A study of a novel aesthetic archwire on its frictional properties and its applications to orthodontics

Chai Kiat Chng, Kelvin Foong[1], Narayan Gandedkar, Yiong Huak Chan[2], Chong Lin Chew[1]

Dental Service, KK Women's and Children's Hospital, [1]Faculty of Dentistry, [2]Yong Loo-Lin School of Medicine, National University of Singapore, Singapore

Abstract

Objectives: To compare sliding friction of prototype 0.018-inch fiber-reinforced polymer composite (FRPC) archwire with 0.018-inch nickel titanium archwire using various bracket-arch wire combinations. **Materials and Methods:** Two wires were tested against four different brackets (3M Gemini Twin bracket; 3M Clarity metal-reinforced ceramic bracket; Ormco Inspire ICE ceramic bracket; and 3M SmartClip) using the Universal testing machine to study and compare frictional characteristics. **Results:** There was no significant difference noted for the frictional wear generated between the various archwire and bracket groups ($P = 0.542$). No statistical significance was detected within individual archwire-bracket groups. A multiple comparison of groups showed significant difference in frictional wear. Least significance difference multiple comparison revealed statistical significance ($P < 0.05$) when comparing Gemini-FRPC with ICE-FRPC group. No other groups showed any significant difference. **Conclusion:** FRPC and NiTi wire show comparable frictional wear when used with ICE, Gemini, Clarity, and SmartClip brackets.

Key words: Aesthetics, arch wire-bracket Fiber-reinforced polymer composite (FRPC) wires, sliding friction

INTRODUCTION

Composites have traditionally been used in dentistry as aesthetic tooth-colored restorative materials. Their aesthetic and mechanical properties in the oral cavity are well established. The composite material's brittle nature is also recognized as a stumbling block in manufacturing of archwires from composites. Through composite technology [Figure 5], an optimal wire in terms of aesthetics and mechanical properties has been fabricated from continuous fibers and polymer matrix, giving rise to a prototype Fiber-reinforced Polymer Composite (FRPC) archwire, potentially suitable for use in orthodontics.[1]

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Springback, stiffness, formability, resilience modulus, biocompatibility, and low friction are desirable characteristics[2] of an archwire for optimum mechanical performance during orthodontic treatment. The FRPC archwire prototype has been shown in a previous study[1] to be comparable in terms of its mechanical properties to clinical nickel titanium wire when tensile and three-point bending tests were carried out. The translucent[14] nature of the polymer matrix confers the aesthetic property to the FRPC archwire. The fiber content gives the material flexibility, overcoming the inherent problem of brittleness. At various stages of the orthodontic treatment, the mechanical properties required of the archwire changes. Different fiber material, fiber content, and fiber arrangement can modify the mechanical properties of the wire to suit the mechanical requirements of the archwire at various stages of treatment.

Address for Correspondence:
Chai Kiat Chng, Head and Consultant Dental Service, KK Women's and Children's Hospital, Women's Tower Level 3, Clinical Offices, 100 Bukit Timah Road, Singapore - 229 899. E-mail: chng.chai.kiat@kkh.com.sg

When metallic wires are used in conjunction with ceramic brackets, although the brackets are aesthetic, the arch wire is still visible. Coated aesthetic archwires have been introduced, but such archwires have higher friction and the aesthetic coating tends to dehisce[3-6] Also, these wires are opaque; there is no transmission of light and therefore, no transmission of the tooth color through the wires. The FRPC archwire, being translucent in nature, will allow for transmission of the color of teeth, thereby improving aesthetics in cases where ceramic brackets are used.

Allergic reactions to nickel,[7-9] a metallic ion found commonly in contemporary metallic archwire, may be averted with the FRPC archwire. In addition, studies have been conducted on the mechanical properties of the FRPC wire. Preliminary typodont studies[1] have shown the wire's ability to align teeth. These studies collectively suggest a strong viability for the wire's clinical usefulness.

These FRPC wires do show promise in providing an aesthetic archwire for orthodontic use. Specifics such as formability, weldability, and frictional coefficients haven't been ascertained as yet, as very little research has been done on FRPC wires. Friction is a critical mechanical consideration throughout the course of fixed mechanotherapy.[10-13] The success or failure of fixed mechanotherapy may be greatly influenced by the frictional properties of the materials used and how friction is controlled and used in the mechanics of treatment.

Aim of the study

A prospective study was carried out with the aim to compare sliding friction for a prototype FRPC archwire with that for a Nickel-titanium archwire using various bracket-archwire combinations using the Universal testing machine (INSTRON 5848 Micro Tester; Instron Corporation; Norwood, Massachusetts, U.S.A).

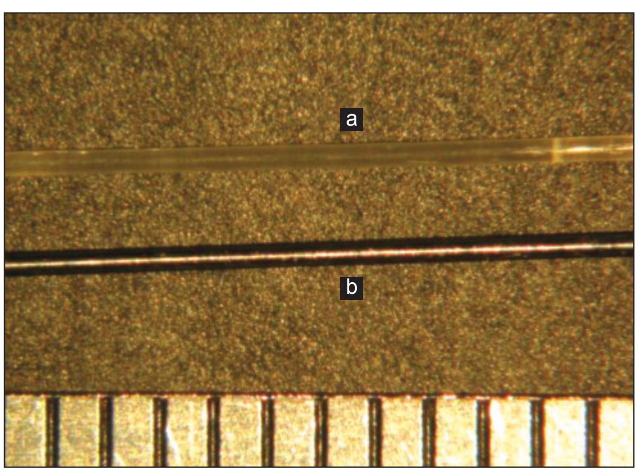

Figure 1: Sample wires of 0.018-inch FRPC (a) and NiTi (b) archwires tested. Both the test wires were supplied in straight form in order to avoid the trifocal eclipse of the preformed archwires

MATERIALS AND METHODS

Selection of archwires and brackets

The 0.018-inch FRPC was compared against a 0.018-inch Nitinol (NiTi) archwire. The two wires were tested against four different brackets: 3M Gemini 0.022 inch slot Twin bracket; 3M Clarity metal-reinforced 0.022 inch slot ceramic bracket; Ormco Inspire ICE 0.022 inch slot ceramic bracket; and the 3M SmartClip, MBT (McLaughlin, Bennett and Trevisi) prescription 0.022 inch slot self-ligating bracket. All the different brackets had similar torque and angulation (−7° torque, 0° angulation). For purpose of standardization, the upper right first premolar brackets were used for all tests. A frictional study of the archwire-bracket interface using an Universal testing machine was carried out for each bracket and archwire combination. With two archwires and four different brackets, there were a total of eight possible archwire and bracket combinations. [Figures 1 and 2] [Table 1].

Friction testing

To simulate wear of the archwire, the universal testing machine was used to carry out sliding friction tests with each archwire bracket combination. For each test, a new archwire and bracket was used. Test wires used were cut from a straight portion of a preformed archwire if no straight wires were available. Each wire was measured precisely with a pair of Vernier calipers (Mitutoyo Corporation, Kanagawa, Japan) and cut to produce test wires of length 10 cm. A customized jig was engineered

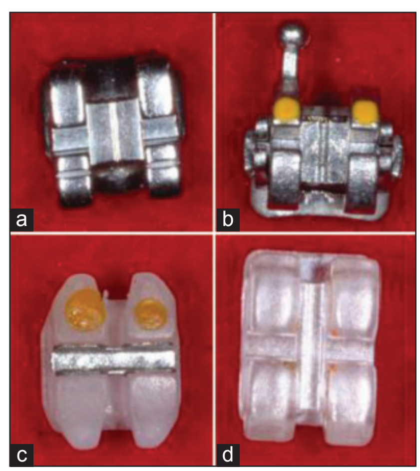

Figure 2: Brackets tested in the study. (a) Gemini True-twin Stainless Steel (3M Unitek, St. Paul, Minnesota) (b) SmartClip True-twin Self-ligating Stainless Steel (3M Unitek, St Paul, Minnesota) (c) Clarity True-twin Polycrystalline metal-reinforced Ceramic (3M Unitek, St Paul, Minnesota) (d) Inspire ICE True-twin Monocrystalline Ceramic (Ormco, Orange, California)

to hold the test wire stationary and straight. The wire-jig assembly was adjustable vertically and horizontally to allow for correction of wire position. The jig was welded onto a table which was secured via screws to the landing of the universal testing machine.

The test bracket was also held in place by another customized jig [Figure 3]. This bracket jig held the bracket while at the same time was attached to the cross head of the universal testing machine via an aluminum rod [Figure 4]. The cross head is the moveable part of the universal testing machine. Hence, in this experimental set-up, it is the bracket that moves along the wire, instead of the wire being pulled through the bracket. The bracket was localized onto the bracket-jig assembly using 2 parallel blocks and a straight length of 0.021 inch by 0.025 inch stainless steel wire. This was done to ensure that the bracket slot would be parallel to the motion of sliding when the test is conducted. After localization, the wire was secured within the bracket using a stainless steel ligature wire. The ligature was twisted till the test wire was firmly secured in the bracket slot and then it was untwisted 3 turns so that it does not cause binding of the wire to the bracket. This was carried out for all test wire and bracket combinations except for those which involved the 3M Smartclip self-ligating bracket, in which case no ligature wires were used to secure the test wire.

When the test wire and bracket were placed in their respective jigs and assembled in the universal testing machine, it gave a test area exactly at the middle of the test wire. Localizing the test area was crucial as the wires were preserved for further testing of the areas of the wires that have undergone frictional wear in the subsequent parts of the study.

The cross head of the universal testing machine was set at a speed of 0.5 mm per minute. It moved the brackets upward for 2 minutes and then downward for 2 minutes, making one cycle lasting 4 minutes. A total of 10 cycles was done for each test wire and bracket combination. Each test therefore lasted 40 minutes. The area of wear that was created was 1mm in length on the test wire and this was the area that was studied in the following 2 parts of this study. This was done in the hope that the wear created will approximate the normal wear an archwire experiences when used clinically. Results of frictional wear of each archwire-bracket test were captured from the universal testing machine on the dedicated Merlin software. The Merlin software controlled and monitored the velocity at which the crossheads moved and recorded the frictional wear as represented by the load in Newtons, as the bracket was pulled along the wire.

STATISTICAL ANALYSIS AND RESULTS

Statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS version 14; SPSS Inc, Chicago IL) software. The mean and standard deviation of the frictional wear was represented by the load in

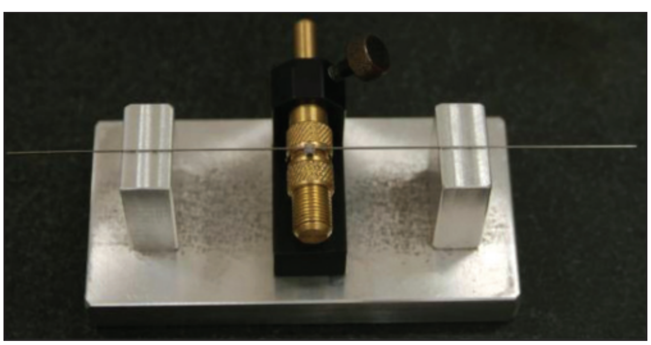

Figure 3: Close-up image showing customized jig. Customized jig allowed the bracket to traverse a specified distance over a specific period of time

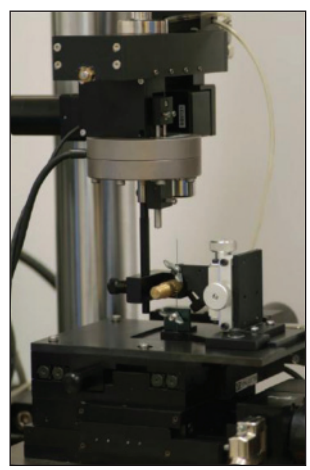

Figure 4: Image showing experimental setup of the Universal testing machine with bracket and archwire mounted on a customized jig

Table 1: Table describing various brackets used in this study with details of brand, manufacturing company, configuration, and structure

Brackets Brand	Manufacturer	Configuration	Structure
Gemini	3M Unitek, St. Paul, Minnesota	True-twin	Stainless steel
Clarity	3M Unitek, St Paul, Minnesota	True-twin	Polycrystalline metal-reinforced Ceramic
Inspire Ice	Ormco, Orange, California	True-twin	Monocrystalline Ceramic
SmartClip	3M Unitek, St Paul, Minnesota	True-twin	Self-ligating stainless steel

Newtons as the bracket was pulled along the wire with the universal testing machine. A one-way ANOVA was carried out to compare between groups and also within groups of the friction wear testing with the universal testing machine. Method error calculation could not be carried out as the tested wires could not be subjected to a repeated frictional test.

Quantitative analysis of friction study

The raw data from the frictional wear testing was corrected to take into account the change in the direction of the crossheads as each test cycle was completed. This was done by a positive value indicating crossheads moving upward, and a negative value indicating crossheads moving downward. The magnitudes of the readings were considered and the direction, i.e., the positive or negative was discounted. The first 10 seconds and last 10 seconds of readings of each 2-minute cycle were also eliminated to factor out inertia as the crossheads change direction. The difference between the final mean frictional values and the initial mean frictional values was evaluated to determine frictional wear caused by the testing. The initial and final frictional values were the average of the first 2 minutes and last 2 minutes of each 40-minute cycle test. This value was taken to be the frictional wear generated from the testing.

From descriptive statistics of frictional wear [Table 2], it can be seen that the frictional wear generated showed a range of values among the different archwire and bracket combination. The highest frictional wear generated was with the Gemini-FRPC group. The results also indicated that some archwire and bracket combinations showed less friction at the end of testing, indicating that the coefficient of friction was possibly reduced after frictional wear.

There was no significant difference noted for the frictional wear generated between the various archwire and bracket groups ($P = 0.542$). No statistical significance was detected within individual archwire-bracket groups.

A multiple comparison was done to see which of the groups showed significant difference in frictional wear. Least significant difference (LSD) multiple comparisons revealed statistical significance ($P < 0.05$) when comparing the Gemini-FRPC with the ICE-FRPC group. No other groups showed any significant difference.

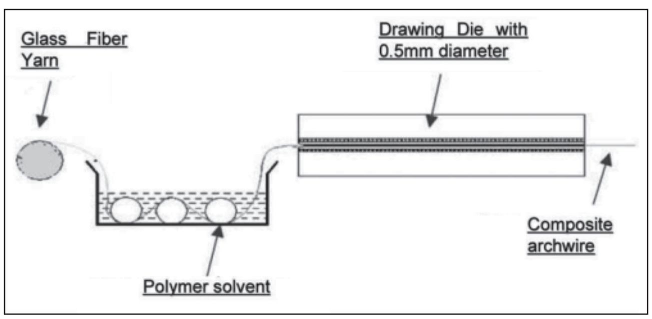

Figure 5: Schematic representation of pultrusion process for the fabrication of composite archwires

DISCUSSION

The FRPC wires that were tested in this study have been designed and manufactured with the intention to function as wires to be used in the initial alignment phase of orthodontic treatment. The use of equivalent diameter contemporary nickel-titanium archwires for comparison of friction and surface roughness is therefore appropriate.[15-19] Different brackets and the two archwire materials were combined to give different bracket-archwire interface combinations to quantify the level of sliding friction using a universal testing machine. Findings from this study were interpreted in context to provide clinical relevance. Results from the friction studies showed no significance difference between groups. From the LSD multiple comparison, it was seen only the ICE-FRPC group showed statistical significance when compared to the Gemini FRPC group. No other groups showed any significant difference. If however, a post-hoc Bonferroni adjustment were done for the multiple comparisons, then the Gemini-FRPC group would no longer be statistically significant. All other

Table 2: Descriptive statistics of various bracket-archwire combinations evaluated for friction

Friction	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Clarity-FRPC	5	−27.88	33.59	15.02	−69.59	13.83
Clarity-NiTi	5	−22.83	34.74	15.53	−65.96	20.31
Gemini-FRPC	5	313.10	802.59	358.93	−683.45	1309.64
Gemini-NiTi	5	75.41	159.06	71.13	−122.09	272.91
ICE-FRPC	5	−71.13	17.08	7.67	−92.33	−49.92
ICE-NITi	5	−28.48	21.44	9.59	−55.10	−1.86
SmartClip-FRPC	5	27.48	72.85	32.58	−62.97	117.93
SmartClip-NiTi	5	−6.94	48.27	21.59	−66.88	53.00

N, number;

FRPC combination groups did not show any statistical significance in the frictional testing. This would indicate that the FRPC wire actually performed as well as NiTi wire during friction testing. This result has to be taken with caution due to the small sample size. The sample size was small as running of the test was very time consuming and the availability of FRPC archwire, being a prototype, was also limited.

FRPC archwires are still in its infancy in development. Future directions in experimentation would be to include a fluid medium like saliva to compare wet and dry states of frictional testing.[20,21] Experiments with the introduction of second order bends should also be considered. No experiments involving third-order bends can be carried out since a rectangular cross-sectional FRPC wire has not been manufactured successfully as yet. It would also be interesting to study the amount of polymer loss due to wear. This could be extrapolated as the amount that a patient could be potentially exposed to and the effects it may have on the patient's health. A more in-depth look at surface roughness using a scanning electron microscope and atomic force microscopy may give us more insights to this FRPC, which could be planned for future experimentation.

CONCLUSION

FRPC and NiTi wires show statistically comparable frictional wear when used with ICE, Gemini, Clarity, and SmartClip brackets. However, validity of this result needs to be taken with caution since fiber-reinforced wires are experimental and not universally commercially available and also the sample size was small.

REFERENCES

1. Huang ZM, Gopal R, Fujihara K, Ramakrishna S, Loh PL, Foong WC, *et al*. Fabrication of a new composite orthodontic archwire and validation by a bridging micromechanics model. Biomaterials 2003;24:2941-53.
2. Kusy RP, Whitley JQ, Prewitt MJ. Comparison of the frictional coefficients for selected archwire-bracket slot combinations in the dry and wet states. Angle Orthod 1991;61:293-302.
3. Corbitt GV. Commentary: Reduced frictional resistances using Teflon-coated ligatures with various bracket-arch wire combinations. Angle Orthod 1995;65:73-4.
4. Husmann P, Bourauel C, Wessinger M, Jäger A. The Frictional Behavior of Coated Guiding Archwires. J Orofac Orthop 2002;63:199-211.
5. Zufall SW, Kennedy KC, Kusy RP. Frictional characteristics of composite orthodontic archwires against stainless steel and ceramic brackets in the passive and active configurations. J Mater Sci Mater Med 1998;9:611-20.
6. De Franco DJ, Spiller RE Jr, von Fraunhofer JA. Frictional resistances using Teflon-coated ligatures with various bracket-archwire combinations. Angle Orthod 1995;65:63-74.
7. David A, Lobner D. *In vitro* cytotoxicity of orthodontic archwires in cortical cell cultures. Eur J Orthod 2004;26:421-6.
8. Eliades T, Pratsinis H, Kletsas D, Eliades G, Makou M. Characterization and cytotoxicity of ions released from stainless steel and nickel-titanium orthodontic alloys. Am J Orthod Dentofacial Orthop 2004;125:24-9.
9. Oh KT, Kim KN. Ion release and cytotoxicity of stainless steel wires. Eur J Orthod 2005;27:533-40.
10. Kusy RP, Whitley JQ. Resistance to sliding of orthodontic appliances in the dry and wet states: influence of archwire alloy, interbracket distance, and bracket engagement. J Biomed Mater Res 2000;52:797-811.
11. Nishio C, da Motta AF, Elias CN, Mucha JN. *In vitro* evaluation of frictional forces between archwires and ceramic brackets. Am J Orthod Dentofacial Orthop 2004;125:56-64.
12. Smart FM. Kinetic friction. Am J Orthod Dentofacial Orthop 2004;125:A17.
13. Clocheret K, Willems G, Carels C, Celis JP. Dynamic frictional behaviour of orthodontic archwires and brackets. Eur J Orthod 2004;26:163-70.
14. Bolt RA, Bosch JJ, Coops JC. Influence of window size in small-window colour measurement, particularly of teeth. Phys Med Biol 1994;39:1133-42.
15. Fallis DW, Kusy RP. Variation in flexural properties of photopultruded composite archwires: Analyses of round and rectangular profiles. J Mater Sci Mater Med 2000;11:683-93.
16. Kusy RP. Influence of force systems on archwire-bracket combinations. Am J Orthod Dentofacial Orthop 2005;127:333-42.
17. Bishara SE Fehr DE. Ceramic brackets: Something old, something new, a review. Semin Orthod 1997;3:178-88.
18. Kusy RP, Whitley JQ. Effects of sliding velocity on the coefficients of friction in a model orthodontic system. Dent Mater 1989;5:235-40.
19. Kusy RP, Whitley JQ. Effects of surface roughness on the coefficients of friction in model orthodontic systems. J Biomech 1990;23:913-25.
20. Eliades T, Bourauel C. Intraoral aging of orthodontic materials: The picture we miss and its clinical relevance. Am J Orthod Dentofacial Orthop 2005;127:403-12.
21. Eliades T, Eliades G, Brantley WA, Johnston WM. Residual monomer leaching from chemically cured and visible light-cured orthodontic adhesives. Am J Orthod Dentofacial Orthop 1995;108:316-21.

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