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Muhammad Fawwaz Orabi
Post-graduate student at the the Department of Orthodontics at the Faculty of Dentistry, Hama University, Syria

Dr. Rabab Al-Sabbagh
Professor, Head of the Department of Orthodontics at the Faculty of Dentistry, Hama University, Syria

Mahmoud Hosny Hashim Elhadidy
Engineer, Research and Teaching Assistant at Zewail City for Science and Technology October Gardens, Cairo, Egypt

Corresponding Author:
Muhammad Fawwaz Orabi
Post-graduate student at the the Department of Orthodontics at the Faculty of Dentistry, Hama University, Syria

Comparison of stainless steel and TMA archwires for En-masse retraction in lingual orthodontics: A 3D finite element study

Muhammad Fawwaz Orabi, Dr. Rabab Al-Sabbagh and Mahmoud Hosny Hashim Elhadidy

Abstract
Introduction: Requirements for more aesthetic solutions have seen an increased demand by orthodontic patients recently. Fixed lingual appliances provide the perfect aesthetic aspect, although it requires a highly-skilled orthodontist due to the fact that mispositioning of a lingual bracket has a more noticeable impact on the resulting tooth movements compared to traditional straight-wire appliances. The choice of material for the archwire used for retraction is one of the factors that have an impact on the tipping of the anterior segment.
Aims: The aim of the study was to analyze a 3D finite elements model of a maxilla after removing the upper first premolars, simulating en-masse retraction of the anterior segment using a fixed lingual orthodontic appliance, with different wire materials: stainless steel (SS) and titanium-molybdenum alloy (TMA).
Materials and Methods: A 3D model for the maxilla, the upper teeth and the PDL was constructed. The first upper molars were removed and a fixed lingual appliance was designed, consisting of a 16x16 mil mushroom-shaped archwire and lingual brackets. The model was imported into ANSYS software to generate a finite elements mesh. A 100 newton horizontal force was applied at the distal end of the archwire behind the last molar. The maximum values for the Von-mises stress equivalent and horizontal tooth displacement were evaluated. Additionally, the M/F ratio of both the anterior and posterior segments was computed.
Results and Discussion: In both types of material of the archwire, the initial movement of the anterior teeth was backwards and downwards (extrusion). Inversely, the posterior teeth moved backwards and upwards (intrusion). The movement in posterior teeth was higher when SS was used. Posterior teeth moved more initially than the anterior teeth, regardless of the type of material. The anterior teeth moved when a TMA wire was used compared to SS. The TMA wire suffered more deformation than the SS. Regardless of the material, the deformation was most noticeable in the posterior half of the archwire. The M/F ratio of both anterior and posterior segments was higher when a TMA wire was used. Both wires produced M/F ratio within the uncontrolled tipping range.
Conclusions: The initial total movement of the anterior teeth during en-masse retraction using a fixed lingual appliace is higher when TMA archwire compared to an SS archwire. The deformation was most noticable in the posterior half of the archwire. Using TMA for the space closure stage with a fixed lingual appliance produces higher M/F ratios compared to an SS archwire, which indicates that TMA is able to achieve movements closer to pure translation (bodily movements) compared to SS.

Keywords: Lingual orthodontics, moment-to-force ratio, finite elements, en-masse retraction, space closure

Introduction
The 1970s saw major leaps in the advancement of orthodontic appliances. Following the first straight-wire applinace, developed by Lawrence Andrews, public demand for orthodontic treatment increased substantially, which posed a new set of challenges for orthodontists with regard to the aesthetic aspects. Transparent brackets were introduce in an attempt to meet the aesthetic demands patients have come to expect. However, these brackets suffered from discoloration overtime. Search for a more aesthetic solution thus continued [1].
Clear aligners did not provide a comprehensive alternative for fixed appliance treatment, because three-dimensional control of tooth movement was not feasible with these aligners.
The development of the first fixed lingual appliances can be attributed to Kinya Fujita in Japan

and Craven Curz in the United States, who both independently designed brackets which could be bonded to the lingual surfaces of teeth [2].

The problems of the first few generations of fixed lingual appliances can be summarized as follows:

1. Speaking difficulties
2. Gingival irritation
3. Occlusal interference
4. Problems with controlling tooth movement
5. Inaccurate fit between the bracket base and the tooth surface
6. Inconvenient bonding and wire fitting

Most of these issues have been overcome with further iteration on the design.

These developments in lingual orthodontics have resulted in a new section to be included in the 4th edition of *Contemporary Orthodontics*, which is considered by many orthodontists as the number 1 orthodontic textbook.

Fig 1: A CAD/CAM designed fixed upper lingual orthodontic appliance [3]

Fig 1: A CAD/CAM designed fixed lower lingual orthodontic appliance [3]

In lingual orthodontics, both loop (fig. 3 and???) and sliding (fig. 2) mechanics can be used. Three types of loops can be used:

- Closed helical loop
- L-loop
- T-loop

Compared to loop mechanics, sliding mechanics suffers from wire friction and difficulty controlling tooth movements, which often causes anchorage loss and intrusion of the anterior segment during retraction.

Loop mechanics, on the other hand, are very efficient for space closure without friction, and allow for adding bends to control the tipping of the teeth. However, this type of retraction requires a more skilled orthodontist [1].

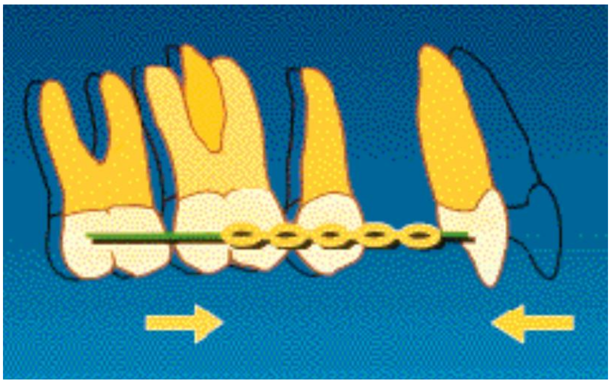

Fig 2: Sliding mechanics for retraction [1]

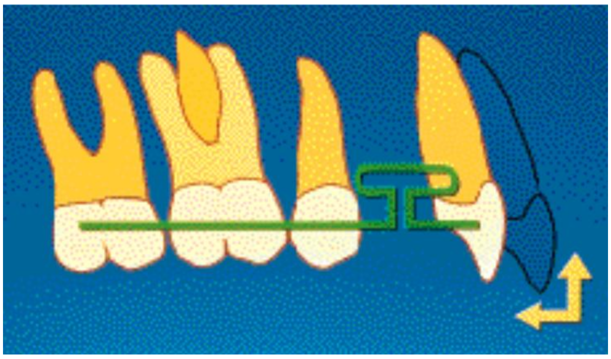

Fig 3: Loop mechanics for retraction [1]

Main differences between lingual and labial techniques for fixed appliances

1. Anatomical variations of the lingual surfaces
2. Torque control
3. Area of adhesion surface

1. Anatomical variations of the lingual surfaces

The labial and lingual surfaces of a tooth are vastly different. Additionally, lingual surfaces vary more widely between individuals compared to labial surfaces.

For example, the labial surface of a central incisor is usually very similar between individuals. This is in contrast to the lingual surface. This means that it is usually very difficult to design a lingual bracket based on mean values for surface dimensions.

This is further complicated with the fact that slight differences in the positioning of a lingual bracket has a more evident impact on the root torque.

2. Torque control

Torque control is particularly important in lingual techniques because incorrect torque causes a completely different result compared to conventional, labial techniques.

When a labial appliance is used, a 10 degree difference in torque is usually unnoticeable to the patient. Only a skilled orthodontic can notice it. Conversely, when a lingual appliance is used, the same 10 degree difference in torque causes a huge change in the vertical position of the tooth. The tooth also appears to be more proclined, which the patient can notice. The issue is further aggravated due to the increased thickness of the lingual bracket.

This indicates that the design of lingual brackets require far more precision such that the amount of torque play is accurately controlled.

3. Area of adhesion surface

Most orthodontic patients are kids or young adults. In this age group, the area of adhesion surface on the lingual surfaces of the teeth is usually small, particularly for newly-erupted teeth. This explains the need for a bracket design that is customized for each individual patient [4].

Stainless Steel (SS) archwires

Stainless steel archwires were first introduced by Wikinsons in 1929 [5]. This alloy has high stiffness and great resistance to deformation, which allows it to be used during the movement stage of orthodontic treatment. However, this stiffness is not suitable for the early stages of alignment because it makes it difficult to bend the stainless steel wire, and even if the orthodontics manages to do it, the wire will be permanently deformed [6].

Beta titanium (TMA) archwires

Also known as titanium-molybdenum alloy archwires, or TMA for short, this material wre first introduced in orthodontics by Burstone in 1979. These wires combine excellent formability, a stiffness value that is less than that of stainless-steel (about a third of the stiffness of stainless-steel) and closer to that of nickel titanium, and acceptable resilience, but suffer from friction caused by surface roughness and a greater tendency to fracture when making loops [7].

Finite Element Analysis

In engineering, it is often hard to obtain an analytical mathematical solution. This type of solution can usually only be achieved with specific, simple problems. For materials with complex properties or boundary value problems, engineers often use numerical solutions which are approximate but within acceptable ranges.

In such cases, the solutions that are used provide approximate values for the required measurements at certain points of the studied object. The process for the selection of these points is called *discretization*.

One of the methods used for discretization is to divide the object into smaller objects such that the assembly of these smaller ones represent the original, larger object. In this case, the solution is obtained for each small object separately, and the results are assembled to obtain the final solution for the original object [8].

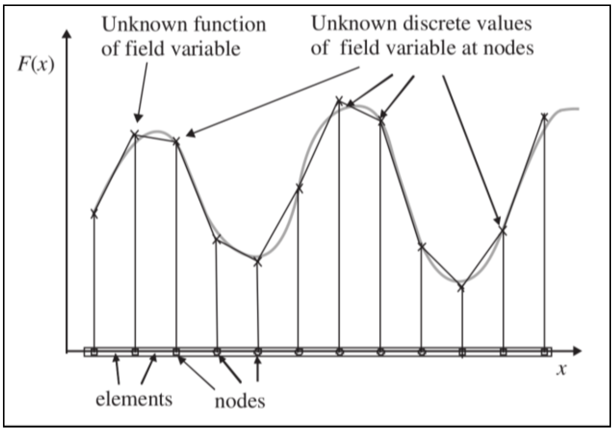

Fig 4: Finite element approximation for a one-dimensional case. Multiple linear equations are used for each part of the curve to approximate the overall equation [9]

The basic concept of the finite elements method is to represent an object or a structure as an assembly of smaller parts. (Fig. 5)

- The parts are called *finite elements*.
- The parts are considered to be connected at junctional points, called the nodes.

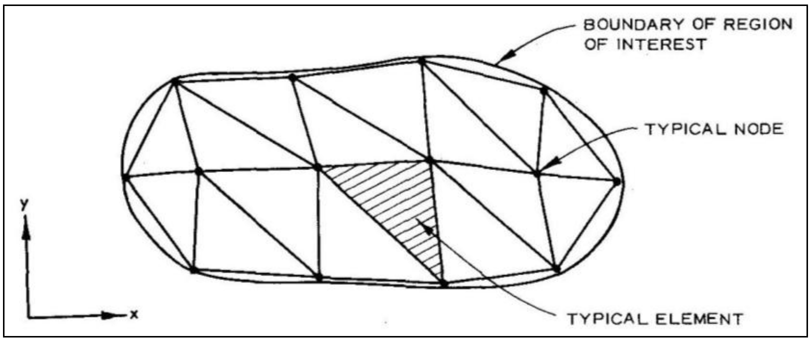

Fig 5: Components of an object in finite elements method (8)

A set of simple equations is selected to calculate the displacement or change amounts that occurs at each of the element. The unknown value in these equations is the amount of displacement at each of the nodes.

Aims

The aim of this study was to analyze the effect of en-masse retraction forces of the anterior segment in cases with increased proclination of the incisors using a fixed lingual appliance with T-loop mechanics using the finite elements method (FEM). Two types of materials for the archwire were compared:

- Stainless steel (SS)
- Titanium-molybdenum alloy (TMA)

The T-loop design chosen for this study was step-less (the two vertical arms of the loop were of equal height, fig. 6).

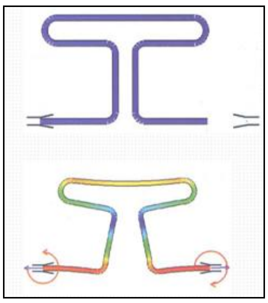

Fig 6: Step-less T-loop design

Materials and Methods

A commercial 3D model of the maxilla and the upper teeth was obtained from the internet. The model had full teeth (crowns and roots) but the periodontal ligaments of the teeth were missing. The model was adjusted such that the first premolars were removed and the empty space re-filled with bone. The angle of the front teeth with the occlusal plane was also adjusted based on average values obtained from cephalometric radiographs for patients with Class II division 1 malocclusion. The average value was found to be 57 degrees. The PDL was added by scaling the teeth and performing boolean operations on the scaled shapes such that the thickness of the PDL is set to 0.2mm [10].

After finishing the adjustment of the model, it was reduced in half using SolidWorks software to save on processing time. Symmetry surfaces were later added in ANSYS workbench.

Using SolidWorks software, models for lingual brackets were designed with 0.018 in slots. An mushroom-shaped, 16x16 mil archwire was also designed with a T-loop that is 7mm height and 8mm wide. An 8-figure ligature wire was fitted on the lingual surfaces of the anterior teeth.

Figure 7 shows the final model that was used to perform the study.

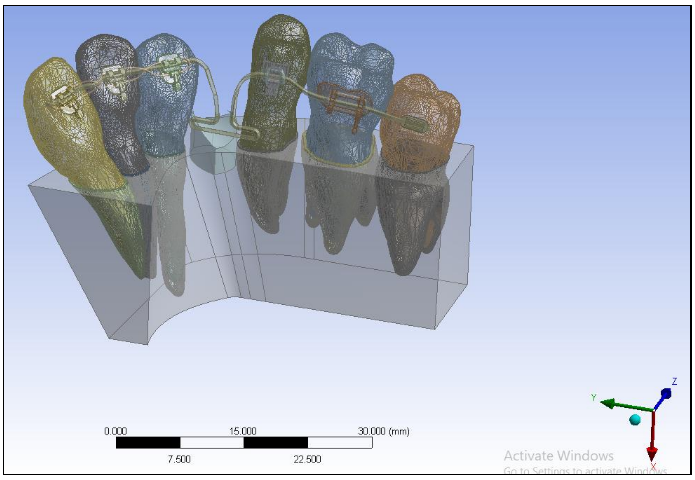

Fig 7: Final model

Inside ANSYS Workbench software, a new engineer data source library was created for the materials based on available literature [10, 11].

All materials were considered homogenous and isotropic.

Table 1.

Material	Young's modulus (MPa)	Poisson's ratio
Cortical bone	1.37×10^4	0.30
Cancelleous bone	7.90×10^3	0.30
Teeth	2.07×10^4	0.30
TMA archwire	6.6×10^4	0.30
SS archwire	2.00×10^5	0.30
SS brackets	1.68×10^4	0.30
PDL	50.00	0.49

In ANSYS Multiphysics Mechanical, a finite element mesh was created from the model using tetrahedrons for the shape of elements.

Fixed support for all bone surfaces was set as boundary conditions.

The point of force application was set at the distal end of the archwire behind the second molar's bracket, to simulate loop activation. The center of resistance for the anterior segment was set 13.5 mm apical and 12 mm distal to the incisal tip of central incisor. For the posterior segment, the center of resistance was considered to be located at the mesial surface of the mesial buccal root of the first molar [11].

For each of the two archwire materials, a 100 gram force was applied at each ends of the wire.

Results and Discussion

Comparison of initial movement

The anterior teeth moved more in the horizontal plane when using TMA wire, the largest difference was at the canine level (fig. 9)

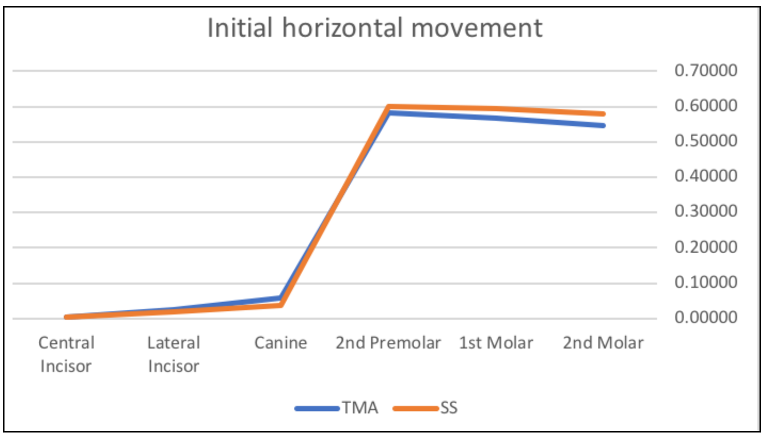

Fig 8: Initial horizontal movement

At the posterior level, teeth moved more in the horizontal plane when an SS wire was used.
Generally, the initial movement of the posterior teeth was always higher compared to the anterior teeth, regardless of the type of material that was used. This could be attributed to the fact that the posterior teeth are closer to the point of force application, which makes the effect of the force greater and the suppression it suffers less.
The total initial movement of the anterior teeth was larger when TMA was used, compared to SS. (fig. 9)

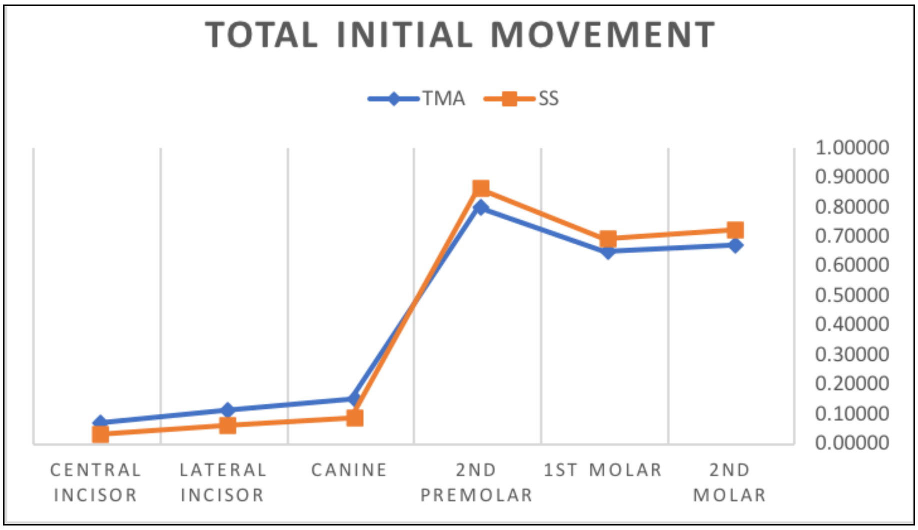

Fig 9: Total initial movement

Conversely, the total initial movement of the posterior teeth was larger when an SS wire was used.
The fact that the posterior teeth moved more (whether directionally or in total) when SS was used can be explained by the higher stiffness of stainless steel compared to TMA, which indicates that it applies greater force levels when compared to a less stiff wire, like TMA.
As for the finding that the TMA caused more movement in the anterior segment, this can be due to the fact that TMA has a more flat stress-strain curve, which means that it produces smaller amounts of force over a longer period of time when the same amount of force is applied to the wire, compared to SS.
This could also explain why the difference between a single posterior tooth's movement for both SS and TMA was larger compared to any of anterior teeth. TMA is able to receive an amount of force and then release it more slowly and more uniformly along the length of the wire compared to SS.
For both types of material, anterior teeth moved backwards and downwards (retraction with extrusion), while the posterior teeth moved backwards and upwards (intrusion).

Comparison of moment-to-force ratio

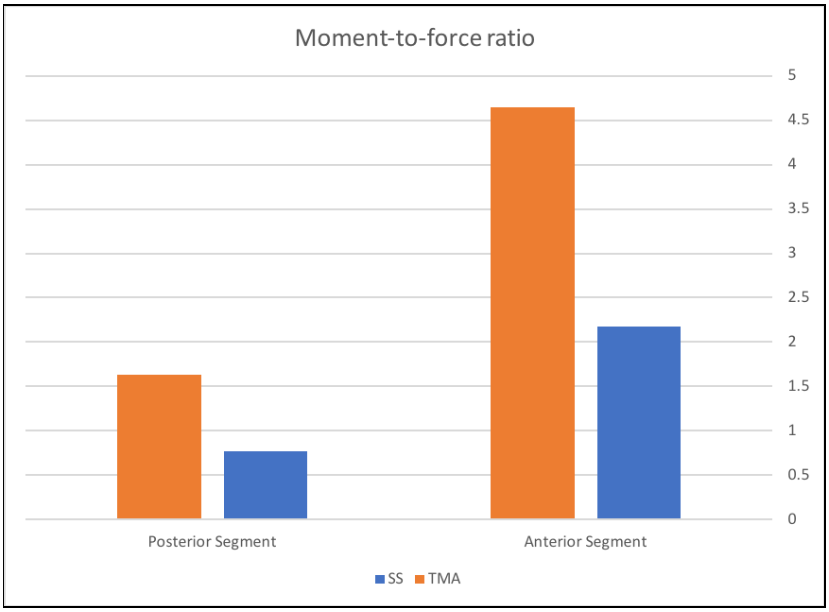

Fig 10: Moment-to-force ratio of both types of material for anterior and posterior segments

Looking at fig. 10, we see that both types of wire materials produced higher M/F ratios at the anterior segment compared to the posterior segment.
For both types of materials, and for both segments, the M/F ratio was less than 10:1, which is the required value to achieve bodily movements (with no tipping) [4]. The values in all cases is withing the range of uncontrolled tipping.
Comparing the M/F values at the anterior segment, we find that the TMA wire produced higher values. This indicates that TMA is able to achieve movements closer to controlled

tipping when compared with SS. This coincides with what the current literature suggests with regard to the clinical properties of TMA and SS.

Conclusions

1. The initial total movement of the anterior teeth during en-masse retraction using a fixed lingual appliace is higher when TMA archwire compared to an SS archwire.
2. Using TMA for the space closure stage with a fixed lingual appliance produces higher M/F ratios compared to an SS archwire, which indicates that TMA is able to achieve movements closer to pure translation (bodily movements) compared to SS.

References

1. Romano R. editor. Lingual orthodontics. Hamilton, Ont.: Decker, 1998, 211 pp.
2. Chatoo A. A view from behind: A history of lingual orthodontics. J Orthod. 2013; 40(1):S2-7.
3. Proffit WR. Contemporary orthodontics. 6th edition. Philadelphia, IL: Elsevier, 2018.
4. Graber LW, Vanarsdall RL, Vig KWL, Huang GJ. editors. Orthodontics: Current principles and techniques. Sixth edition. St. Louis, Missouri: Elsevier, 2017, 1016pp.
5. Singh G. Textbook of orthodontics. New Delhi: Jaypee Brothers, 2007.
6. Cobourne MT, DiBiase AT. Handbook of orthodontics. Edinburgh; New York: Mosby, 2009, 427 pp.
7. Gurgel JARM, Pinzan-Vercelino C, Powers JM. Mechanical properties of beta-titanium wires. The Angle Orthodontist [Internet]. May [cited 2018 Jan 14], 2011; 81(3):478-83. Available from: http://www.angle.org/doi/10.2319/070510-379.1
8. Desai CS, Abel JF. Introduction to the finite element method: A numerical method for engineering analysis. New York, NY: Van Nostrand Reinhold, 1972, 477 pp.
9. Liu GR, Quek SS. The finite element method: A practical course. Oxford; Boston: Butterworth-Heinemann, 2003, 348 pp.
10. Kang J-M, Park JH, Bayome M, Oh M, Park CO, Kook Y-A *et al*. A three-dimensional finite element analysis of molar distalization with a palatal plate, pendulum, and headgear according to molar eruption stage. The Korean Journal of Orthodontics [Internet]. 2016; 46(5):290. [cited 2019 Apr 14]; Available from: https://synapse.koreamed.org/DOIx.php?id=10.4041/kjod.2016.46.5.290
11. Chacko A, Tikku T, Khanna R, Maurya RP, Srivastava K. Comparative assessment of the efficacy of closed helical loop and t-loop for space closure in lingual orthodontics—a finite element study. Progress in Orthodontics [Internet]. 2018; 19(1). [cited 2019 Apr 14] Available from: https://progressinorthodontics.springeropen.com/articles/10.1186/s40510-018-0210-8