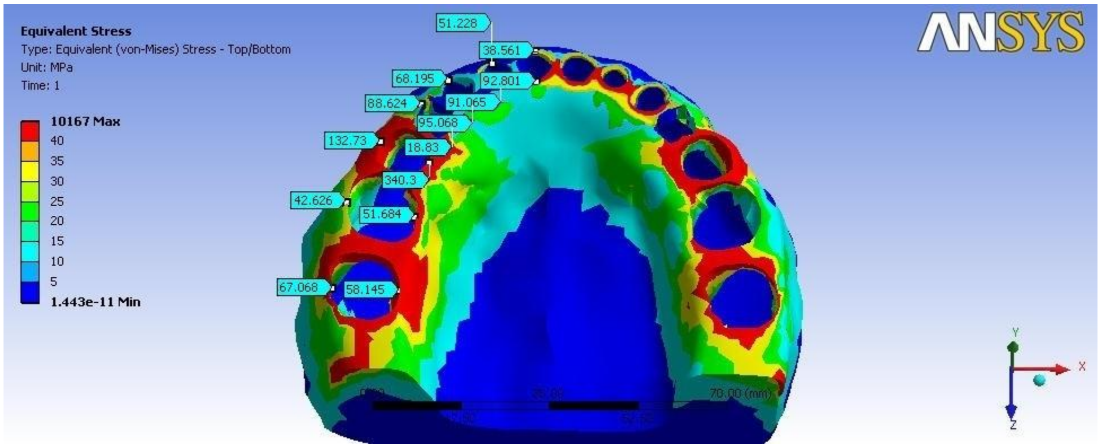


15 Degree

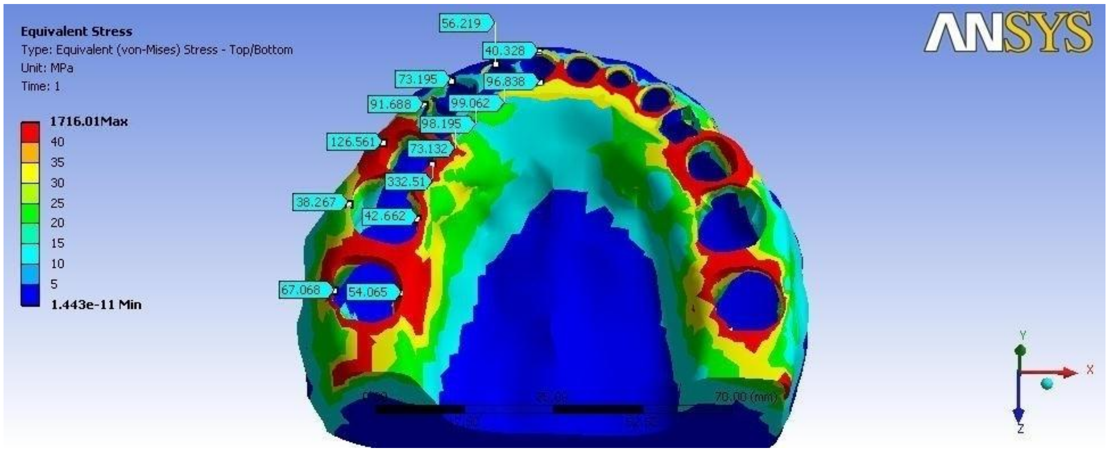


30 Degree

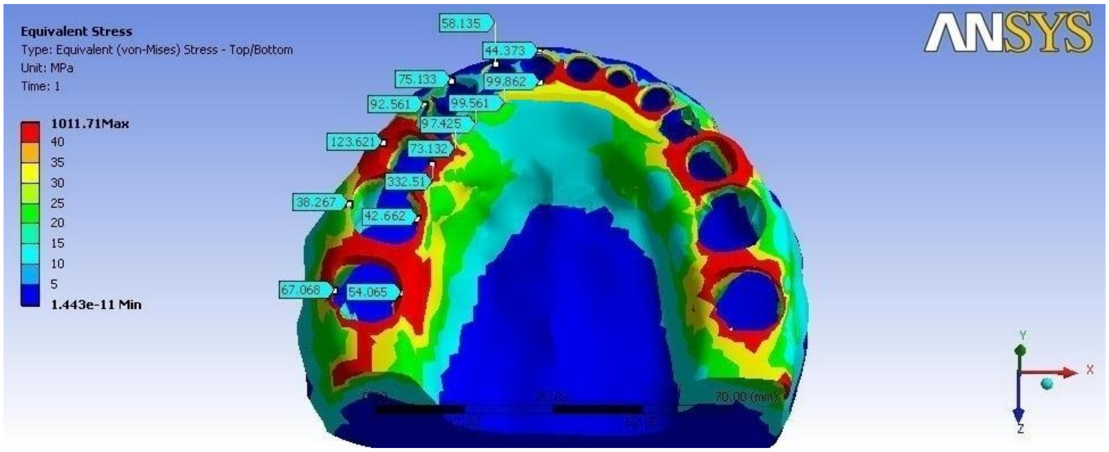
Figure 9: Double key hole loop – V2 – Ligature –tie and Gable Bend to First Loop



0 Degree

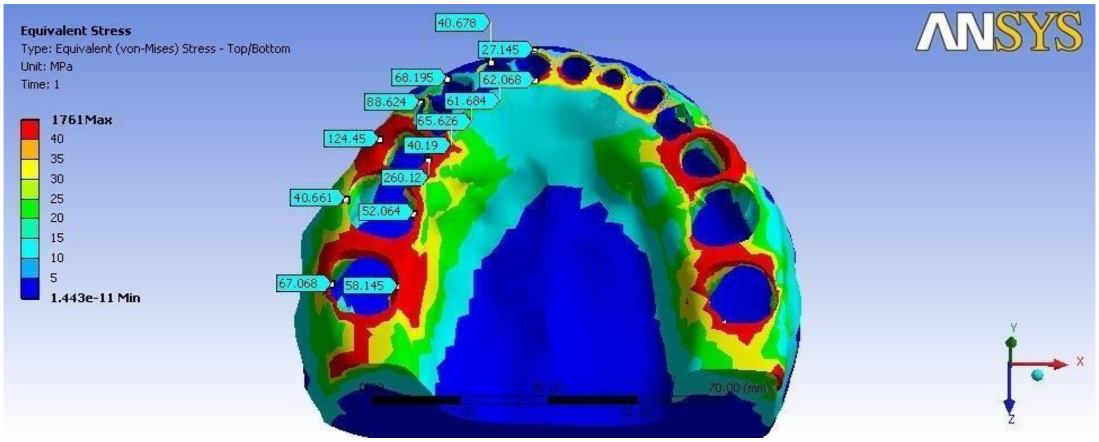


15 Degree

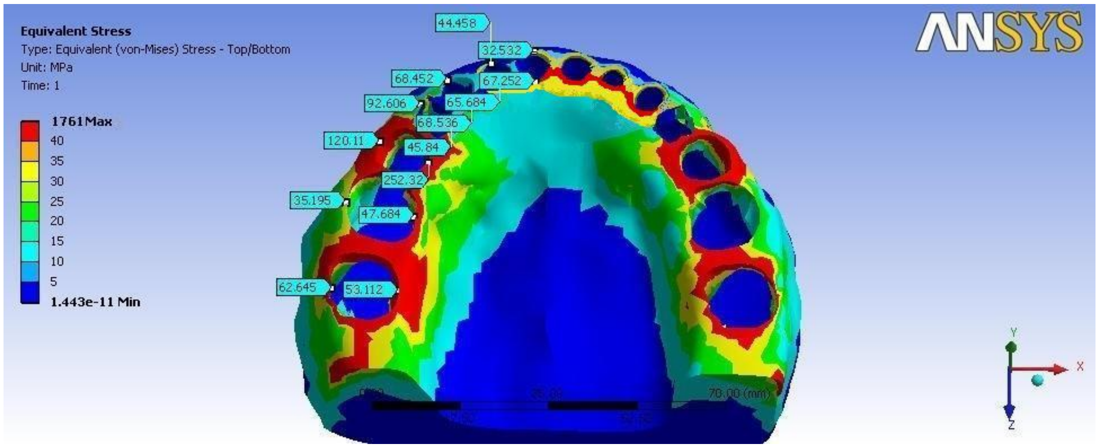


30 Degree

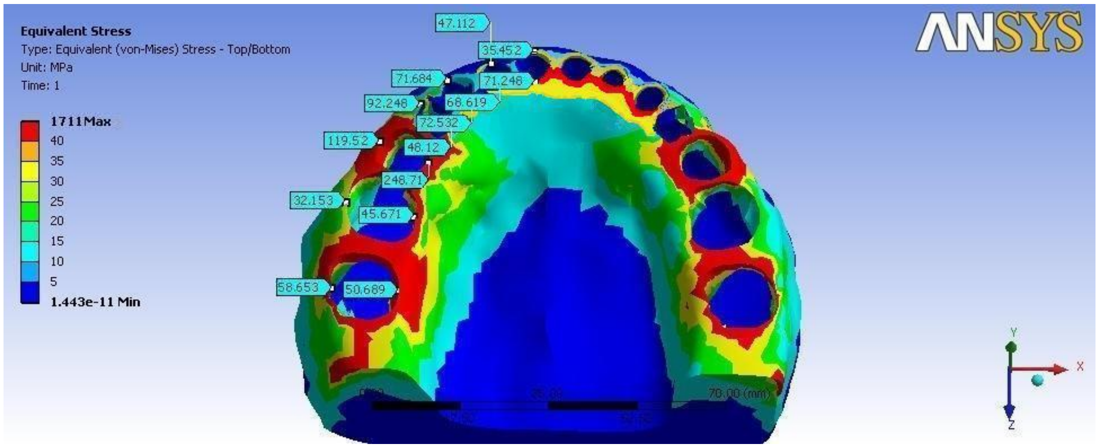
Figure 10: T-Loop - Cinching



0 Degree



15 Degree



30 Degree

Figure 11: T-Loop –Ligature tie

RESULTS

The study was conducted to compare the biomechanical efficiency of Double keyhole loop and continuous T-loop for en-masse space closure. The resultant stress, displacement of the dentition and moment-force ratio was calculated for 0,15 and 30 degree gable bend activated 1 mm using Cinching and Ligature-tie while space closure in maximum anchorage cases using Finite Element Analysis.

Stress distribution:

The values of stress distribution were shown in the spectrum of colours ranging from red (very high) to blue (lowest) in the obtained analysis image. The finite element analysis showed no statistically significant difference in overall stress distribution for all the groups (Table 3 & Graph 1,2).

Maximum stress concentration was seen in the second premolar region in all the groups when compared to anterior teeth.

Tooth Displacement:

The tooth displacement in all the groups were tabulated. The overall displacement of dentition was not statistically significant in all the groups.(Table 4 & Graph 3,4).

Center of resistance in 'Y' direction:

The center of resistance was calculated in all the groups for enmass retraction of six anterior teeth in 'Y' direction. The results showed an apical shift of the center of resistance with increase in gable bend from 0 degree to 30 degree for all the groups (Table 5 & 6).

Maximum center of resistance was observed in Group III at 30 degree gable bend (9.18mm).

Center of resistance in 'X' direction:

The center of resistance in 'X' direction remained relatively constant in all the groups even with increasing the degree of gable bend (approximately 15 mm posterior to the bracket of the central incisor) (Table 5 & 6).

Comparison of Moment-force ratio:

There was a progressive increase in moment-force ratio with increase in gable bend with both the groups. (Table 5 & 6).

Maximum moment-force ratio of 11.2Nmm was observed in Group IV when the gable bend was shifted mesially to th ligature-tito fthe firstloope first loop and Ligature-tie was placed to the first loop (Graph 3 & 4).

Table 3: Comparison of stress distribution in all the groups

Sub group	Group	Mean	SD	sig
0 deg	DC	.1534	.1057	.945
	DS	.1637	.1144	
	V1	.1736	.1204	
	V2	.1802	.1251	
	TC	.1603	.1113	
	TS	.1678	.1169	
15 deg	DC	.1485	.1007	.886
	DS	.1612	.1108	
	V1	.1678	.1135	
	V2	.1738	.1186	
	TC	.1548	.1067	
	TS	.1617	.1102	
30 deg	DC	.1520	.1030	.890
	DS	.1544	.1071	
	V1	.1654	.1161	
	V2	.1699	.1192	
	TC	.1595	.1065	
	TS	.1656	.1110	

NS: Not significant;*p < 0.05 (significant);**p < 0.001 (highly significant)

Table 4: Comparison of displacements of teeth in all the groups

Sub group	Group	Mean	SD	sig
0 deg	DC	189.9809	154.6930	.223
	DS	147.2331	123.9884	
	V1	151.8523	126.0723	
	V2	151.6494	124.2276	
	TC	185.2750	129.2550	
	TS	150.9597	104.5518	
15 deg	DC	185.7537	151.3631	.426
	DS	149.7646	121.9405	
	V1	153.8344	122.4700	
	V2	148.7084	104.4232	
	TC	184.2557	125.0230	
	TS	150.9180	99.6328	
30 deg	DC	184.0869	146.3060	.505
	DS	151.8319	119.0067	
	V1	155.9759	117.7378	
	V2	151.4666	97.4291	
	TC	185.4821	123.3930	
	TS	151.7730	98.0138	

NS: Not significant;*p < 0.05 (significant);**p < 0.001 (highly significant)

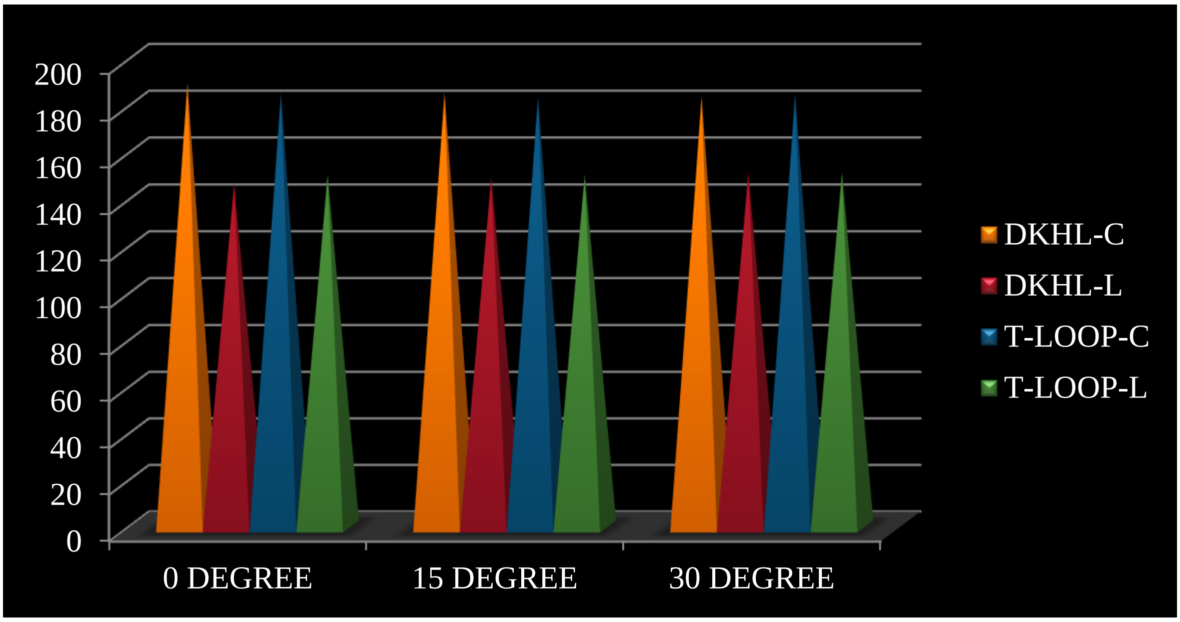
Table 5:- Comparison of Moment-Force Ratio in T-loop

	0 DEGREE				15 DEGREE				30 DEGREE			
DKHL	DKHL-C	DKHL-L	DKHL-V1	DKHL-V2	DKHL-C	DKHL-l	DKHL-V1	DKHL-V2	DKHL-C	DKHL-L	DKHL-V1	DKHL-V2
CR - Y	8.6	8.5	8.4	8.7	8.9	8.8	8.6	8.7	9.1	8.9	8.8	8.7
CR- X	15.6	15.5	15.4	15.4	15.4	15.0	15.1	15.2	15.4	15.2	15.4	15.5
MOMENT	169.7	150.8	185.3	188.3	170.4	181.3	167.9	195.5	163.8	176.3	182.5	208.3
FORCE	20.4	21.9	21.7	21.9	16.1	17.3	17.8	18.0	17.1	17.2	18.3	18.6
M:F RATIO	8.3:1	8.5:1	8.5:1	8.6:1	9.3:1	9.5:1	9.4:1	10.8:1	9.9:1	10.2:1	9.9:1	**11.2:1**

Table 6:- Comparison of moment – force ratio in T-loop

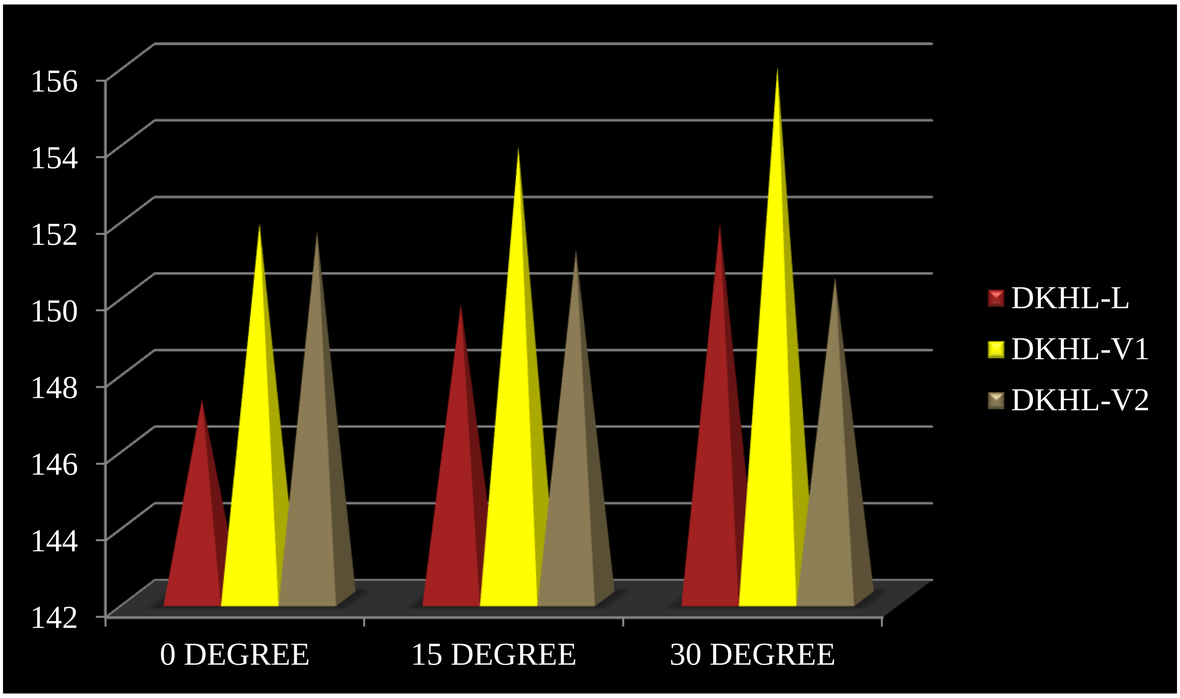
	0 DEG		15 DEG		30 DEG	
T-LOOP	T-LOOP-C	T-LOOP-L	T-LOOP-C	T-LOOP-L	T-LOOP-C	T-LOOP-L
CR - Y	8.8147	8.629	8.92465	8.817	9.189	9.019
CR- X	15.6827	15.598	15.267	15.126	15.407	15.319
MOMENT	185.5	159.4	180.5	197.5	167.317	195.4
FORCE	20.8067	21.9285	16.8782	17.5832	17.6974	18.5294
M:F RATIO	8.9:1	9.0:1	9.4:1	9.5:1	10.2:1	10.5:1

Graph 1:- Comparison of stress distribution between Group I & Group II

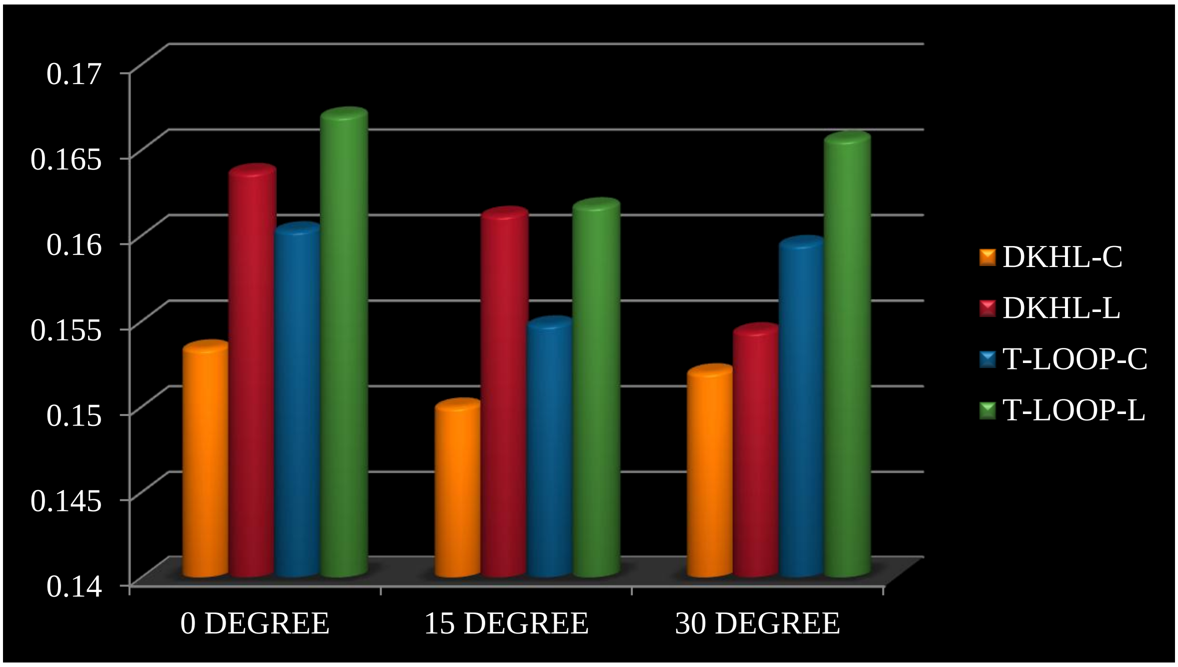


Graph 2: Comparison of stress distribution between Group I (DKHL-L)

Group III & Group IV

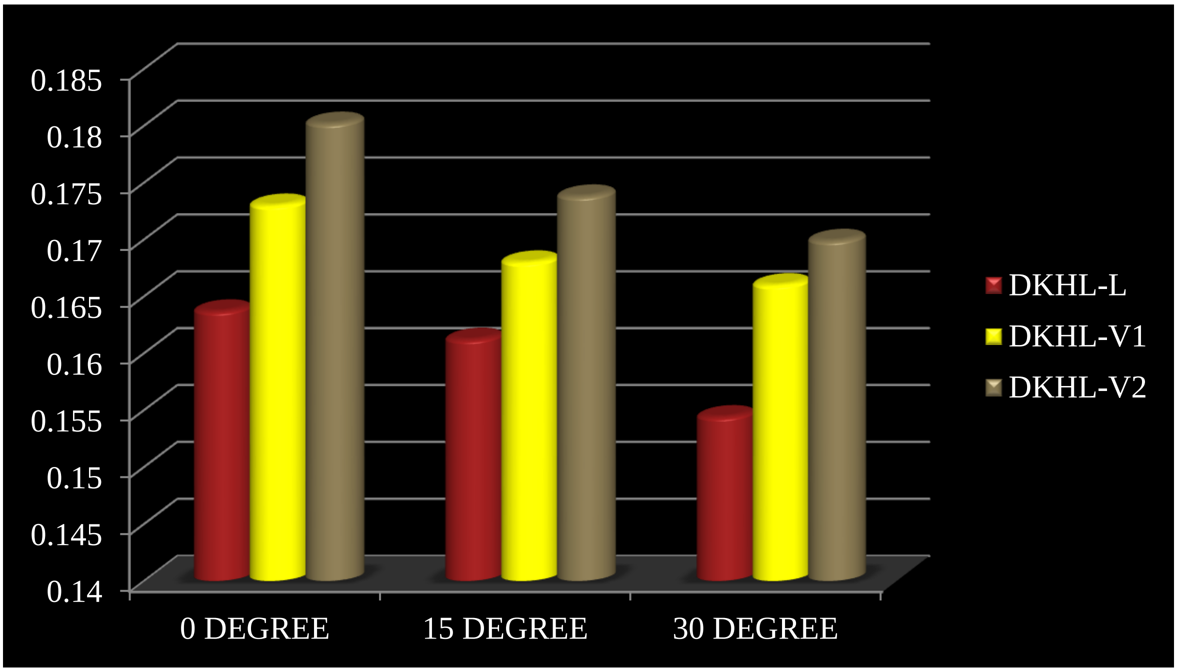


Graph 3: Comparison of tooth displacement between Group I & Group II

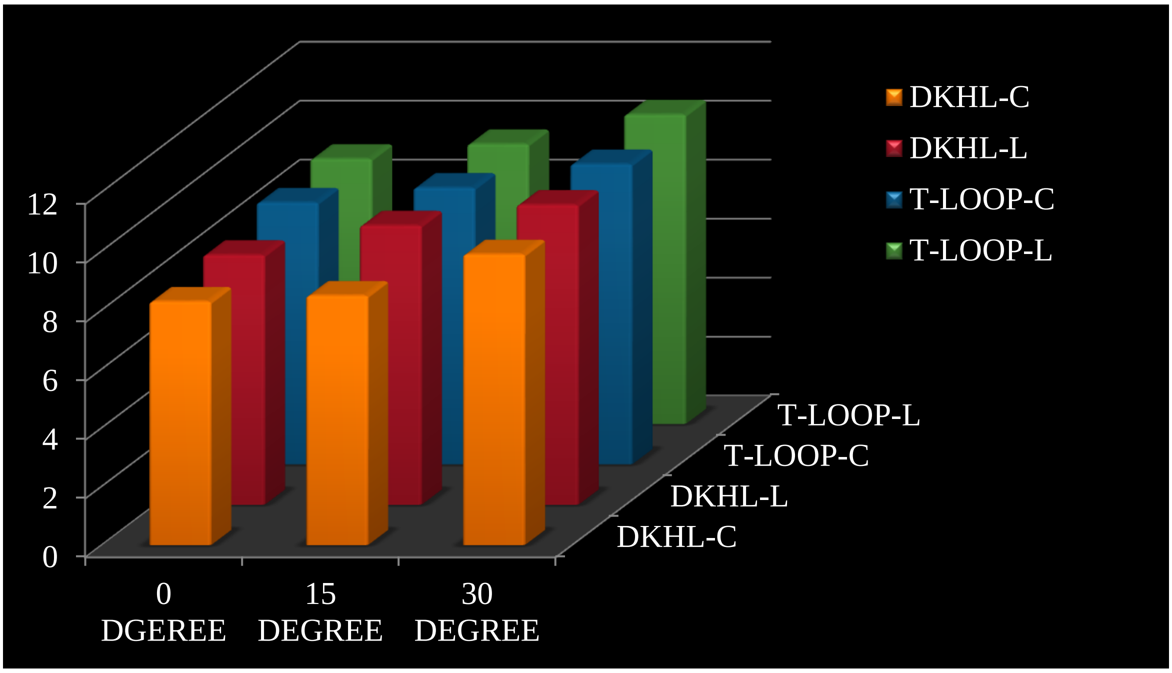


Graph 4 : Comparison of tooth displacement between Group I (DKHL-L),

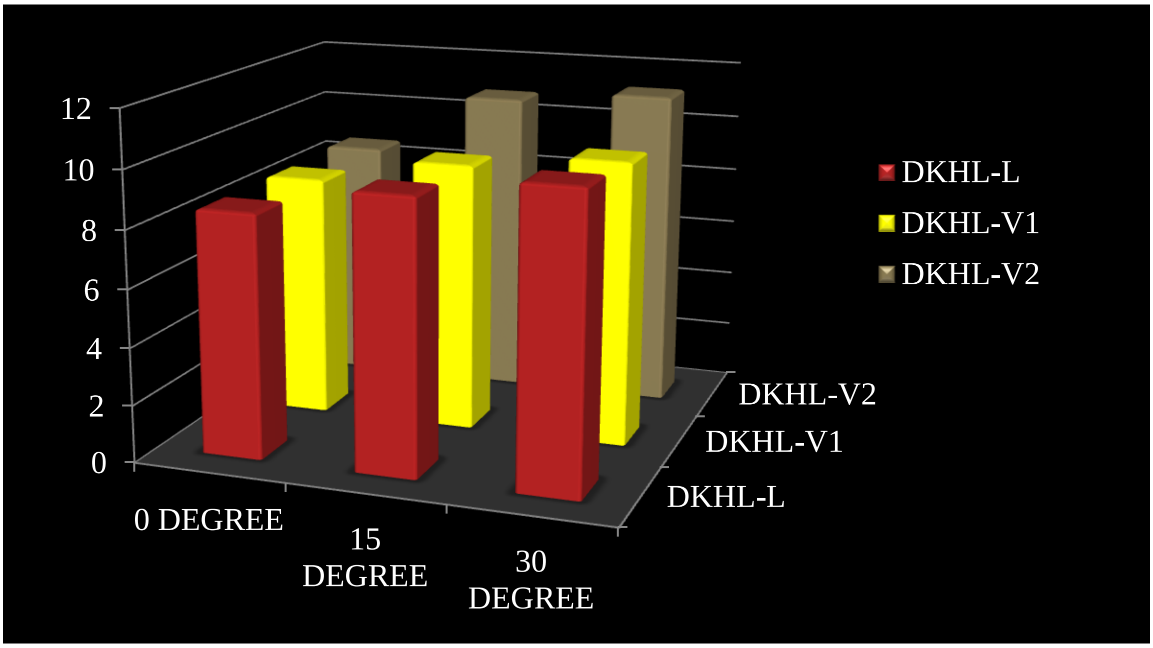
Group III & Group IV



Graph 5: Comparison of moment-force ratio between Group I & Group II



Graph 6:- Comparison of moment-force between Group I (DKHL-L), Group III & Group IV



DISCUSSION

Over the years, there has been a constant debate on the different methods of space closure depending on the relative merits of friction and frictionless mechanics. However, much of this could not be resolved without the knowledge of the optimal force levels involved. Storey and Smith developed the concept of optimal force as the minimum force that results in the maximum rate of tooth movement within the limits of biologic response[65, 74]. Quinn and Yoshikawa conducted a critical review on the different theories that relate the orthodontic force to tooth movement and concluded that the rate of tooth movement increases with increasing force up to a point, after which increasing the force further no longer results in increase in tooth movement[45]. Nikolai defined optimum orthodontic force as that which produces the most desirable biologic response and tooth movement with minimum tissue damage and maximum patient comfort[38].

Space closure can be accomplished by friction and frictionless mechanics. Friction mechanics causes binding and swing effect of the archwire, thereby taxing the anchorage, increasing the force levels, resulting in unwanted tooth movement[25]. In this regard, loop/frictionless mechanics is more beneficial in that a known force system is delivered to the teeth and spaces are closed with the help of loops with forces and couples built into it.

Therefore, while selecting the loop design for space closure, variables such as loop design, thickness and properties of the wire used, type of tooth movement desired and amount of force necessary must be taken into consideration[8].

Space closure using frictionless/loop mechanics can be done either as segmental (two step retraction) where the canines are first distalized followed by anterior retraction that is supposed to be less detrimental to anchorage. However, the treatment time is prolonged. On the contrary, an en-mass /one step retraction is more advantageous in terms of duration of treatment.

Two popular loops commonly employed in space closure are the DKHL & T-loop. To best of our knowledge the literature is scant for Double key hole loop and T-loop with regard to the force system delivered by these loops during space closure. Thus in the present study we have evaluated the efficacy of Double keyhole loop and continuous T-loop archwire mechanics using finite element analysis.

The Finite Element Analysis (FEA) is a modern tool for numerical stress analysis, which has the advantage of being applicable to solids of irregular geometry that contain heterogeneous material properties. It provides the orthodontist with quantitative data that can extend the understanding of physiologic reactions that occur within the dento-alveolar complex. Finite element method allows for exact modeling of the tooth, periodontal ligament and mechanical properties of the tissue in three dimensions[71].

Several studies have demonstrated that the FEM provides a solid, workable foundation for modeling the system[20, 21 42,71]. The greatest strength of the FEM model is that it can be magnified infinitely both in terms of the actual volumetric construction itself and the mathematical variability of its material parameters. In biomechanics of tooth movement it is commonly used in describing the reactions of dental and facial structures to orthodontic forces and solving stress-strain problems in the mechanics[14].

When a continuous loop archwire is used the force system generated becomes a statically indeterminate system thereby producing complex 3D interactions[24]. Finite element analysis facilitates the study of this 3D interaction and the force system exhibited by it.

This is one of the first study, to compare the retraction efficiency of Double key hole loop and T-loop evaluating the mechanical properties, moment-force ratio and the stress distribution by two different methods of activation (Cinching and Ligature-tie) at various degrees of gable bend (0, 15 & 30°).

Double keyhole loop is the most preferred retraction loop for space closure with 0.22x0.028 inch slot Roth prescription as suggested by Roth[55]. In maximum anchorage cases a 0.019x0.025 inch stainless steel double key hole loop is used[3]. This design of the loop provides a reasonably happy medium between severe tipping and sliding mechanics of space closure with better control of canine rotation and the entire extraction space can be closed with one set of archwire[55].

Symmetrical, T-loop was also used with the loop configuration according to the specifications suggested by Burstone[10].

Gable bends are frequently incorporated into the loop configuration to provide a moment to prevent the root apices of the teeth from moving in a direction opposite to that of their crowns (uncontrolled tipping). In both the loops gable bend was incorporated to prevent undesirable tooth movement usually generated during activation of spring (distal tipping of canine) thus providing a more controlled or bodily movement of the teeth and mild reverse curve of spee was included for overbite control during space closure[64]. The moment-force ratio was calculated with respect to the center of resistance of six anterior teeth as suggested by Gwang-Mo Jeong[19].

The present study evaluated the efficiency of en-masse space closure using Double keyhole loop and T-loop under the following:-

- ✓ Stress distribution.
- ✓ Displacement of teeth.
- ✓ Moment-force ratio.

- Comparison of conventional methods of activation in double keyhole loop and T-loop (Group I and Group II)
- Comparison of double keyhole loop activated through Ligature-tie to 2nd loop (Group I) and double keyhole loop- V1(Group III) activated through Ligature-tie to first loop.
- Comparison of Group III (DKHL-V1) and Group IV (DKHL-V2).

Comparison of Double keyhole loop (Group I) & T-loop (Group II):

The stress patterns during conventional methods of activation (Cinching & Ligature-tie) was compared in both Group I(DKHL-C and DKHL-L) and group II (T-loop-C and T-loop-L) for 1 mm of activation at different degrees of gable bend showed no statistically significant difference in stress distribution. This could be attributed to the morphology / design of the loops, as the T-loop design has increased horizontal arm and two loops incorporated in double key hole loop similarly increases the flexibility of archwire producing an optimal force delivery leading to less stress distribution in the anterior region.

However, the maximum amount of stress concentration was observed in the second premolar region due to the proximity of gable bend in the posterior region along with mild reverse Curve of Spee in the archwire..

Similarly, the overall displacement of the dentition was not satatistically significant in all the groups.

It is interesting to note that the moment-force ratio increased progressively with increase in the degree of gable bend with both the loops. Burstone stated that increasing the quantum of wire in the apical region as in T-loop increases the moment-force ratio[8,10]. However, DKHL was also found to be equally efficient in delivering the desired moment-force ratio comparable to the T-loop. This could be possibly due to the incorporation of two loops along with the increase in gable bend.

The Ligature-tie activated T-loop (Group II – T-loop-L) showed higher moment-force ratio with increasing the gable bend as compared to other groups with maximum of 10.5Nmm at 30 degree gable bend. In this group along with increase in moment-force ratio the centre of resistance also shifted more apically(9.01mm) compared to other groups there by better torque control of anterior teeth could be observed. This is in accordance with results published by Yoshida et al in an invitro study who compared the height of hook placement and force applied with respect to centre of resistance for en-masse retraction and concluded that as the height of force application increased more translatory tooth movement was observed[34].

In previous literature **Jie Chen et al**[22] did an invitro study using 0.016x0.022 stainless steel segmented T-loop and compared the moment-force ratio with respect to geometry and preactivation bends. The study showed that increasing the horizontal and vertical dimension of the loop decreased the moment-force ratio. The highest moment-force ratios were achieved at 1mm of activation ranging from 4-5Nmm without any gable bend / preactivation bends.

Mohammad Reza Safavi[37] compared the moment-force ratios of four different closing loops with and without preactivation using FEM. The results showed that stainless steel Opus and T-loop without preactivation bends had constant moment-force ratios 7.6 & 7.2 mm respectively but both were below the optimum moment-force ratio of 10:1.

However, in the present study we used 0.019x0.025 inch stainless steel Continuous T-loop with loop configuration as suggested by Burstone[10]. In the present study moment-force ratio of 8 – 10 was achieved that is considered desirable for bodily tooth moment. This could be possibly due to the incorporation of gable bend along with mild reverse Curve of Spee.

Hoenigl et al[30] examined the force and moment characteristics of a prefabricated and preactivated centered T-loop. The result showed that the moment-force ratio produced with the centered T-loop was 7.5 – 8 and suggested that centered T-loop can be used to control clinically the force system in the patients mouth.

Raymond E. Siatkwoski[48] suggested that a constant moment-force ratio of 8.0-9.1mm with out any residual moments could be achieved during en-masse space closure with an uniform stress distribution in the periodontal ligament using a continuous closing loop archwire which is in concurrence with our present study showing moment-force ratio of 8-10. Our study is the first of its kind that shows that the Double Keyhole loop also has similar efficiency as the T-loop.

Comparison of Group I (DKHL-L) and Group III (DKHL-V1) :

In Group III (DKHL-V1) wherein the Ligature-tie was shifted from second loop to the first loop when compared to Group I (DKHL-L) showed no statistically significant difference in stress distribution and overall displacement of dentition among both the groups. The moment force ratio was found to be similar in both the groups and consistently increased with increasing the degree of gable bend as suggested in previous literature[64]. Maximum moment-force ratio was found in DKHL-L 10.2 Nmm at 30 degree of gable bend.

Comparison of Group III (DKHL-V1) and Group IV (DKHL-V2):

The gable bend was shifted from mesial of second loop to the mesial of first loop in Group IV compared to Group III with Ligature-tie tied to first loop the stress distribution and displacement of teeth was not statistically significant.

There was significant increase in the moment-force ratio when the gable bend was shifted mesial to the first loop and tied with the Ligature-tie to first loop. This could be due to the proximity of gable bend to the anterior region along with the ligature tie to first loop the center of resistance shifted apically thereby increasing the moment-force ratio as high as 11.2Nmm at 30 degree gable bend producing lingual root movement of the anterior teeth.

Therefore, the Group IV (DKHL-V2) is beneficial in cases requiring maximum anterior torque control after space closure.

Clinical Implications:

1. Maximum stress distribution was observed in the second premolar region in all the groups. This could be due to the excessive force produced on that region leading to undermining resorption thus preventing orthodontic tooth movement and thereby increasing the anchorage in the posterior segment.
2. Double key hole loop was found to be equally efficient as T-loop for enmass retraction of anterior teeth, producing bodily tooth movement.
3. Morphology of two different loop was found to produce similar biomechanical properties and similar increase in moment-force ratio with progressive increase in gable bend.
4. The variation in Group IV (DKHL-V2) can be beneficially used for maximum anchorage cases requiring anterior torque control with the same archwire by shifting the gable bend mesial to first loop and ligature-tie to first loop after space closure.

Future :- This is an in-vitro (FEM) and cannot be directly extrapolated to clinical situation because of the difference in biological response to dentition and individual variation. Therefore clinical studies need to be done to evaluate the biomechanical efficiency of Double keyhole loop and continuous T-loop for maximum anchorage cases.

SUMMARY AND CONCLUSION

The present **FEM** study was carried out to compare the retraction efficiency of two commonly used loops Double keyhole loop and Continuous T-loop using finite element analysis.

The following conclusions can be drawn from the present study:

1. The resultant stress distribution and the overall displacement of the dentition was not statistically significant among all the groups. However, the maximum stress concentration was seen in the 2nd premolar region due to the proximity of the gable bend and reverse Curve of Spee. This is beneficial especially in maximum anchorage cases, wherein the increased stress in the posterior region causes undermining resorption, thereby prevents the mesial movement of the posterior teeth.
2. The resultant moment-force ratio achieved a ratio of 8-10 in all the groups. Nevertheless maximum moment-force ratio of 11.2Nmm was observed in Group IV where the gable bend was shifted mesially to the first loop and ligature tied to the first loop. This is more advantageous in cases requiring maximum anterior torque control.
3. Therefore, both the loops were found to be equally efficient producing desirable moment-force ratio for bodily tooth movement.
4. However, altering the gable bend and ligature tie produces greater moment-force ratio for better anterior torque control.

BIBLIOGRAPHY

1. **Ammar HH, Ngan P** - Three-dimensional modeling and finite element analysis in treatment planning for orthodontic tooth movement. Am J Orthod Dentofacial Orthop. 2011 Jan;139(1):e59-71.
2. **Andrew J. Kuhlberg and Charles J. Burstone** - T-loop position and anchorage control. Am J Orthod Dentofac Orthop 1997;112:12-8.
3. **Antonino G. Secchi, Jorge Ayala** – Contemporary treatment mechanics using the straight wire appliance. Orthodontics current principles and techniques. Grabber. Vanarsdall. Vig. 2012 Fifth Edition.
4. **Booth** – Thesis – optimum forces from activation loops. University of Texas, Houston.1971.
5. **Cattaneo PM, Dalstra M, Melsen B.** - The finite element method: a tool to study orthodontic tooth movement. J Dent Res. 2005 May;84(5):428-33.
6. **Chang Y I, Shin S J, Baek S H –** Three dimensional analysis in the distal enmasse movement of the maxillary dentition with multi loop edgewise mechanics. European Journal of Orthodontics.2004:26(3) 339-345.

7. **C.J.Burstone , J.J.Baldwin, D.T.Lawless** - The application of continuous forces to orthodontics. Angle orthodontics; 1961: 31 (1) : 1-14.
8. **Charles J. Burstone, and Herbert A. Koenig** - Optimizing anterior and canine retraction. Am J Orthod Dentofacial 1976 July vol 70 : 1-19.
9. **Charles J. Burstone and Ryszard J. Pryputniewicz** – Holographic determination of center of rotation produced by orthodontic force. Am J Orthod Dentofacial Orthop 1980 April vol 77 : 29-38.
10. **Charles J. Burstone** – The segmented arch approach to space closure. Am J Orthod Dentofacial Orthop 1982 November vol 82 : 361-378.
11. **Christoph Bourauel, Dieter Drescher, Jan Ebling, David Broome and Andreas Kanarachos** - Superelastic nickel titanium alloy retraction springs-an experimental investigation of force systems. European Journal of Orthodontics 1997; 491-500.
12. **Dalstra M, Melson B** – Force systems develop by six different cantilever configurations. Clin-Orth Res 1999; 2(1) 3-9.
13. **Darnell Rose, Andrew Quick, Michael Swain, and Peter Herbison -** Moment-to-force characteristics of preactivated nickel-titanium and titanium-molybdenum alloy symmetrical T-loops. Am J Orthod Dentofacial Orthop 2009;135:757-63.

14. **David J. Rudolph, Michael G. Willes -** A Finite Element Model of apical force distribution from orthodontic tooth movement**.** *Angle Orthod* 2001;71:127–131
15. **Demetrios J. Halazonetis** – Understanding orthodontic loop preactivation. Am J Orthod Dentofacial Orthop 1998 February 237 – 241.
16. **Domenico Mazza, Michele Mazza, Mech Eng** - Specialized Spring Design in Segmented Edgewise Orthodontics: Further Verification of Dedicated Software. Angle Orthod 2000;70:52–62.
17. **Don Raboud, Gary Faulkner, Bill Lipsett, and Doug Haberstock** - Three-dimensional force systems from vertically activated orthodontic loops. Am J Orthod Dentofacial Orthop 2001;119:21-9.
18. **Guilherme Thiesen, Marcus Vinicius Neiva Nunes do Rego, Luciane Macedo de Menezes and Roberto Hideo Shimizu** - Force systems yielded by different designs of T:loop. Aust Orthod J 2OO5 vol 2; l : 103-l 1O.
19. **Gwang-Mo Jeong, Sang-Jin Sung, Kee-Joon Lee** - Finite-element investigation of the center of resistance of the maxillary dentition. Korean J Orthod 2009;39(2):83-94.
20. **Haskell B S, Spencer W A, Day M.** – Auxiliary springs in continuous arch treatment part I an analytical study using finite element method. Am J Orthod Dentofacial Orthop 1990;98 – 387-397.

21. **Issa Fathima Jasmine -** Analysis of stress in bone and microimplants during en-masse retraction of maxillary and mandibular anterior teeth with different insertion angulations: A 3-dimensional finite element analysis study. Am J Orthod Dentofacial Orthop 2012;141:71-80.
22. **Jie Chen, David L. Markham, Thomas R. Katona** - Effects of T-Loop Geometry on Its Forces and Moments. Angle Orthod 2000;70:48–51.
23. **Jie Chen, Irina Bulucea, Thomas R. Katona and Susan Ofner** - Complete orthodontic load systems on teeth in a continuous full archwire: The role of triangular loop position. Am J Orthod Dentofacial Orthop 2007;132: 143.e1-143.
24. **Jie Chen, Serkis C. Isikbay, Edward J. Brizendine** - Quantification of three-dimensional orthodontic force systems of T-loop archwires. Angle Orthod. 2010;80:754–758.
25. **Joon-No Rhee, Youn-Sic Chun** - A comparison between friction and frictionless mechanics with a new typodont simulation system. Am J Orthod Dentofacial Orthop 2001;119:292-9.
26. **Kazuo Tanne, Takao Nagataki** – Patterns of initial tooth displacements associated with various root lengths and alveolar bone heights. Am J Orthod Dentofac Orthop 1991;100:66-71.
27. **Kazuo Tanne, Herbert A. Koenig and Charles J. Burstone** - Moment to force ratios and the center of rotation. Am J Orthod Dentofac Orthop 1988;94:426-31.

28. **Kazuo Tanne, Mamoru Sakuda, and Charles J. Burstone** - Three-dimensional finite element analysis for stress in the periodontal tissue by orthodontic forces. AM J Orthod Dentofac Orthop 1987;92:499-505.
29. **Kazuo Tanne** – Stress distribution in the maxillary complex from headgear forces. Angle Orthodontist, 1993 Vol 63; 111-118.
30. **Klaus D. Hoenigl, Josef Freudenthaler, Michael R. Marcotte, and Hans-Peter Bantleon** – The centered T-loop-a new way of preactivation. Am J Orthod Dentofac Orthop 1995; 108:149-53.
31. **Luiz Guilherme Martins Maia, Luiz Gonzaga Gandini** - Photoelastic analysis of forces generated by T-loop springs made with stainless steel or titanium-molybdenum alloy. Am J Orthod Dentofacial Orthop 2011;140:e123-e128.
32. **Marcelo do Amaral Ferreira** - The wire material and cross-section effect on double delta closing loops regarding load and spring rate magnitude: An in vitro stud. Am J Orthod Dentofacial Orthop 1999;115:275-82.
33. **Maria Elisa Rodrigues Coimbra, Norman Duque Penedo** - Mechanical testing and finite element analysis of orthodontic teardrop loop. Am J Orthod Dentofacial Orthop 2008;133:188.
34. **Masaru Kobayashi; Noriaki Yoshida -** Optimal Loading Conditions for Controlled Movement of Anterior Teeth in Sliding Mechanics.A 3D Finite Element Study. Angle Orthod. 2009;79:1102–1107.

35. **Melvin L. Moss, Richard Skalak** - Finite element method modeling of craniofacial growth. Am J Orthod Dentofacial Orthop 1985; June vol 87 p.453-472.
36. **M.G. Faulkner, A.W. Lipsett, K. EI-Rayes, D.L. Haberstock** - On the use of vertical loops in retraction systems. Am J Orthod Dentofacial Orthop 1991 April vol.99 p. 328-336.
37. **Mohammad Reza Safavi, Allahyar Geramy and Amir Kamyar Khezri** - M/F ratios of four different closing loops: 3D analysis using the finite element method (FEM). Australian Orthodontic Journal Volume 22 No. 2 November 2006.
38. **Nikolai RJ**. On optimum force orthodontic theory as applied to canine retraction. Am J Orthod 1975;68:290-302.
39. **Noriaki Yoshida, Paul-Georg Jost-Brinkman** - Experimental evaluation of initial tooth displacement, center of resistance, and center of rotation under the influence of an orthodontic force. Am J Orthod Dentofacial Orthop 2001;120:190-7.
40. **N.Yoshida, Y.Koga** – In vivo determination of the centres of resistance of maxillary anterior teeth subjected to retraction forces. Eur J Orthod. 2001 529-534.
41. **Pedersen E, Isidor F, Gjessing P, Andersen K** - Location of centres of resistance for maxillary anterior teeth measured on human autopsy material. Eur J Orthod. 1991 Dec;13(6):452-8.

42. **Prasad Konda, Tarannum SA. -** Basic principles of finite element method and its applications in orthodontics. JPBMS, 2012, 16 (11).
43. **Proffit W R**. – Contemporary orthodontics ; 4th edition 2007. (593-595).
44. **Poul Gjessing** - Controlled retraction of maxillary incisors. Am. J. Orthod. Dentofac. Orthop.1992 February.
45. **Quinn RS, Yoshikawa DK**. A reassessment of force magnitude in orthodontics. Am J Orthod 1985;8:252-60.
46. **Ravindra Nanda** – Biomechanics in clinical orthodontics. 1997.
47. **Raymond E. Siatkowski** - Continuous arch wire closing. Part I loop design, optimization and verification. Am J Orthod Dentofac Orthop 1997;112:393-402.
48. **Raymond E. Siatkowski -** Continuous arch wire closing loop design, optimization, and verification. Part II. Am J Orthod Dentofac Orthop 1997;112:487-95.
49. **Renato Parsekian Martins, Peter H. Buschang, Rodrigo Viecill, Ary dos Santos-Pinto** - Curvature Versus V-Bends in a Group B Titanium T-Loop Spring. Angle Orthodontist, Vol 78, No 3, 2008.
50. **Renato Parsekian Martins, Peter H. Buschang, Lidia Parsekian Martins, and Luiz Gonzaga Gandini Jr** - Optimizing the design of preactivated titanium T-loop springs with Loop software. Am J Orthod Dentofacial Orthop 2008;134:161-6.

51. **Renato Parsekian Martins, Peter H. Buschang, and Luiz Gonzaga Gandini Jr** - Group A T-loop for differential moment mechanics: An implant study. Am J Orthod Dentofacial Orthop 2009;135:182-9.
52. **Richard J. Smith and Charles J. Burstone** - Mechanics of tooth movement. Am. J. Orthod. April 1984.
53. **Robert P. Kusy, and J. F. Camilla Tulloch** - Analysis of moment~force ratios in the mechanics of tooth movement. AM J Orthod Dentofacial Orthop 90: 127-131, 1986.
54. **Rodrigo F. Viecilli** - Self-corrective T-loop design for differential space closure. Am J Orthod Dentofacial Orthop 2006;129:48-53.
55. **Roth. H. Ronald, Graber and Swain**- Treatment mechanics for straight wire appliance. Orthodontic current principles and technique. First indian edition 1991; 688-690.
56. **Schneider** – Numerical experiments on long time orthodontic tooth movement. Am J Orthod Dentofacial Orthop 2002, 121 (3) 257-265.
57. **Schwarz AM.** Tissue changes incident to orthodontic tooth movement.*Int J Orthod.* 1932;18:331–352.
58. **SheauSoon Sia, Yoshiyuki Koga, Noriaki Yoshida** - Determining the Center of Resistance of Maxillary Anterior Teeth Subjected to Retraction Forces in Sliding Mechanics.An In Vivo Study. Angle Orthodontist, Vol 77, No 6, 2007.
59. **Sergei Godeiro Fernandes Rabelo Caldas, Renato Parsekian Martins** - Force system evaluation of symmetrical beta-titanium T-

loop springs preactivated by curvature and concentrated bends. Am J Orthod Dentofacial Orthop 2011;140:e53-e58.

60. **Sergei Godeiro Fernandes Rabelo Caldas, Renato Parsekian Martins** - Effects of stress relaxation in beta-titanium orthodontic loops. Am J Orthod Dentofacial Orthop 2011;140:e85-e92.
61. **Spiro J. Chaconas, Angelo A. Caputo and Riley K. Hayashi** - Effects of wire size, loop configuration, and gabling on canine-retraction springs. Am J Orthod Dentofacial Orthop 1974 January p.A36 : 58-66.
62. **Spiro J. Chaconas, Angelo A. Caputo, K. Miyashita.** Force distribution comparisons of various retraction archwires. Angle Orthodontics 1989 No. 1, 25-30.
63. **Staggers. A. j. Germane. N-** Clinical consideration in the use of retraction mechanics. Journal of clinical orthod. 1991;364-369.
64. **Stanley Braun, and Jose´ L. Garcia** - The Gable bend revisited. Am J Orthod Dentofacial Orthop 2002;122:523-7.
65. **Storey E, Smith R**. Force in orthodontics and its relation to tooth movement. Aust Dent J. 1952;56:11–18.
66. **Su JH, Zhang DQ, Xu LY, Zhong PP**.- 3-D finite element analysis on center of resistance of upper anterior teeth. Shanghai Kou Qiang Yi Xue. 2010 Oct;19(5):534-40.

67. **Thomas R. Katona, Yen P. Le and Jie Chen** - The effects of first- and second-order gable bends on forces and moments generated by triangular loops. Am J Orthod Dentofacial Orthop 2006;129:54-59.
68. **Wilson** – A finite element study of canine retraction with a palatal spring; European Journal of Orthodontics 1991- 211-218.
69. **Wook Heo, Dong-Seok Nahm, Seung-Hak Baek** - En Masse Retraction and Two-Step Retraction of Maxillary Anterior Teeth in Adult Class I Women. A Comparison of Anchorage Loss. Angle Orthodontist, Vol 77, No 6, 2007.
70. **Vanden Bulcke MM, Dermaut LR, Sachdeva RC, Burstone CJ**.- The center of resistance of anterior teeth during intrusion using the laser reflection technique and holographic interferometry. Am J Orthod Dentofacial Orthop. 1986 Sep;90(3):211-20.
71. **Vishal Seth Prasanth Kamath**- A Marvel Of Modern Technology: Finite Element Model. Virtual J Orthod – 2010 Dec.
72. **Y. Mahesh Kumar, N.S. Ravindran and M.R. Balasubramaniam** - Holographic Analysis of the Initial Canine Displacement Produced by Four Different Retraction Springs. Angle Orthod. 2008;00:368–372
73. **Yeen Lim, Andrew Quick, Michael Swain, Peter Herbison** - Temperature Effects on the Forces, Moments and Moment to Force Ratio of Nickel-Titanium and TMA Symmetrical T-loops. Angle Orthodontist 2008 Vol 78, No 6.

74. **Yijin Ren, Jaap C. Maltha -** Optimum Force Magnitude for Orthodontic Tooth Movement: A Systematic Literature Review. Angle Orthod 2003;73:86–92.
75. **Yue Huang, Ludger Keilig** - Numeric modeling of torque capabilities of self-ligating and conventional brackets. Am J Orthod Dentofacial Orthop 2009;136:638-43.
76. **Yukio Kojima, Jun Kawamura** - Finite element analysis of the effect of force directions on tooth movement in extraction space closure with miniscrew sliding mechanics. Am J Orthod Dentofacial Orthop 2012;142:501-8.