DOI:10.21276/sjodr.2016.1.3.6

Saudi Journal of Oral and Dental Research
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2518-1300 (Print)
ISSN 2518-1297 (Online)

Original Research Article

Effects of clinical recycling on mechanical properties of three commonly used types of orthodontic archwires

Joji Isac[1], Mahendra. S[2], B.S Chandrashekar[3] , Vinay P. Reddy[4], Ramesh Kumar P. C[2] , Bala Mohan Shetty[2]

[1]Post Graduate Student, Department of Orthodontics and Dentofacial Orthopedics, Krishnadevaraya College of Dental Sciences, Bangalore.

[2]Reader, Department of Orthodontics and Dentofacial Orthopedics, Krishnadevaraya College of Dental Sciences, Bangalore

[3]Professor, Department of Orthodontics and Dentofacial Orthopedics, Krishnadevaraya College of Dental Sciences, Bangalore.

[4]Professor and Head of Department, Department of Orthodontics and Dentofacial Orthopedics, Krishnadevaraya College of Dental Sciences, Bangalore

***Corresponding Author:**
Dr. Joji Isac
Email: jogiisac@gmail.com

Abstract: The aim of the present study is to evaluate the changes in mechanical properties of stainless steel, nickel titanium and beta titanium archwires after clinical use and sterilization. Thirty wires each of Stainless steel, Nitinol and Beta titanium (3M Unitek) were tested in as received (Group A), as received and autoclaved (Group B), and clinically retrieved then autoclaved conditions (Group C). A sterilization protocol of 134 ^{0}C for 18 minutes was performed using an autoclave**.** Mechanical properties were tested using an universal testing machine and the load deflection data was plotted as stress-strain curves from which ultimate tensile strength, elastic modulus as well as 0.2% offset yield strength was calculated. Ultimate tensile strength of Group C archwires showed significantly lower values when compared with Group A and B archwires (P<0.001). Elastic modulus of stainless steel and beta titanium Group C archwires showed significantly lower values when compared with Group A and B archwires (P< 0.001). Elastic modulus of Group Band Group C Nitinol wires showed significantly higher values when compared with Group A archwires (P = 0.03 and P =0.02 respectively). Yield strength of Group C beta titanium archwires showed significantly lower values when compared with Group Aarchwires(P< 0.001). Autoclave sterilization did not affect considerably on mechanical properties of any archwire. Ultimate tensile strength of all archwires were significantly reduced after intraoral exposure.
Keywords: Ultimate tensile strength, Elastic Modulus, Yield strength

INTRODUCTION

Orthodontic wires which generate biomechanical forces communicated through brackets for tooth movement are central to the practice of the profession [1]. Orthodontic wires made from different alloys offer alternative sequences of wire usage during all phases of treatment. Until the recent introduction of new types of orthodontic alloys, increments in wire stiffness during treatment were instituted by progressively increasing the cross-section of stainless steel wires. Burstone refers to this as variable cross-section orthodontics [2].

Several characteristics of orthodontic wires are considered desirable for optimum performance during treatment. These include a large spring back, low stiffness, high formability, high stored energy, biocompatibility and environmental stability, low surface friction, and the capability to be welded or soldered to auxiliaries and attachments. The properties of orthodontic wires are commonly determined by means of various laboratory tests. Tension, bending and torsion are uniquely different stress states and place varied demands on wire performance. Graphic description of stress against strain can be used to determine yield strength, modulus of elasticity, stored energy, and spring back when the wire is subjected to tensile loading [3].

Stainless steel (SS) archwires remain popular because of their low cost and excellent formability, along with good mechanical properties [4]. Nickel-titanium (NiTi) archwires have become increasingly popular because of their ability to release constant, light forces and the ability to show complete recovery even when deformed.[5]The Beta-titanium (β-Ti) wires are Titanium –Molybdenum alloys, introduced for orthodontic use by Goldberg and Burstone. These wires are used in orthodontics after recognizing advantages such as elastic modulus below stainless steel and near to nickel-titanium (NiTi) alloy, excellent formability, weld ability, and low potential for hypersensitivity [6].

The price differential between stainless steel and titanium archwires has led to suggestion that wires made of these alloys might be sterilized and reused. There is considerable debate about whether patients should be treated with recycled and sterilized materials, particularly in areas such as orthopedic surgery and orthodontics. Reuse of materials would be of some economic benefit if recycling would not materially affect the properties of devices in question.[7] Recycling involves repeated exposure of the wire for several weeks or months to mechanical stresses and elements of the oral environment, as well as sterilization. The combined effects of repeated clinical use and sterilization may subject the wire to corrosion and cold working, with a resultant alteration in its properties [8]. Hence the present study is undertaken to evaluate the feasibility of recycling archwires by determining whether the mechanical properties of archwires are altered significantly by combination of clinical use and sterilization.

MATERIALS AND METHODS:

Thirty wires of each type: Stainless steel, Nitinol Super Elastic and Beta III Titanium (3M Unitek Orthodontic Products, USA) were used: 0.017×0.025″ (0.43 ×0.64 mm) Ortho Form III- Ovoid rectangular wires were selected in each group.

Group A comprises ten wires each of Stainless Steel (subgroup A1), Nitinol super elastic (subgroup A2) and Beta III Titanium (A3) in their as-received condition from manufacturer to serve as the control group.

Group B includes ten wires each of Stainless Steel (subgroup B1), Nitinol super elastic (B2) and Beta III Titanium (B3) which were autoclaved in their as-received condition from manufacturer.

In Group C includes ten wires each of Stainless Steel (C1), Nitinol super elastic (C2) and Beta III Titanium(C3) which were used in patient's mouth for 1-2 months. After clinical use, all wires were disinfected with an 70% absolute alcohol(7 parts alcohol and 3 parts distilled water) for 10 minutes, and allowed to air dry before being placed into separate storage envelopes (Sterilization flat reel pouch, Libral Traders) with a blue colour indicator which turns brown after sterilization.

Wires were discarded if bends were placed by clinician or if surface was corroded.

The Sterilization Technique:

The autoclave sterilization was chosen because it is a technique frequently used in orthodontic practice and is recommended by manufacturers. A sterilization protocol of 134^0C at 2.1 kg/cm^2 for 18 minutes (12 minutes sterilization + 6 minutes drying period) was performed using an autoclave (Unique Clave C-79, Confident Dental Equipments Ltd) .

Assessment of wires:

1. Mechanical Properties:

A standard tensile test was performed on each of the arch wire alloys from groups A, B, C using a Universal Testing Machine (Instron 3365, National Aerospace Laboratory, Bangalore). A full scale load of 1000 N was set in the machine with a crosshead speed of one mm/minute. The span of wire between crossheads was standardized as 40mm. The load taken to break the wire divided by cross-sectional area of the wire will give the value for ultimate tensile strength. The load deflection data obtained from tensile testing was plotted as stress-strain curves as shown in Figure 1,2,3 from which elastic modulus as well as 0.2% offset yield strength was calculated.

RESULTS:

One way ANOVA was used to compare the mean values of ultimate tensile strength, elastic modulus, 0.2% offset yield strength in all three groups. Tukey's multiple post hoc procedures were used for inter group pair wise comparisons.

1. Stainless Steel Wires

The comparison of Ultimate tensile strength, Elastic Modulus and 0.2 % offset Yield strength of stainless steel in each sub groups: As Received (A1), As Received and Autoclaved (B1), Used and Autoclaved (C1) are illustrated in representative graphs 1, 2 and 3. Significant differences were observed among sub groups as depicted in Tables 1, 2 and 3. Ultimate tensile strength of as received stainless steel wires (Mean-1944 MPa) was higher than those of nickel-titanium and beta-titanium wires. Ultimate tensile strength of stainless steel wires increased in subgroup B1 which was not statistically significant (P=0.13), whereas UTS in subgroup C1 showed lower values when compared with subgroup A1 and subgroup B1 which was statistically significant (P< 0.001) as illustrated in Table 1 and Graph 1.

Elastic Modulus (E) of wires in subgroup B1 showed higher values when compared with subgroup A1 which was not significant (P=0.48), whereas subgroup C1 wires showed significantly lower E values when compared with subgroup A1 and subgroup B1 (P< 0.001) as depicted in Table 2 and Graph 2.

Yield strength of stainless steel wires in subgroup B1 showed higher values when compared with subgroup A1 which was not significant (P=0.17). Subgroup C1 showed lower values when compared with subgroup A1 which was also not significant (*P*=0.19). Subgroup C1 showed significantly lower values when compared with subgroup B1 for 0.2 % offset Yield Strength (*P* = 0.003) as illustrated in Table 3 and Graph 3.

2. Nitinol Superelastic Wires

Ultimate tensile strength, Elastic Modulus and 0.2 % offset Yield strength of Nitinol wires in each sub groups: As Received (A2), As Received and Autoclaved (B2), Used and Autoclaved (C2) are compared and are illustrated in representative graphs 4, 5 and 6. Pair wise comparisons and mean values are depicted in Table 4, 5 and 6.

Ultimate tensile strength of Nitinol wires in subgroup B2 showed significantly lower values when compared with subgroup A2 (*P*= 0.001). Subgroup C2 wires also showed lower values when compared with subgroup A2 (*P*=0.009) and was statistically significant as illustrated in Table 4 and Graph 4.

Elastic Modulus of Nitinol wires in subgroup B2 showed significantly higher values when compared with subgroup A2 (*P*=0.03). Subgroup C2 wires also showed significant increase in E values when compared with subgroup A2 (*P*=0.02) as depicted in Table and Graph 5.

Yield strength of Nitinol wires in B2 and C2 subgroups showed lower values when compared with subgroup A2, but were not statistically significant as illustrated in Table 6 and Graph 6.

3. Beta Titanium Wires

Ultimate tensile strength, Elastic Modulus and 0.2 % offset Yield strength of Beta-titanium wires in each sub groups: As Received (A3), As Received and Autoclaved (B3), Used and Autoclaved (C3) are compared and are illustrated in representative graphs 7, 8 and 9. Pair wise comparisons and mean values are depicted in Table 7, 8 and 9.

Ultimate tensile strength of wires in subgroup B3 showed lower values when compared with subgroup A3, but was not statistically significant (*P*= 0.28). Subgroup C3 wires showed a significant decrease in tensile strength when compared with A3 and B3 as illustrated in Table 7 and Graph 7.

Elastic modulus values of wires in subgroup B3 and subgroup C3 showed significant lower values when compared with subgroup A3 (*P* < 0.001). Subgroup C3 also showed lower values when compared with subgroup B3 which was also statistically significant (*P* < 0.001) as depicted in Table 8 and Graph 8.

Yield Strength of wires in subgroup B3 showed lower values when compared with subgroup A3 but was not significant statistically (*P*=0.13). Subgroup C3 showed lower values of YS when compared with subgroup B3 which was statistically significant (*P* = 0.001). Subgroup C3 also showed lower values when compared with subgroup A3 and was statistically significant (*P*< 0.001) as illustrated in Table 9 and Graph 9.

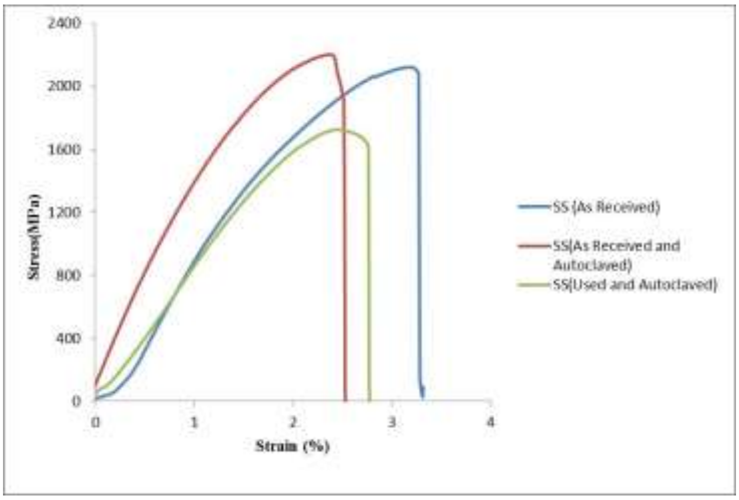


Fig-1: Stress strain diagram of Stainless steel wires

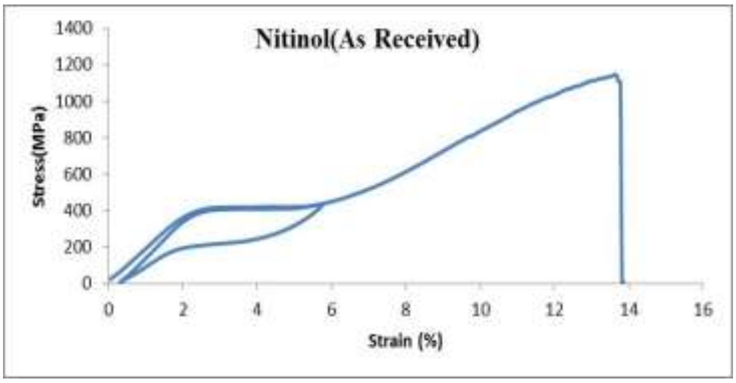


Fig-2(a): Stress strain diagram of Nitinol wires (As Received)

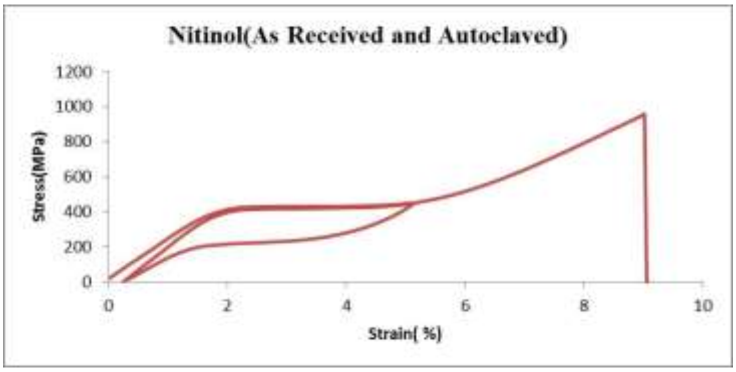


Fig-2(b): Stress strain diagram of Nitinol wires (As Received and autoclaved)

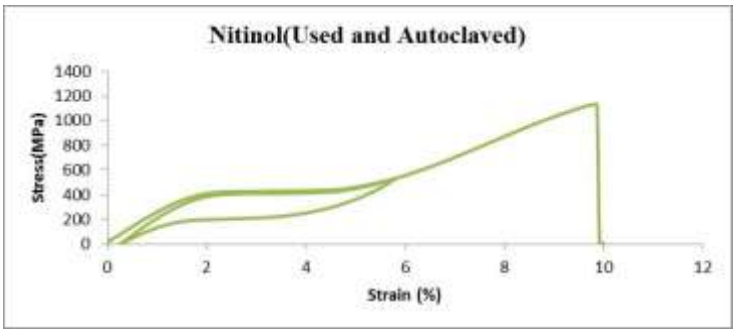


Fig-2(c): Stress strain diagram of Nitinol wires (Used and Autoclaved)

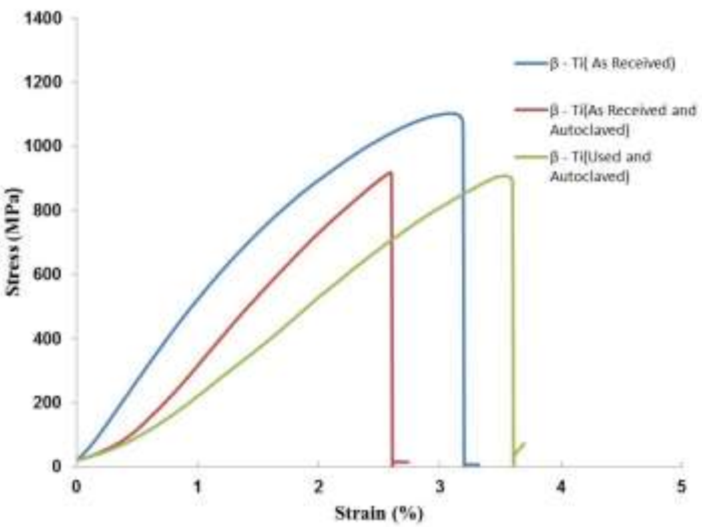
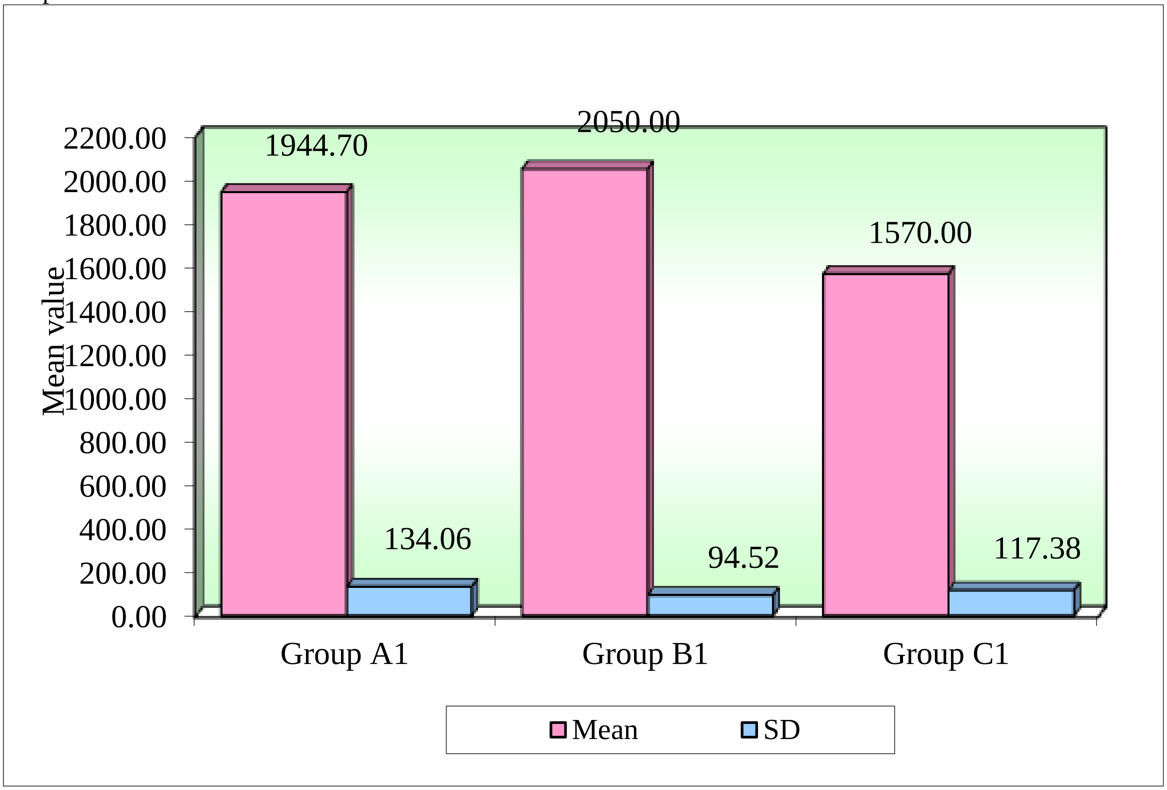


Fig-3:Stress strain diagram of Beta- titanium wires

Table 1: Comparison of three Stainless steel archwire groups (A1, B1, C1) with respect to Ultimate Tensile Strength (MPa) by one way ANOVA

Groups	**Mean**	**SD**	**SE**
Group A1	1944.70	134.06	42.39
Group B1	2050.00	94.52	29.89
Group C1	1570.00	117.38	37.12
F- value	46.9347		
P- value	0.00001*		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A1 vs Group B1	p=0.1263		
Group A1 vs Group C1	p=0.0001*		
Group B1 vs Group C1	p=0.0001*		

*p<0.05

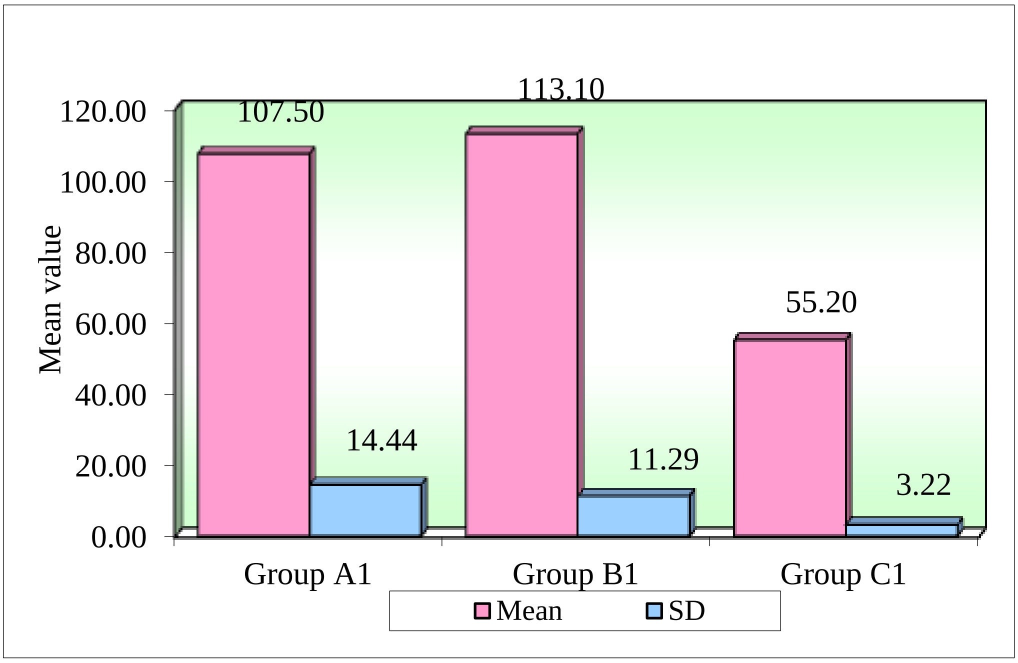


Graph 1: Comparison of three groups (A1, B1, C1) with respect to ultimate Tensile Strength (MPa)

Table 2: Comparison of three Stainless steel archwire groups (A1, B1, C1) with respect to Elastic Modulus (GPa) by one way ANOVA

Groups	Mean	SD	SE
Group A1	107.50	14.44	4.57
Group B1	113.10	11.29	3.57
Group C1	55.20	3.22	1.02
F- value	88.3406		
P- value	0.00001*		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A1 vs Group B1	0.4836		
Group A1 vs Group C1	0.0001*		
Group B1 vs Group C1	0.0001*		

*p<0.05

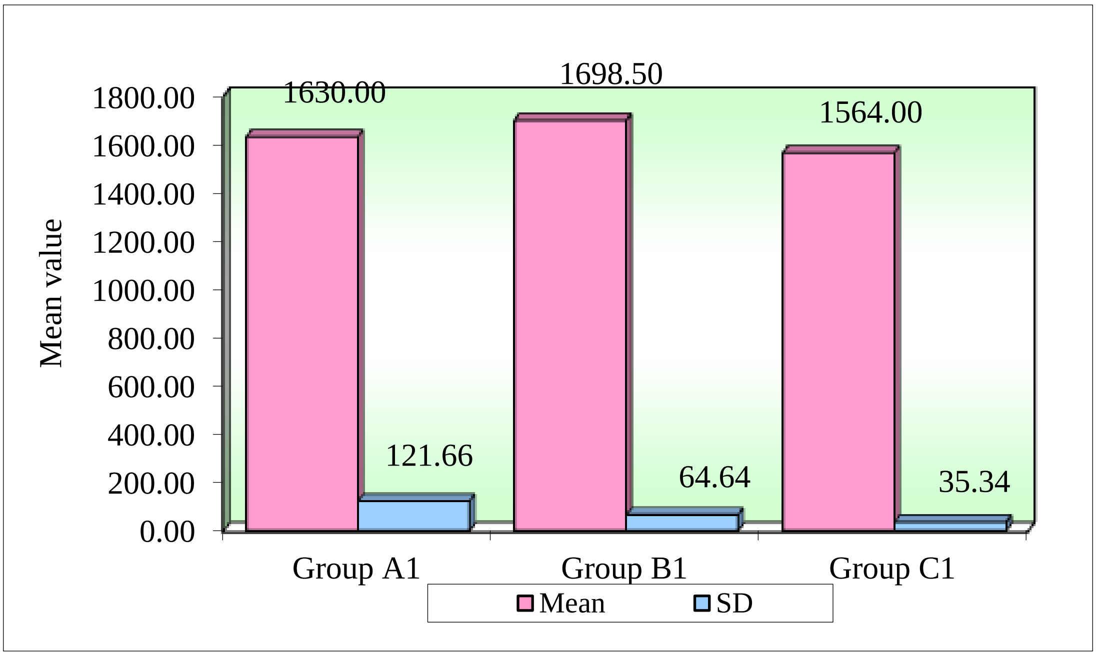


Graph 2 : Comparison of three groups (A1, B1, C1) with respect to Elastic Modulus (GPa)

Table 3: Comparison of three Stainless steel archwire groups (A1, B1, C1) with respect to 0.2 % Yield Strength (MPa) by one way ANOVA

Groups	Mean	SD	SE
Group A1	1630.00	121.66	38.47
Group B1	1698.50	64.64	20.44
Group C1	1564.00	35.34	11.18
F- value	6.7085		
P- value	0.0043*		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A1 vs Group B1	p=0.1683		
Group A1 vs Group C1	p=0.1896		
Group B1 vs Group C1	p=0.0031*		

*p<0.05

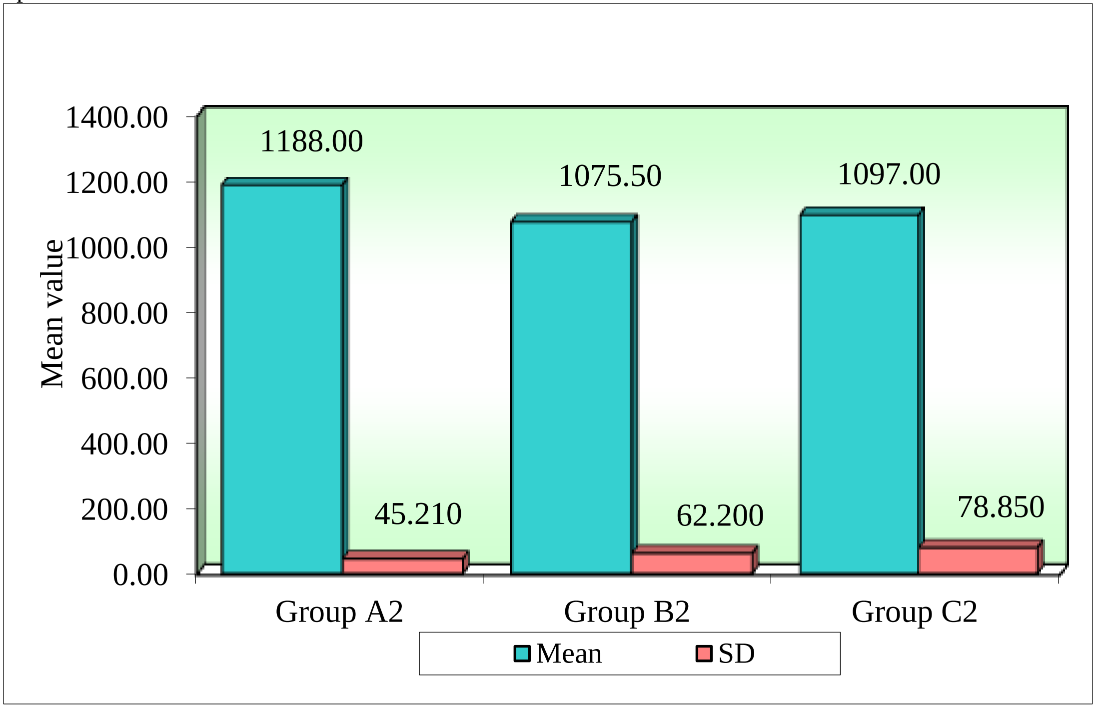


Graph 3 : Comparison of three groups (A1, B1, C1) with respect to 0.2 % Yield Strength (MPa)

Table 4: Comparison of three Nitinol archwire groups (A2, B2, C2) with respect to Ultimate Tensile Strength (MPa) by one way ANOVA

Groups	Mean	SD	SE
Group A2	1188.00	45.21	14.30
Group B2	1075.50	62.20	19.67
Group C2	1097.00	78.85	24.94
F- value	8.8205		
P- value	0.0011*		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A2 vs Group B2	p=0.0015*		
Group A2 vs Group C2	p=0.0096*		
Group B2 vs Group C2	p=0.7327		

*p<0.05

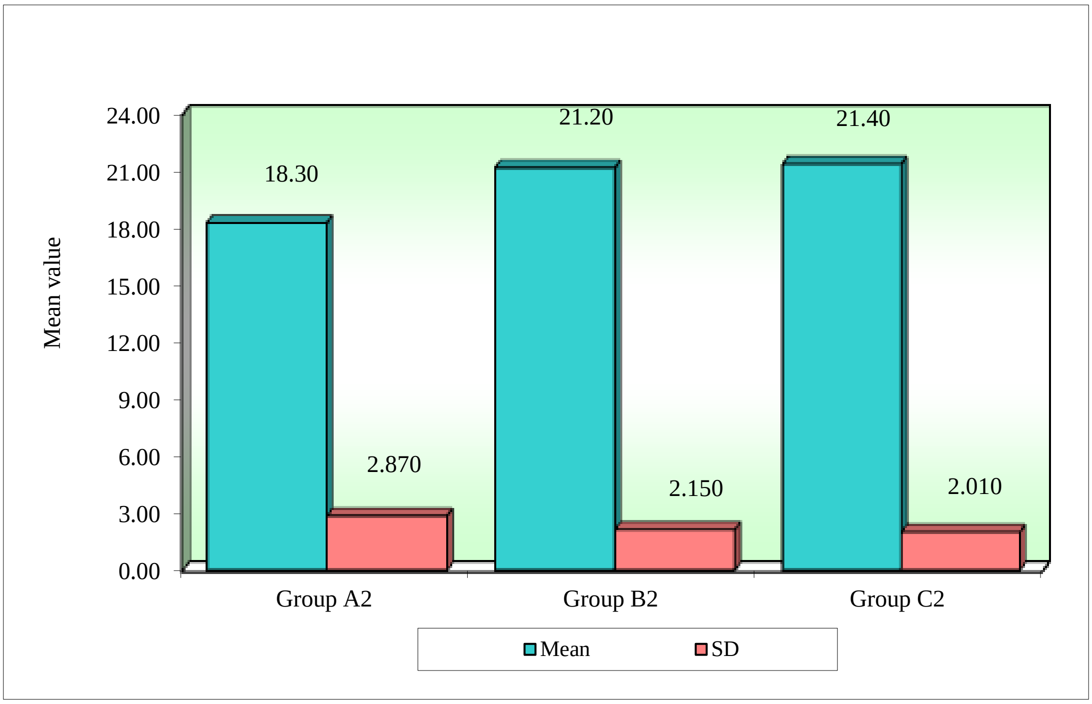


Graph 4 : Comparison of three groups (A2, B2, C2) with respect to ultimate Tensile Strength (MPa)

Table 5: Comparison of three Nitinol archwire groups (A2, B2, C2) with respect to Elastic Modulus (GPa) by one way ANOVA

Groups	Mean	SD	SE
Group A2	18.30	2.87	0.91
Group B2	21.20	2.15	0.68
Group C2	21.40	2.01	0.64
F- value	5.3432		
P- value	0.0111*		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A2 vs Group B2	p=0.0287*		
Group A2 vs Group C2	p=0.0186*		
Group B2 vs Group C2	p=0.9807		

*p<0.05

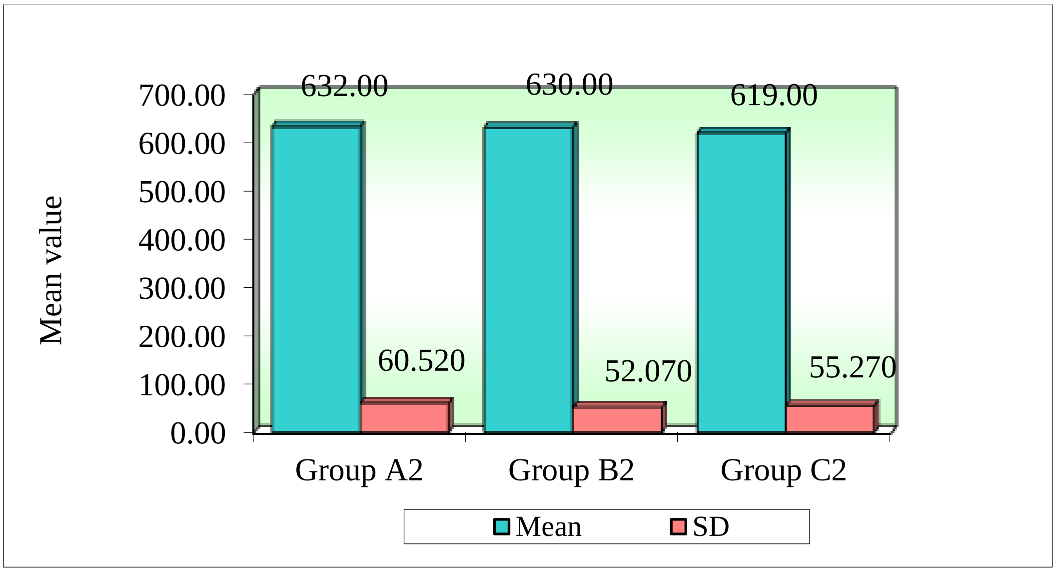


Graph 5 : Comparison of three groups (A2, B2, C2) with respect to Elastic Modulus (GPa)

Table 6: Comparison of three Nitinol archwire groups (A2, B2, C2) with respect to 0.2 % Yield Strength (MPa) by one way ANOVA

Groups	Mean	SD	SE
Group A2	632.00	60.52	19.14
Group B2	630.00	52.07	16.47
Group C2	619.00	55.27	17.48
F- value	0.1559		
P- value	0.8564		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A2 vs Group B2	p=0.9966		
Group A2 vs Group C2	p=0.8631		
Group B2 vs Group C2	p=0.8998		

*p<0.05

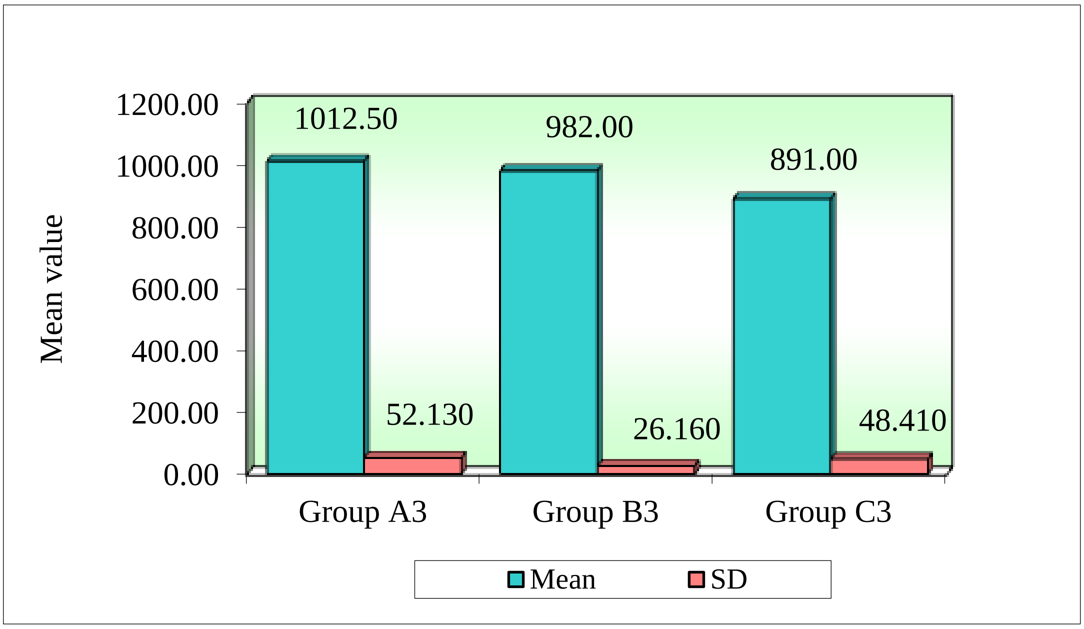


Graph 6 : Comparison of three groups (A2, B2, C2) with respect to 0.2 % Yield Strength (MPa)

Table 7: Comparison of three Beta titanium archwire groups (A3, B3, C3) with respect to Ultimate Tensile Strength (MPa) by one way ANOVA

Groups	Mean	SD	SE
Group A3	1012.50	52.13	16.49
Group B3	982.00	26.16	8.27
Group C3	891.00	48.41	15.31
F- value	20.8616		
P- value	0.00001*		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A3 vs Group B3	p=0.2807		
Group A3 vs Group C3	p=0.0001*		
Group B3 vs Group C3	p=0.0003*		

*p<0.05

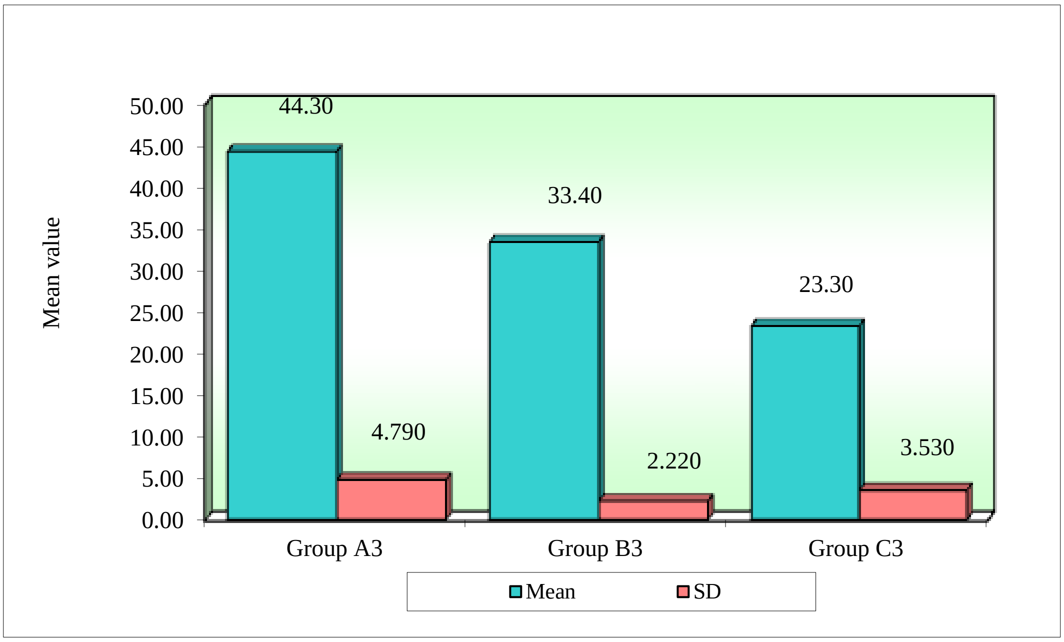


Graph 7 : Comparison of three groups (A3, B3, C3) with respect to Ultimate Tensile Strength (MPa)

Table 8: Comparison of three Beta titanium groups (A3, B3, C3) with respect to Elastic Modulus (GPa) by one way ANOVA

Groups	Mean	SD	SE
Group A3	44.30	4.79	1.51
Group B3	33.40	2.22	0.70
Group C3	23.30	3.53	1.12
F- value	82.1343		
P- value	0.00001*		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A3 vs Group B3	0.0001*		
Group A3 vs Group C3	0.0001*		
Group B3 vs Group C3	0.0001*		

*p<0.05

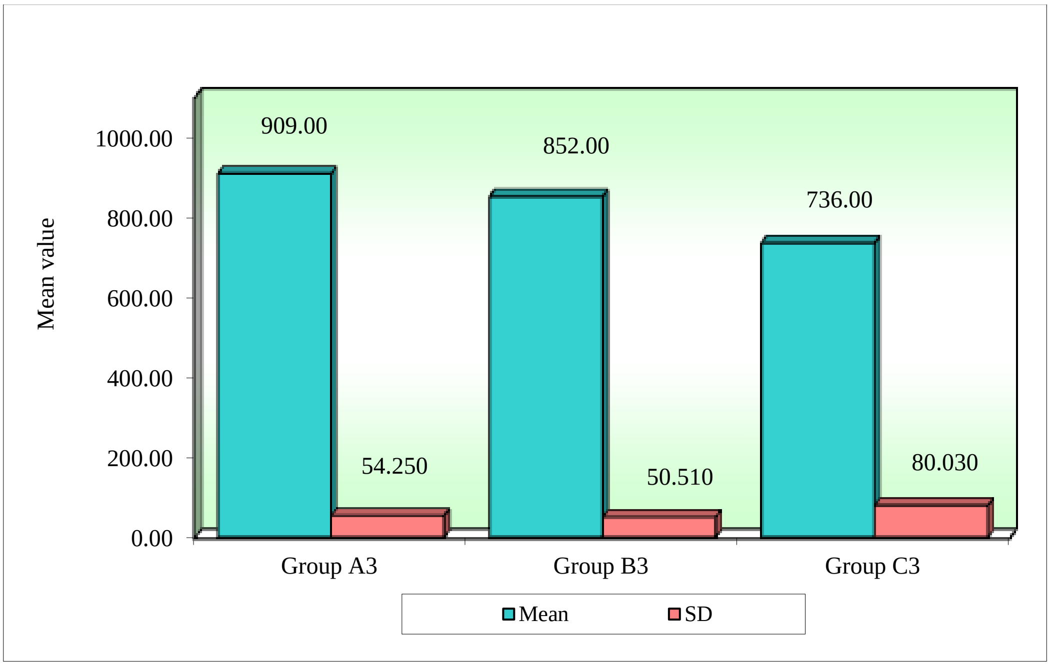


Graph 8: Comparison of three groups (A3, B3, C3) with respect to Elastic Modulus (GPa)

Table 9: Comparison of three Beta titanium archwire groups (A3, B3, C3) with respect to 0.2 % Yield Strength (MPa) by one way ANOVA

Groups	Mean	SD	SE
Group A3	909.00	54.25	17.16
Group B3	852.00	50.51	15.97
Group C3	736.00	80.03	25.31
F- value	19.5959		
P- value	0.00001		
Pair wise comparisons by Tukey's multiple post hoc procedures			
Group A3 vs Group B3	p=0.1259		
Group A3 vs Group C3	p=0.0001*		
Group B3 vs Group C3	p=0.0010*		

*p<0.05



Graph 9: Comparison of three groups (A3, B3, C3) with respect to 0.2 % Yield Strength (MPa)

DISCUSSION:

Orthodontic arch wires should be able to move teeth with a light continuous force. The availability of different alloys for orthodontic arch wires has been one of the main breakthroughs in orthodontic materials research, leading to key improvements in the field of mechanotherapy [9].

Mechanical properties are expressed most often in units of stress or strain. Stress is force per unit area within a structure subjected to an elastic force or pressure where as a strain is change in length per unit length and is the relative deformation of an object subjected to a stress [10]. The elastic behaviour of any material is defined in terms of stress-strain response to an external load, both of which correspond to the internal state of the material being studied. A tensile test is recommended for evaluation of stress-strain behaviour, where an entire piece of alloy arch wire reaches the elastic limit at the same time [11].

In the present study we evaluated three mechanical properties - Ultimate tensile strength (UTS) in MPa, Elastic Modulus (E) in GPa and 0.2% offset yield strength (YS) in MPa using a tensile test and values plotted from stress-strain diagram. Ultimate tensile strength is the tensile stress at the point of fracture and is calculated as the peak point in stress-strain graph. Elastic modulus which describes the relative stiffness or rigidity of a material is measured by the slope of the elastic region of the stress- strain graph. Yield strength is a property that represents the stress value at which a small amount of plastic strain has occurred [11]. in the present study stress required to produce 0.2% strain has been chosen (0.2% offset). The ratio YS/E is considered to be a very useful index of wire performance [12]. This ratio indicates clinical performance of wire in terms of load deflection rate, working range, stiffness and resilience.

Upon tensile evaluation of as received specimens, stainless steel was the strongest alloy with high values for UTS, E, and 0.2% offset YS. The ultimate tensile strength (1944 ± 134 MPa) and 0.2 % offset yield strength (1630 ± 121 MPa) were similar to studies by Krishnan et al [13]. When considering the reuse of orthodontic arch wires, one must evaluate the effect that sterilization has on mechanical properties of wire [14]. No significant difference was found between as received SS wires, and specimens which are sterilized using an autoclave. Staggers et al [14]. showed similar tensile strength values of stainless steel wires with same sterilization protocol as used in this study. A study by Pernier et al showed that autoclave sterilization had no adverse effects on the selected mechanical properties [15]. However, the present study evaluated decreased elastic modulus values when compared to previous studies [15]. This difference could be attributed to the different tests used in their study (three-point bending) and in present study. Iijima et al found significantly different values of Elastic modulus and Yield strength when bending, tension and nano-indentation tests were compared [16]. The difference could also be related to the cross section of wires, machine adjustments and manufacturing procedure[17].

There was a slight increase in UTS, E and 0.2 % offset YS of sterilized specimens in present study which was not significant. Heat treatment of straight as received wire segments yielded an increase in modulus of elasticity and yield strength [1]. The slight increase in mechanical properties of SS wires after sterilization may be due to its heat treatment effect even though the temperature was well below 400^0C. Khieret al [17]. reported an increase in the modulus of elasticity after wire autoclaving, supported the findings of the present study.

The effects of clinical use and sterilization on mechanical properties of SS arch wires were tested using Tukey’s multiple post hoc procedures. Ultimate tensile strength and Elastic Modulus were significantly decreased when compared with as received samples. 0.2 % Yield strength was found to be decreased when compared with values of autoclaved specimens. Oshagh et al found decreased values of Elastic Modulus and Yield strength in a similar study on 0.016" SS wires [18]. Changes in the tensile strength will have a direct impact on the clinical use of wire. If a wire’s ultimate tensile strength is decreased, it is more prone to breakage which presents a problem for patient and the orthodontist alike [14]. Ageing induced structural changes might have cause a potent effect on the mechanical performance of material, particularly reduction in the modulus of alloys [19]. Ageing of orthodontic alloys can also cause reduction in fatigue resistance induced by exposure to a corrosive medium such as saliva [20].

The Ultimate tensile strength values of Nitinol as received wires were higher than Beta Titanium and lower when compared to stainless steel. This finding agrees with a study by Smith et al on 0.016" arch wires [7]. When NiTinol wires were tested after autoclave sterilisation, ultimate tensile strength was found significantly reduced. Wentz concluded that the impacts of sterilization on wires are related to wire type and sterilization method [21] It is possible that high temperatures from autoclave sterilization has an effect on NiTi and TMA arch wires [7]. However in present study its magnitude is small and its clinical relevance is open to question.

In present study Elastic Modulus of NiTinol wires were significantly increased after autoclave sterilization. Super elastic Nickel-Titanium characteristics may show exceptional temperature sensitivity. Thus slight elevation in deformation temperature can significantly increase arch wire stiffness [21]. NiTinol wires were more affected by heating than cooling. However the load level after short term cooling did not completely reach baseline level after 5 minutes post exposure restitution [21].

When the mechanical properties of clinically retrieved NiTinol arch wires were compared with as received wires, a significant reduction in ultimate tensile strength was found. Elastic Modulus was found to be increased after clinical recycling. This may be due to the temperature sensitivity of these wires. Kapila et al reported considerable impairment of mechanical properties of NiTinol wires when a combination of sterilization and clinical reapplication was studied [8]. Nikolai and Huerter reported that although considerable changes occur in round Nitinol wires due to a combination of sterilization and recycling, these wires are still clinically applicable [22]. The increase in stiffness of NiTinol wires after clinical recycling may have resulted because of work hardening as a consequence of repetitive intraoral mechanical stresses to which wires were exposed during clinical use [8].

Loading of the wire induced by the engagement into the slot and masticatory forces might later change the microstructure of the alloy, involving a reduction in grain size at the compressed locations, which extended beyond the near-surface region [23]. Aging was found to exert potent effects on the fracture resistance of Ni-Ti archwires [24]. At a given predefined deflection, the retrieved wires exhibited fracture at significantly reduced loading cycles relative to as-received products [19].

Despite the inherent excellent formability of β-Ti wire, this wire processing can be problematic because of reactivity of titanium that result in some batches of β-Ti wire being susceptible to fracture during clinical manipulation [6]. In present study, there was no significant difference in ultimate tensile strength and yield strength values after autoclave sterilization. Smith et al found no difference exists between as received and autoclaved TMA wires [7]. whereas Staggers et al found an increase in tensile strength of TMA wires after 1 cycle of dry heat sterilization [14]. In present study, ultimate tensile strength, elastic modulus and yield strength was found to be significantly reduced after clinical recycling. Kaneko et al proposed one of the reasons for the fracture of titanium alloys is hydrogen embrittlement in oral cavity. The fracture or degradation of mechanical properties caused by hydrogen is generally called as hydrogen embrittlement [25]. No direct evidence of association of hydrides with brittle fracture of Beta-titanium has been reported, although brittle fracture of alpha-Titanium is caused by hydride formation [26, 27].

The present study evaluated only selected mechanical properties and were performed using a standard tensile test and the values may differ from other studies performed using a three point bending test. The study evaluated changes in properties after autoclave sterilization method and didn't take into account any other sterilization techniques. However changes in selected mechanical properties can be considered before recycling any of these archwires.

CONCLUSION:

- Ultimate tensile strength and Yield strength of all three type of archwires significantly decreased after clinical recycling.
- Elastic modulus values were found decreased in stainless steel and beta-titanium wire alloys after clinical recycling, whereas values increased in Nitinol group.
- Autoclave sterilization did not affect considerably on mechanical properties of any archwire.

REFERENCES

1. Brantley, W. A., & Eliades, T. (2001). *Orthodontic materials: scientific and clinical aspects* (pp. 147-169). Stuttgart: Thieme.
2. Burstone, C. J. (1981). Variable-modulus orthodontics. *American journal of orthodontics*, *80*(1), 1-16.
3. Kapila, S., & Sachdeva, R. (1989). Mechanical properties and clinical applications of orthodontic wires. *American Journal of Orthodontics and Dentofacial Orthopedics*, *96*(2), 100-109.
4. Daems, J., Celis, J. P., & Willems, G. (2009). Morphological characterization of as-received and in vivo orthodontic stainless steel archwires. *The European Journal of Orthodontics*, *31*(3), 260-265.
5. Eliades, T., Eliades, G., Athanasiou, A. E., & Bradley, T. G. (2000). Surface characterization of retrieved NiTi orthodontic archwires. *The European Journal of Orthodontics*, *22*(3), 317-326.
6. Gurgel, J. A., RM Pinzan-Vercelino, C., & Powers, J. M. (2011). Mechanical properties of beta-titanium wires. *The Angle Orthodontist*, *81*(3), 478-483.
7. Smith, G. A., Von Fraunhofer, J. A., & Casey, G. R. (1992). The effect of clinical use and sterilization on selected orthodontic arch wires. *American Journal of Orthodontics and Dentofacial Orthopedics*, *102*(2), 153-159.
8. Kapila, S., Haugen, J. W., & Watanabe, L. G. (1992). Load-deflection characteristics of nickel-titanium alloy wires after clinical recycling and dry heat sterilization. *American Journal of Orthodontics and Dentofacial Orthopedics*, *102*(2), 120-126.
9. Eliades, T. (2007). Orthodontic materials research and applications: part 2. Current status and projected future developments in materials and biocompatibility. *American Journal of Orthodontics and Dentofacial Orthopedics*, *131*(2), 253-262.

10. Anusavice, K. J., Shen, C., & Rawls, H. R. (2013). *Phillips' science of dental materials*. Elsevier Health Sciences.
11. Oltjen, J. M., Duncanson Jr, M. G., Ghosh, J., Nanda, R. S., & Frans Currier, G. (1997). Stiffness-deflection behavior of selected orthodontic wires. *The Angle Orthodontist*, *67*(3), 209-218.
12. Burstone, C. J., & Goldberg, A. J. (1983). Maximum forces and deflections from orthodontic appliances. *American journal of orthodontics*, *84*(2), 95-103.
13. Krishnan, V., & Kumar, K. J. (2004). Mechanical properties and surface characteristics of three archwire alloys. *The Angle Orthodontist*, *74*(6), 825-831.
14. Staggers, J. A., & Margeson, D. (1993). The effects of sterilization on the tensile strength of orthodontic wires. *The Angle Orthodontist*, *63*(2), 141-144.
15. Pernier, C., Grosgogeat, B., Ponsonnet, L., Benay, G., & Lissac, M. (2005). Influence of autoclave sterilization on the surface parameters and mechanical properties of six orthodontic wires. *The European Journal of Orthodontics*, *27*(1), 72-81.
16. Iijima, M., Muguruma, T., Brantley, W. A., & Mizoguchi, I. (2011). Comparisons of nanoindentation, 3-point bending, and tension tests for orthodontic wires. *American Journal of Orthodontics and Dentofacial Orthopedics*, *140*(1), 65-71.
17. Khier, S. E., Brantley, W. A., & Fournelle, R. A. (1988). Structure and mechanical properties of as-received and heat-treated stainless steel orthodontic wires. *American Journal of Orthodontics and Dentofacial Orthopedics*, *93*(3), 206-212.
18. Oshagh, M., Hematiyan, M. R., Mohandes, Y., Oshagh, M. R., & Pishbin, L. (2012). Autoclaving and clinical recycling: effects on mechanical properties of orthodontic wires. *Indian Journal of Dental Research*, *23*(5), 638.
19. Eliades, T., & Bourauel, C. (2005). Intraoral aging of orthodontic materials: the picture we miss and its clinical relevance. *American Journal of Orthodontics and Dentofacial Orthopedics*, *127*(4), 403-412.
20. Eliades, T., & Athanasiou, A. E. (2002). In vivo aging of orthodontic alloys: implications for corrosion potential, nickel release, and biocompatibility. *The Angle orthodontist*, *72*(3), 222-237.
21. Meling, T. R., & Ødegaard, J. (1998). Short-term temperature changes influence the force exerted by superelastic nickel-titanium archwires activated in orthodontic bending. *American journal of orthodontics and dentofacial orthopedics*, *114*(5), 503-509.
22. Huerter, T. J., & Nikolai, R. J. (1981, January). On The Mechanical-Behavior Of Recycled Nitinol Orthodontic Wire. In *Journal Of Dental Research* (Vol. 60, Pp. 542-542). 1619 Duke St, Alexandria, Va 22314: Amer Assoc Dental Research.
23. Zinelis, S., Eliades, T., Pandis, N., Eliades, G., & Bourauel, C. (2007). Why do nickel-titanium archwires fracture intraorally? Fractographic analysis and failure mechanism of in-vivo fractured wires. *American Journal of Orthodontics and Dentofacial Orthopedics*, *132*(1), 84-89.
24. Verstrynge, A., Van Humbeeck, J., & Willems, G. (2006). In-vitro evaluation of the material characteristics of stainless steel and beta-titanium orthodontic wires. *American journal of orthodontics and dentofacial orthopedics*, *130*(4), 460-470.
25. Kaneko, K., Yokoyama, K. I., Moriyama, K., Asaoka, K., Sakai, J. I., & Nagumo, M. (2003). Delayed fracture of beta titanium orthodontic wire in fluoride aqueous solutions. *Biomaterials*, *24*(12), 2113-2120.
26. Pardee, W. J., & Paton, N. E. (1980). Model of sustained load cracking by hydride growth in Ti alloys. *Metallurgical Transactions A*, *11*(8), 1391-1400.
27. Shih, D. S., Robertson, I. M., & Birnbaum, H. K. (1988). Hydrogen embrittlement of α titanium: in situ TEM studies. *Acta Metallurgica*, *36*(1), 111-124.