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Research Article

Comparison of Mechanical Properties between Different Orthodontic Stainless Steel Archwires

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Noraini Abu Bakar[1]*, Fraser McDonald[2] and Lawrence Tan[3]

[1]*Department of Orthodontics, Dental Faculty, International Islamic University Malaysia, Kuantan Campus, Malaysia*

[2]*Professor of Orthodontics in Relation to Oral Biology/Cons, Kings College London, UK*

[3]*Jalan Gambut Dental Clinic, 25000 Kuantan, Pahang, Malaysia*

Abstract

Introduction: The Damon system recommended the use of revolutionary, high-technology Damon edgewise 0.019" x 0.025" orthodontic stainless steel archwires (OSSA) for major mechanics and finishing and claimed that this new archwires offer greater efficiency during orthodontic treatment. No study has been carried out to compare this relatively new archwires to other popular OSSA already in the market.

Aim: The aim of this study was to compare the mechanical properties of Damon 0.019" x 0.025" OSSA with Standard Ormco and 3M archwires.

Method: 30 preformed archwires of each type (Standard Ormco, 3M and Damon) were tested in the as-received condition. Tensile tests were performed on a Instron Universal Testing Machine with an inter-crosshead span of 10mm. Data were obtained using Bluehill software for maximum load, automatic modulus, 0.1% yield strength and Young's modulus.

Results: For maximum load, there was no difference between Damon (Mean 659.8 ± 26.6N) and 3M (Mean 668.4 ± 9.1N), but both Damon and 3M were statistically superior compared to Standard Ormco (Mean 611.9 ± 23.2N). With respect to automatic modulus, Damon (Mean 41786.0 ± 5104.2MPa) was proven to be statistically inferior to both Standard Ormco (Mean 47318.2 ± 6106.2MPa) and 3M (Mean 49897.6 ± 3286.1MPa). For the 0.1% yield strength, there was no difference between Damon (Mean 2150.1 ± 88.6MPa) and 3M (Mean 2178.8 ± 29.6MPa), but both Damon and 3M were statistically superior compared to Standard Ormco (Mean 1990.8 ± 74.5MPa). With regard to the Young's modulus, Damon (Mean 40598.3 ± 5077.4MPa) was proven to be statistically inferior to both Standard Ormco (Mean 44910.9 ± 5463.4MPa) and 3M (Mean 47500.7 ± 3431.6MPa).

Conclusion Damon 0.019" x 0.025" OSSA were proven to be similar to 3M in maximum load and 0.1% yield strength. As for Young's and Automatic Modulus, Damon was proven to be statistically inferior to 3M and Standard Ormco. 3M was proven to be superior in all parameters.

Keywords: Mechanical properties, Stainless steel, Archwire

Introduction

The properties of orthodontic wires are commonly determined by means of various laboratory tests. Wires have been investigated under tension [1-5], in bending [3,4] and torsion [4,5]. The first standard test protocol for orthodontic wires was prepared, approved and published in the early 1930s [6]. As stainless steel became more and more popular, various authors have investigated mechanical properties of stainless steel archwires and some compared properties of different orthodontics wires [4,5,7-11].

Ormco introduced new Damon archwires to the market few years ago. The key to the Damon system as claimed by the manufacturer is a systematic approach to archwire selection and sequencing. The Damon system recommended the use of revolutionary, high-technology Damon edgewise wires (0.019" x 0.025" stainless steel) for major mechanics (Phase III) and finishing (Phase IV) as part of four-phase sequencing to ensure high quality clinical results with the Damon brackets. The manufacturer also claimed that Damon archwires facilitates fast, efficient tooth movement and greater efficiency during treatment [12].

In Phase III, Damon edgewise wires (0.019" x 0.025" stainless steel) are used as working archwires for posterior space closure, anteroposterior dental correction and

***Corresponding Author:** Noraini Abu Bakar, Department of Orthodontics, Dental Faculty, International Islamic University Malaysia, Kuantan Campus, 25200 Indera Mahkota, Kuantan, Pahang, Malaysia, Tel : +060127140094, Email: nor_aini@iium.edu.my

adjusting buccolingual discrepancies. This archwire is primarily used to maintain vertical and buccolingual control during this major phase of treatment. This wire is also said to be an excellent wire to maintain arch integrity and is used during anteroposterior correction and closure and is also great for maintaining the anterior, vertical and posterior buccolingual tooth positions. The fourth phase is the finishing and detailing phase of archwire sequencing. If adjustments and torque requirements are minimal, the working archwire can be used to complete treatment [12].

However, no study has been carried out to compare this relatively new Damon stainless steel archwires to other popular stainless steel archwires already in the market.

Objective

The purpose of this laboratory based study was to compare the mechanical properties of Damon 0.019" x 0.025" orthodontic stainless steel archwires to Standard Ormco 0.019" x 0.025" stainless steel archwires and 3M 0.019" x 0.025" stainless steel archwires.

Materials

The wires evaluated in the present study consisted of three types of preformed 0.019" X 0.025" orthodontic stainless steel archwires and divided to group as:

Group I → 3M 0.019" x 0.025" stainless steel archwires

Group II → Damon 0.019" x 0.025" stainless steel archwires

Group III → Standard Ormco 0.019" x 0.025" stainless steel archwires

Archwires of the same batch number were used to ensure consistency.

Methods

The height of each wire was measured to 30mm to the nearest 0.01mm with micrometer.

A standard tensile test for each archwire from the three groups was performed in the Universal Testing Machine (Instron Corporation, Canton, and Mass). The Universal Testing Machine is a device used to test the tensile stress and the compressive strength of materials. It consists of the load frame and a moveable crosshead that were controlled to move up and down at a constant speed and connected to the output device to record all the results with computer interface for analysis.

For this study, the Universal Testing device was turned on and was calibrated automatically. The device was reset at 0mm and the machine was balanced. A full-scale load set in the machine with a crosshead speed of 1mm per minute. The span of the wire between the grips was standardized at 10mm.

The outcome measures were recorded by Bluehill testing software from the computer that was connected to the Universal Testing device. The software is designed for simple and static cyclic testing application providing data collection, results analysing and reporting.

In this study, the mechanical properties tested were:

1) Maximum Load (N)
2) Automatic Modulus (MPa)
3) 0.1% Yield Strength (MPa)
4) Young's Modulus (MPa)

Statistical methods

The data was first manually entered in Microsoft Excel which was then analyzed via software Statistical Package for Social Sciences (SPSS) version 20.0. Data conformed to a Normal distribution and was described using Mean and Standard Deviation. The difference between the materials was tested using Analysis of Variance (ANOVA). Post-ANOVA contrasts were performed using the Sidak's test.

Results

Section 1: Maximum Load

The value obtained for maximum load of these three different archwires indicated superiority of 3M 0.019" x 0.025" stainless steel archwires (Group I), followed closely by Damon 0.019" x 0.025" stainless steel archwires (Group II) and Standard Ormco 0.019" x 0.025" stainless steel archwires (Group III) had the lowest maximum load.

Figure 1, is the adjusted plot that shows mean and 95% confidence intervals of maximum load for 3M, Damon and Ormco 0.019" x 0.025" stainless steel archwires(n=30). Overall Standard Ormco 0.019" x 0.025" stainless steel archwires has the lowest maximum load and significantly inferior to 3M and Damon 0.019" x 0.025" stainless steel archwires.

Analysis of Variance (ANOVA) indicated that there was a statistically significant differences between the three materials F (2,87) = 62, ($p < 0.001$).

Post-ANOVA analysis using the Sidak's test for multiple comparisons indicated that there were significant differences in maximum load between Ormco and both 3M and Damon 0.019" x 0.025" stainless steel archwires ($p < 0.001$). There was no

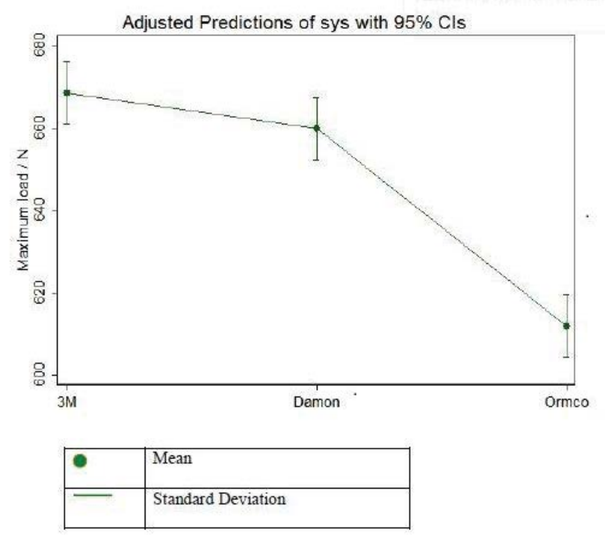

Figure 1: Adjusted plor that shows mean and 95% confidence intervals of maximum load.

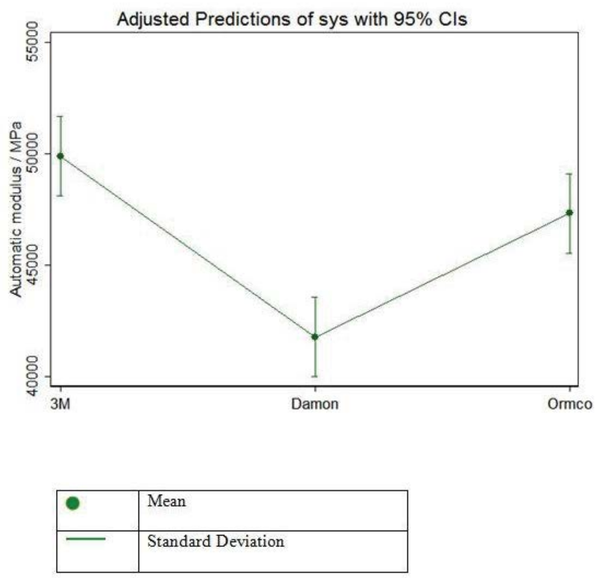

Figure 2: Adjusted plor that shows mean and 95% confidence intervals of automatic modulus.

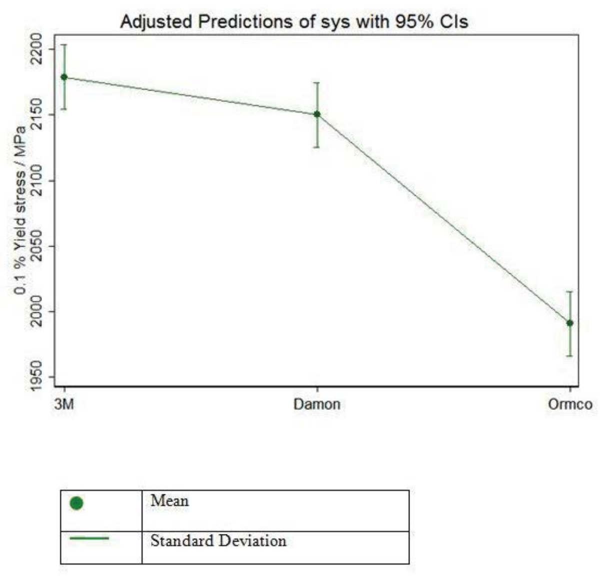

Figure 3: Adjusted plor that shows mean and 95% confidence intervals of yield strength.

difference between 3M and Damon 0.019" x 0.025" stainless steel archwires ($p = 0.297$).

Section 2: Automatic Modulus

The value obtained for automatic modulus of these three different archwires indicated superior strength of 3M 0.019" x 0.025" stainless steel archwires (Group I), followed closely by Ormco 0.019" x 0.025" stainless steel archwires (Group III) and Damon 0.019" x 0.025" stainless steel archwires (Group II) has the lowest reading.

Figure 2 showed the adjusted plot that shows mean and 95% confidence intervals of automatic modulus for 3M, Damon and Ormco 0.019" x 0.025" stainless steel archwires (n=30). Overall, Damon 0.019" x 0.025" stainless steel archwires has the lowest automatic modulus and was significantly inferior to Standard Ormco and 3M 0.019" x 0.025" stainless steel archwires.

Analysis of variance (ANOVA) indicated that there was a statistically significant difference between the three materials with $F(2,87) = 20$,($p < 0.001$).

Post-ANOVA analysis using the Sidak's test for multiple comparisons indicated that there were significant differences in automatic modulus between Damon and both 3M and Ormco 0.019" x 0.025" stainless steel archwires ($p < 0.001$). There was no difference between 3M and Ormco 0.019" x 0.025" stainless steel archwires ($p = 0.128$).

Section 3: 0.1% Yield Strength

The value obtained for 0.1% yield strength of these three different 0.019" x 0.025" stainless steel archwires indicated superior strength of 3M (Group I), followed closely by Damon (Group II) and Standard Ormco (Group III) has the lowest yield strength.

Figure 3 showed the adjusted plot that shows mean and 95% confidence interval of 0.1% yield strength for 3M, Damon and Ormco 0.019" x 0.025" stainless steel archwires (n=30). Overall, Standard Ormco 0.019" x 0.025" stainless steel archwires has the lowest yield strength and was significantly inferior to Damon and 3M 0.019" x 0.025" stainless steel archwires.

Analysis of variance (ANOVA) indicated that there was a statistically significant difference between the three materials with $F(2,87) = 64$, ($p < 0.001$).

Post-ANOVA analysis using the Sidak test for multiple comparisons indicated that there were significant differences in 0.1% yield strength between Ormco and both 3M and Damon 0.019" x 0.025" stainless steel archwires ($p < 0.001$). There was no difference between 3M and Damon 0.019" x 0.025" stainless steel archwires ($p = 0.287$).

Section 4: Young's Modulus

The value obtained for Young's modulus of these three different 0.019" x 0.025" stainless steel archwires indicated superior strength of 3M (Group I), followed closely by Standard Ormco (Group III) and Damon (Group III) has the lowest Young's modulus.

Figure 4 showed the adjusted plot that shows mean and 95% confidence intervals of Young's Modulus for 3M, Damon and Ormco 0.019" x 0.025" stainless steel archwires (n=30). Overall Damon 0.019" x 0.025" stainless steel archwires has the lowest Young's modulus and was significantly inferior to 3M and Ormco 0.019" x 0.025" stainless steel archwires.

Analysis of variance (ANOVA) indicated that there was a statistically significant difference between the three materials $F(2,87) = 16$,($p < 0.001$).

Post-ANOVA analysis using the Sidak's test for multiple comparisons indicated that there were significant differences in Young's modulus between Damon and 3M 0.019" x 0.025" stainless steel archwires ($p < 0.001$) and between Damon and Ormco 0.019" x 0.025" stainless steel archwires ($p=0.001$).

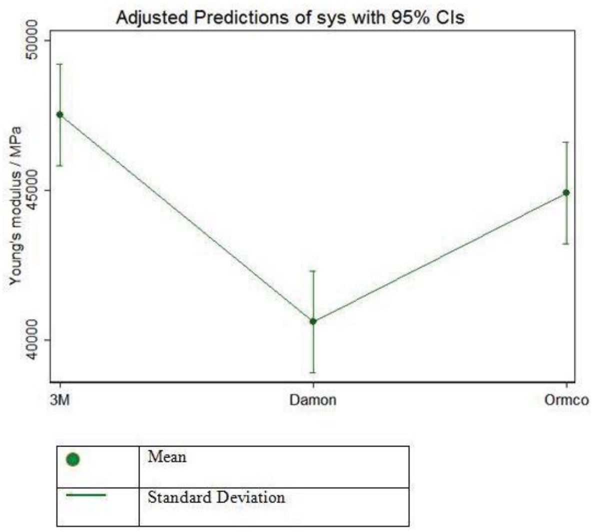

Figure 4: Adjusted plor that shows mean and 95% confidence intervals of Young' s Modulus.

There was no difference between 3M and Ormco 0.019" x 0.025" stainless steel archwires (p = 0.100).

Discussion

Discussions of the results and their clinical relevance

The mechanical properties of orthodontic wires are determined by the chemical composition and the microstructure, which is affected by the manufacturing processes. Although laboratory tests do not necessarily reflect the clinical situations to which wires are usually subjected, but they do provide a basis for comparison of these wires [13]. Tests in bending reflect wire behaviour in first order and second order bends. Torsional tests reflect to a certain degree, wire characteristics in a third order direction [13]. The results of the individual parameters together their clinical relevance will be discussed below.

Maximum Load (N): The rank order of value for maximum load can be summarized as 3M>Damon>Ormco 0.019" x 0.025" stainless steel archwires with Standard Ormco being significantly lower compared to the other two.

Maximum load is the working load limit which should ever be applied to a wire. Although not clinically relevant, archwires with bigger maximum load are much stronger, therefore more resistant to deformation and fracture. Damon in this parameter is similar to 3M stainless steel archwires. Ormco was statistically inferior in maximum load; hence theoretically a much weaker archwires compared to 3M and Damon.

Young's / Automatic Modulus (MPa): The rank order of value for Young's/Automatic modulus can be summarized as 3M>Ormco>Damon with Damon 0.019" x 0.025" stainless steel archwires identified to have significantly lower modulus of elasticity compared to the other two wires.

The modulus of elasticity describes the resistance to elastic deformation and determines the magnitude of force delivered by a wire activated within the elastic range. Clinically, the wire with the higher modulus should be more resistant to deformation caused by extraoral or intraoral orthodontic tractional forces. Burstone argued that stiffness is the most important variable in clinical wire selection, especially to level the dentition, overbite reduction and space closure [14]. Damon 0.019" X 0.025" stainless steel archwires was proven to be inferior in this parameter hence more is theoretically more prone to deformation and provide lesser vertical and buccolingual control compared to 3M and Standard Ormco 0.019" x 0.025" stainless steel archwires.

0.1% Yield Strength (MPa): In this study, the rank order of value for 0.1% yield strength can be summarized 3M > Damon> Ormco. Standard Ormco 0.019" x 0.025" stainless steel archwires being significantly inferior compared to 3M and Damon 0.019" x 0.025" stainless steel archwires. The yield strength is a contrived value that allows for an unperceivable amount of plastic deformation. Between the yield point and the ultimate tensile strength the wire can be formed into shape. If the stiffness of two wires are the same, then the one with higher yield strength wire should be chosen [7]. In this aspect, 3M and Damon has the advantage as their higher yield strength should result in greater flexibility, working range and the resilience of the wire.

Comparison with previous studies

Stiffness value: Previous studies mainly used all straight archwires or combination of straight and preformed for tensile strength research [7]. In this study however, all preformed archwires were used for standardization purposes. The main reason behind this was Damon does not manufacture straight 0.019" X 0.025" stainless steel archwires. To ensure only the straight part of the wires were tested, the span between the grips were reduced form about 40mm or even longer from previous studies to 10mm in this study. Structural engineering theory, supported by various studies had shown that characteristic of length fundamentally influence the stiffness and elastic range values of interest together with the wire material , the cross-sectional size, shape, and length [8]. Therefore, the wire values in this study are not comparable with those values reported for E (179-193GPa or 26.0-28.0Msi) of stainless steel in the recent references of the general literature. The stiffness values obtained were very much lower in this study and the length differences may be account for the difference.

Research design: Tension, bending and torsion are uniquely different stress states and places varying demands on wire performance. The properties of wires under these three stress states are therefore considered independently. In recent years stiffness and elastic range values for orthodontic wires have been done in various procedures. There are "sets of stiffness numbers" with wire material/composition and cross sectional contributions [14]. There are also formula for stiffness, elastic range and elastic-strength values for wires, and prepared nomographs to enable rapid graphical quantifications and comparisons [15]. Another method is ADA Specification no 32 [16] format to determine stiffness and elastic range values for sample of wires [17] while other study compared localized stiffness of continuous of wires curvature and deflection directions [18]. However, because of differences in research designs, direct comparisons of specific parametric values across all studies are not feasible. Therefore, the values obtained for 3M and Standard Ormco cannot be directly compared to values from previous studies as the settings are not the same [19,20-28].

Conclusion

Damon 0.019" x 0.025" stainless steel was proven to be similar with 3M in maximum load and 0.1% yield strength. With respect to Young's/Automatic modulus, Damon was proven to be statistically inferior to 3M and Standard Ormco. 3M was proven to be superior in all parameters.

Future Work

In the future, more research can be done to further understand Damon 0.019" X 0.025" stainless steel archwires including evaluating bending characteristics and surface properties as part of archwires alloy characterization. Frictional properties also worth to be looking at as for sliding mechanics this properties will have significant influence on the efficiency of tooth movement. If Damon decides to produce straight 0.019" X 0.025" stainless steel archwires, the tensile strength test using all straight wire should be carried out to directly compare archwires.

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Conflict of Interest

There are none.

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