Original Article

The effect of water storage on the bending properties of esthetic, fiber-reinforced composite orthodontic archwires

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ABSTRACT

Objective: To study the effect of water storage on the bending properties of fiber-reinforced composite archwires and compare it to nickel-titanium (NiTi), stainless steel (SS), and beta-titanium archwires.

Materials and Methods: Align A, B, and C and TorQ A and B composite wires from BioMers Products, 0.014-, 0.016, and 0.018-inch, and 0.019 × 0.025-inch NiTi, 0.016-inch SS, and 0.019 × 0.025-inch beta-titanium archwires were tested (n = 10/type/size/condition). A 20-mm segment was cut from each end of the archwire; one end was then stored in water at 37°C for 30 days, while the other was stored dry. The segments were tested using three-point bending to a maximum deflection of 3.1 mm with force monitored during loading (activation) and unloading (deactivation). Statistical analysis was completed via two-way analysis of variance with wire and condition (dry and water-stored) as factors.

Results: In terms of stiffness and force delivery during activation, in general: beta-titanium was > TorQ B > TorQ A > 0.019 × 0.025-inch NiTi and 0.016-inch SS > Align C > 0.018-inch NiTi > Align B > 0.016-inch NiTi > Align A > 0.014-inch NiTi. Water exposure was detrimental to the larger translucent wires (Align B and C, TorQ A and B) because they were more likely to craze during bending, resulting in decreased forces applied at a given deflection. Align A and the alloy wires were not significantly ($P > .05$) affected by water storage. Overall, the alloy wires possessed more consistent force values compared to the composite wires.

Conclusion: Environmental conditions are more likely to affect fiber-reinforced composite archwires compared to alloy wires. (*Angle Orthod.* 2014;84:417–423.)

KEY WORDS: Archwires; Fiber-reinforced composite; Nickel-titanium; Bending; Water degradation

INTRODUCTION

Fiber-reinforced composite has been used in various dental applications for at least 30 years.[1] With increasing esthetic demands, fiber-reinforced composite has also been investigated as a replacement to alloy wires in orthodontics.[2,3] Some research has been conducted on fiber-reinforced composite wires, but translation from laboratory prototypes to commercial markets has been slow.[1–7] However, one fiber-reinforced, esthetic composite orthodontic archwire is currently commercially available (BioMers Products, LLC, Jacksonville, Fla). It is available both as a round wire (Align A, B, and C with diameters of 0.018, 0.019, and 0.021 inches, respectively) or rectangular wire (TorQ A and TorQ B with dimensions of 0.019 × 0.025-inch and 0.021 × 0.025-inch, respectively). These wires are manufactured by incorporating glass fibers into a resin contained within a shrinkable and flexible die that reacts to heat.[8,9] As the die shrinks, the composite is compressed to form its predetermined transverse cross-sectional shape. The bending properties of these wires via premarket experimental versions[9] and commercially available wires[10] have been documented.

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Table 1. Manufacturer Specified Dimensions, Measured Dimensions, and Manufacturer Comparison and Deflection Limits

Wire Type[a]	Dimension Specified by Manufacturer, inches[14]	Dimension Specified by Manufacturer, mm	Average Measured Dimension, mm	Force Similarity Claimed by Manufacturer	Deflection Limit Stated by Manufacturer, mm
Align A	0.018	0.457	0.456 ± 0.010	0.016-inch NiTi	2–3
Align B	0.019	0.483	0.468 ± 0.016	0.018-inch NiTi	1–1.5
Align C	0.021	0.533	0.524 ± 0.010	0.016-inch SS	0.5
NiTi 0.014-inch	0.014	0.356	0.340		
NiTi 0.016-inch	0.016	0.406	0.390		
NiTi 0.018-inch	0.018	0.457	0.435		
SS 0.016-inch	0.016	0.406	0.390		
TorQ A	0.019 × 0.025	0.483 × 0.635	0.520 ± 0.014 × 0.720 ± 0.029	0.019 × 0.025-inch NiTi	0.5
TorQ B	0.021 × 0.025	0.533 × 0.635	0.590 ± 0.032 × 0.770 ± 0.035	0.019 × 0.025-inch beta-titanium	0.5
NiTi 0.019 × 0.025-inch	0.019 × 0.025	0.483 × 0.635	0.470 × 0.630		
Beta-titanium 0.019 × 0.025-inch	0.019 × 0.025	0.483 × 0.635	0.470 × 0.630		

[a] NiTi indicates nickel-titanium; SS, stainless steel.

Orthodontic wires are utilized in the oral cavity for a substantial period of time where they are exposed to saliva, water, and various beverages. These solutions have the potential to impact the properties of the fiber-reinforced composite wires. Studies have shown that water storage decreases the strength of fiber-reinforced composite.[5,11–13] When fiber-reinforced composite is stored in water, water molecules diffuse into the resin matrix and act as a dispersant to increase the plasticity or fluidity of resin polymer chains; therefore, the strength of the composite decreases. The objective of this research was to study the effect of water storage on the bending properties of fiber-reinforced composite archwires and compare it to nickel-titanium (NiTi), stainless steel (SS), and beta-titanium archwires. The null hypothesis was that water storage would not have any effect on the bending properties of the wires tested.

MATERIALS AND METHODS

Fiber-reinforced composite (Align A, B, and C, and TorQ A and B, BioMers Products), 0.014-, 0.016-, and 0.018-inch, and 0.019 × 0.025-inch martensitic-stabilized NiTi (Nitinol Classic, 3M Unitek, Monrovia, Calif), 0.016-inch stainless steel (3M Unitek), and 0.019 × 0.025-inch beta-titanium (Beta III Titanium, 3M Unitek) archwires were tested in this study (Table 1).[14] Each type and size of archwire consisted of 10 specimens (n = 10/type/size/condition).

A 20-mm segment was cut from each end of the archwire. The diameter or width/thickness of the wire segments was measured at three different points on the wire using a digital caliper with a resolution of 0.01 mm. A segment from one end of the archwire was stored in distilled water at 37°C for 30 days, while the other segment from the same archwire was stored dry. Segment dimensions were also measured after water storage. The segments were tested using three-point bending at 37° ± 2°C. The specimens were centered between two support beams, which had a span length of 14 mm. The load was applied vertically with a universal testing machine (Instron Corp, Norwood, Mass) to the middle of the specimens at the rate of 2 mm/min to a maximum deflection of 3.1 mm, and then it was returned to its starting position at the same rate. The three-point bend test was carried out following American National Standard/American Dental Association Specification (ADA) No. 32,[15] with the modification that the support length was 14 mm instead of 12 mm. Due to the curvature in the posterior segment of the fiber-reinforced composite wires, all of the rectangular wires were tested edge-wise to prevent the wires from slipping off the testing fixture.

The force required to deflect the specimens was monitored and recorded by dedicated software (Merlin, Instron) during loading (activation) and unloading (deactivation). The slope (g/mm) of the linear portion of the force vs deflection curve and force (g) values at 1.0, 2.0, and 3.0 mm deflection during both activation and deactivation comprised the data harvested from each test. Additionally, the slope was converted to bending modulus (GPa), and the percent of elastic recovery was computed. The measured dimensions, instead of manufacturer-specified dimensions, were used for calculating bending modulus. Statistical analysis was performed using two-way analysis of variance (ANOVA) with wire and condition (dry and water-stored) as factors followed by a post-hoc Tukey test when indicated. All statistical tests were done using a $P < .05$ level of significance and statistical software (SAS Institute Inc, Cary, NC).

RESULTS

All of the wire segments were measured at three different points along the segments; the averages of the measurements are listed in Table 1. The average dimensions of all wires were different from the dimensions specified by manufacturers. For each type or size of alloy archwire (NiTi 0.014-, 0.016-, and 0.018-inch, and 0.019 × 0.025-inch; SS 0.016-inch; beta-titanium 0.019 × 0.025-inch), no variations in dimensions were detected along the same wire segment nor among different specimens. In contrast to the alloy wires, the measurements taken from the fiber-reinforced composite wires (Align A, B, and C; TorQ A and B) varied among the different segments and also from one point to another on the same segment.

Comparisons of the force vs deflection bending curve for the round wires may be observed in Figure 1a,b. The fiber-reinforced composite and NiTi wires generally have similar bending profiles but with differing force values depending on the size of the wire; stainless steel is not displayed due to its permanent deformation and dissimilar profile. As supported from the numerical data (Tables 2 and 3), the order of stiffness during activation was 0.016-inch SS > Align C > 0.018-inch NiTi > Align B > 0.016-inch NiTi > Align A > 0.014-inch NiTi ($P < .05$). Force values at the given deflections generally ranked in this order also. With regard to the effect of 30 days of water immersion on the bending properties of the wires, as expected, the alloy wires were not affected ($P > .05$; Tables 2 and 3), and as such, their bending profiles are not shown because the profiles were essentially superimposed upon one another for the two conditions. However, the fiber-reinforced composite wires were affected to different degrees depending on the size of the wire. Align A was not significantly ($P > .05$) affected in terms of force values (Figure 1c; Tables 2 and 3), except that crazing occurred in 30% of the water-stored specimens, whereas none of the dry specimens exhibited crazing. Crazing is defined as a region of ultrafine cracks in the resin phase leading to the appearance of a white band.[16] The larger composite wires were more affected by water immersion, though, generally showing a greater propensity to craze with a resultant permanent deformation and lower deactivation forces (Figure 1d,e; Tables 2 and 3). The instance of crazing is noticed by a significant drop in force values.

Comparisons of the force vs deflection bending curve for the rectangular wires are displayed in Figure 1f,g. NiTi shows nearly 100% elastic recovery, beta-titanium displays permanent deflection of slightly more than 1 mm, and TorQ A and TorQ B are intermediate. Additionally, TorQ A and TorQ B show one to two drops in force signifying crazing (Figure 1h,i); this generally occurred at lower deflections for TorQ B when the wires were exposed to water. In terms of activation stiffness (Tables 2 and 3), the order for the rectangular wires was beta-titanium > TorQ B > TorQ A > NiTi ($P < .05$). Complete data for the 0.019 × 0.025-inch NiTi wires are not shown in Tables 2 and 3 because these wires had a tendency to flip from edgewise to flat-wise, thus their tests were terminated once the wires had flipped; they were tested edgewise to be consistent with the orientation of the composite wires. Water storage similarly affected the rectangular fiber-reinforced composite wires as supported numerically by the dry wires delivering greater force levels compared to their corresponding water-stored groups in many instances.

Finally, of note for all of the round and rectangular wire bending data, the alloy wires exhibited very low standard deviations, whereas the fiber-reinforced composite wires had much greater standard deviations even before any crazing occurred.

DISCUSSION

In this study, the dimensions of all wire segments were measured and found to be different from the dimensions specified by manufacturers. All of the round wires and alloy rectangular wires were measured to be within 5% of that stated by the manufacturers. However, for the rectangular fiber-reinforced composite wires, the dimensions varied from expected by 7% to 21%. Overall, the dimensions of the alloy wires were consistent among the same group and along a segment, but the dimensions of the fiber-reinforced composite wires were not. This inconsistent variation from the specified dimension could cause the composite archwires to not fit in the slot of the brackets as well. Also, there might be an increase in friction if the sizes are greater than expected. Therefore, utilization of composite wires in space closure using sliding mechanics might result in reduced efficiency. In addition, with the variation in dimension, the force values may then be different from expected.

The rectangular wires had larger dimensions than the round wires that were tested; therefore, as expected, the rectangular wires had greater stiffness (g/mm), which in descending order were 0.019 × 0.025-inch beta-titanium > TorQ B (0.021 × 0.025-inch) > TorQ A (0.019 × 0.025-inch) > 0.019 × 0.025-inch NiTi > 0.016-inch SS > Align C (0.021-inch) > 0.018-inch NiTi > Align B (0.019-inch) > 0.016-inch NiTi > Align A (0.018-inch) > 0.014-inch NiTi. The rectangular fiber-reinforced composite wire had smaller stiffness comparing to beta-titanium of the same

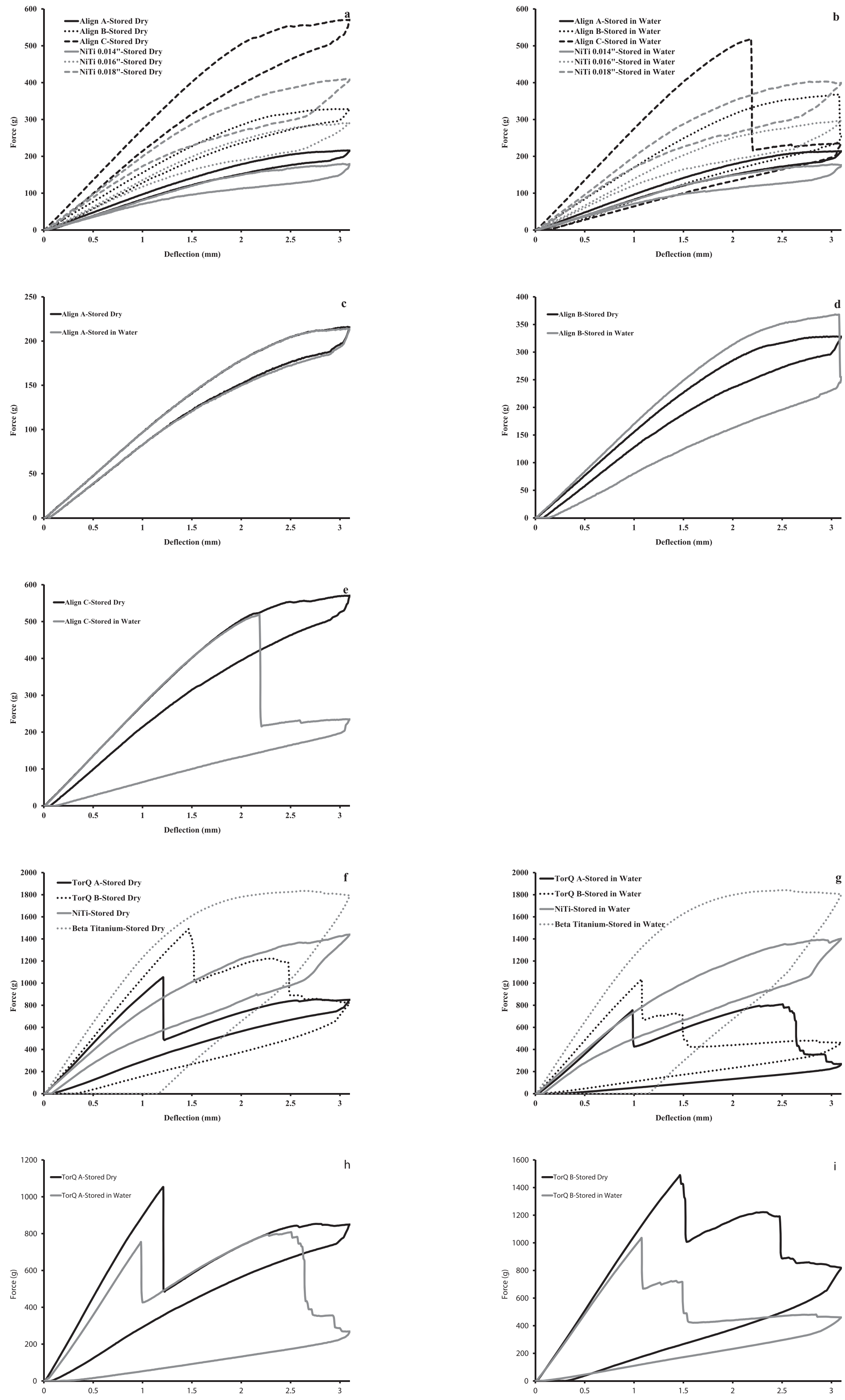

Figure 1. Comparison of typical force-deflection curves. (a) Round wires after dry storage. (b) Round wires after 30 days of storage in water. (c) Align A after dry and water storage. (d) Align B after dry and water storage. (e) Align C after dry and water storage. (f) All rectangular wires after dry storage. (g) All rectangular wires after 30 days of storage in water. (h) TorQ A after dry and water storage. (i) TorQ B after dry and water storage.

Table 2. Bending Values During Activation for All Wires[a]

Archwire[b]	Activation					
	Stiffness, g/mm	Modulus, GPa	Force at 1 mm, g	Force at 2 mm, g	Force at 3 mm, g	% With Cracks (at Deflection)
Align A (0.018-inch), dry	111 ± 18 F	28.9 ± 4.8 E	110 ± 17 F	199 ± 28 F	237 ± 29 DE	0
Align A (0.018-inch), water 30 d, 37°C	117 ± 17	31.8 ± 5.8	115 ± 16	192 ± 18	231 ± 24	30 (1.39 ± 0.34 mm)
Align B (0.019-inch), dry	172 ± 23 D	41.5 ± 3.5 D	169 ± 23 D	284 ± 93 D	298 ± 119 CD	50 (2.59 ± 0.56 mm)
Align B (0.019-inch), water 30 d, 37°C	176 ± 13	41.1 ± 3.2	173 ± 13	317 ± 23	214 ± 154	60 (2.60 ± 0.46 mm)
Align C (0.021-inch), dry	268 ± 13 B	39.7 ± 2.7 D	265 ± 14 B	478 ± 24 B	475 ± 151 C*	40 (2.55 ± 0.43 mm)
Align C (0.021-inch), water 30 d, 37°C	258 ± 26	40.1 ± 2.9	254 ± 25	409 ± 133	163 ± 174 *	100 (2.22 ± 0.44 mm)
NiTi 0.014-inch, dry	82 ± 1 G	69.9 ± 1.1 B	81 ± 1 G	147 ± 2 G	175 ± 3 E	0
NiTi 0.014-inch, water 30 d, 37°C	82 ± 1	69.6 ± 0.8	81 ± 1	148 ± 2	175 ± 3	0
NiTi 0.016-inch, dry	143 ± 1 E	70.5 ± 0.6 B	140 ± 1 E	249 ± 2 E	294 ± 4 CD	0
NiTi 0.016-inch, water 30 d, 37°C	143 ± 1	70.5 ± 0.7	140 ± 2	249 ± 2	292 ± 4	0
NiTi 0.018-inch, dry	205 ± 3 C	65.3 ± 0.8 C	201 ± 2 C	348 ± 4 C	406 ± 10 B	0
NiTi 0.018-inch, water 30 d, 37°C	205 ± 1	65.2 ± 0.4	201 ± 2	348 ± 3	408 ± 10	0
SS 0.016-inch, dry	489 ± 7 A	241.5 ± 3.5 A	475 ± 5 A	741 ± 4 A	717 ± 7 A	0
SS 0.016-inch, water 30 d, 37°C	488 ± 3	240.5 ± 1.6	474 ± 5	739 ± 4	717 ± 9	0
TorQ A (0.019 × 0.025-inch), dry	857 ± 215 C	28.0 ± 6.4 C	771 ± 224 C	767 ± 27 D*	786 ± 246 B*	100 (1.12 ± 0.23 mm)
TorQ A, water 30 d, 37°C	843 ± 73	30.4 ± 1.3	744 ± 162	572 ± 187 *	360 ± 198 *	100 (1.10 ± 0.20 mm)
TorQ B (0.021 × 0.025-inch), dry	1162 ± 114 B	28.9 ± 2.3 C	973 ± 257 B	1005 ± 107 C*	656 ± 329 B*	100 (1.17 ± 0.22 mm)
TorQ B, water 30 d, 37°C	1100 ± 138	27.8 ± 5.2	819 ± 253	732 ± 296 *	350 ± 145 *	100 (0.99 ± 0.13 mm)
Beta-titanium (0.019 × 0.025-inch), dry	1274 ± 15 A	72.9 ± 0.9 A	1244 ± 44 A	1801 ± 25 A	1813 ± 24 A	0
Beta-titanium, water 30 d, 37°C	1285 ± 14	73.5 ± 0.8	1252 ± 15	1813 ± 22	1824 ± 35	0
NiTi (0.019 × 0.025-inch), dry	765 ± 11 D	44.8 ± 0.7 B	739 ± 13 C	1184 ± 31 B	N/A	0
NiTi (0.019 × 0.025-inch), water 30 d, 37°C	762 ± 10	44.7 ± 0.6	738 ± 8	1188 ± 20	N/A	0

[a] Statistical analysis via two-way ANOVA with wire and condition (dry and water-stored) as factors. Round and rectangular wires were modeled separately. Within each parameter, different letters denote significant differences ($P < .05$) exist between wires (eg, Align A, Align B, NiTi 0.014-inch).

[b] NiTi indicates nickel-titanium; SS, stainless steel.

* Significant difference ($P < .05$) between dry and water-stored wires of the same type/size.

size, but slightly higher stiffness than martensitic-stabilized NiTi of the same size. For round wires, composite wires had a lower stiffness than stainless steel and martensitic-stabilized NiTi archwires of comparable size. The force delivery values corresponded with the stiffness values well, until crazing occurred in the fiber-reinforced composite wires. It is important clinically to know that composite wires are not as stiff as the stainless steel and beta-titanium wires of the same size because this may make them less suitable for certain types of mechanics that require rigid archwires, like closing spaces using sliding mechanics, correcting anteroposterior relationships using interarch elastics, or maintaining transverse dimension. For the round wires, fiber-reinforced composite archwires had lower stiffness than martensitic-stabilized NiTi of similar size so they will deliver gentler forces. The apparent discrepancy in comparison between the stiffness of rectangular and round wires with respect to composite vs NiTi may be related to the actual size of the wires when measured instead of relying on the manufacturer-specified dimensions. For instance, the rectangular NiTi wires were less stiff than the "same size" TorQ A, but the modulus of the rectangular NiTi was larger when computed out with the actual dimensions factored. This is in contrast to the round wires where the "same size" NiTi was stiffer and had a greater modulus. Due to the dimensions of the round wire composite being closer to stated and less differential to the NiTi wires, the stiffness and modulus followed the same trend.

No significant difference was detected in the stiffness or resultant force applied of the alloy wires between the water-stored and dry groups. Alloy archwires were not affected by water because water cannot diffuse into the alloys, and, although surface corrosion is possible, a period of 30 days is too short for it to cause an effect when stored in only water. Thus, the null hypothesis could not be rejected for the alloy wires, but this was not the case for all of the fiber-reinforced composite wires. For fiber-reinforced composite, water may diffuse into the resin matrix and act as a plasticizer and make the movement of polymer chains easier under stress.[13] Hydrolytic degradation of resin may explain the lower force level delivery of the wires in the water-stored group; however, another mechanism is likely at play since the drop in force is largely tied to the higher crazing rate (discussed

Table 3. Bending Values During Deactivation for All Wires[a,b]

	Deactivation					
Archwire[c]	Stiffness, g/mm	Modulus, GPa	Force at 3 mm, g	Force at 2 mm, g	Force at 1 mm, g	Elastic Recovery, %
Align A (0.018-inch), dry	98 ± 16 DE	25.7 ± 4.2 C	217 ± 27 CDE	170 ± 24 B	94 ± 16 BC	99.0 ± 0.7 AB
Align A (0.018-inch), water 30 d, 37°C	90 ± 15	24.0 ± 3.9	196 ± 54	161 ± 19	86 ± 15	97.4 ± 4.6 AB
Align B (0.019-inch), dry	110 ± 59 DE	26.8 ± 14.7 CD*	257 ± 123 CDE	191 ± 99 BC	103 ± 56 C	98.0 ± 2.8 B*
Align B (0.019-inch), water 30 d, 37°C	72 ± 57	16.0 ± 12.1*	175 ± 131	123 ± 100	64 ± 56	96.5 ± 3.3 B*
Align C (0.021-inch), dry	176 ± 75 CD*	26.3 ± 11.2 D*	425 ± 147 D*	301 ± 125 B*	162 ± 72 BC*	96.7 ± 3.7 C*
Align C (0.021-inch), water 30 d, 37°C	36 ± 36*	5.6 ± 5.3*	124 ± 129*	65 ± 63*	30 ± 29*	89.1 ± 4.9 C*
NiTi 0.014-inch, dry	74 ± 1 E	62.9 ± 1.0 B	151 ± 2 E	114 ± 2 C	71 ± 1 C	99.9 ± 0.2 A*
NiTi 0.014-inch, water 30 d, 37°C	74 ± 2	63.3 ± 2.1	150 ± 2	113 ± 1	71 ± 1	99.6 ± 0.3 A*
NiTi 0.016-inch, dry	127 ± 2 C	62.6 ± 0.8 B	273 ± 3 C	193 ± 2 B	120 ± 2 B	99.4 ± 0.5 AB
NiTi 0.016-inch, water 30 d, 37°C	128 ± 2	63.1 ± 0.8	271 ± 4	192 ± 2	121 ± 2	99.3 ± 0.6 AB
NiTi 0.018-inch, dry	182 ± 2 B	58.2 ± 0.5 B	381 ± 13 B	265 ± 3 A	170 ± 3 A	99.2 ± 0.6 AB
NiTi 0.018-inch, water 30 d, 37°C	182 ± 2	57.9 ± 0.6	382 ± 11	265 ± 3	170 ± 3	99.4 ± 0.3 AB
SS 0.016-inch, dry	320 ± 4 A	158.1 ± 2.1 A	652 ± 10 A	295 ± 6 A	0	64.4 ± 0.6 D
SS 0.016-inch, water 30 d, 37°C	320 ± 5	158.1 ± 2.3	650 ± 11	294 ± 6	0	64.5 ± 0.4 D
TorQ A (0.019 × 0.025-inch), dry	254 ± 119 B*	8.3 ± 3.7 B*	641 ± 255 B*	448 ± 202 B*	229 ± 109 A*	97.1 ± 3.3 A*
TorQ A, water 30 d, 37°C	59 ± 41 *	2.2 ± 1.5 *	253 ± 121 *	120 ± 74 *	51 ± 35 *	91.1 ± 5.9 A*
TorQ B (0.021 × 0.025-inch), dry	161 ± 104 B*	3.9 ± 2.5 C	550 ± 290 B*	304 ± 187 B*	139 ± 93 A	94.6 ± 3.5 A
TorQ B, water 30 d, 37°C	65 ± 47 *	1.7 ± 1.3	270 ± 129 *	138 ± 78 *	56 ± 39	90.1 ± 5.5 A
Beta-titanium (0.019 × 0.025-inch), dry	753 ± 15 A	176.2 ± 3.4 A	1617 ± 13 A	636 ± 16 A	0	62.3 ± 0.5 B
Beta-titanium, water 30 d, 37°C	756 ± 16	176.7 ± 3.8	1628 ± 20	643 ± 13	0	62.5 ± 0.6 B

[a] Statistical analysis via two-way ANOVA with wire and condition (dry and water-stored) as factors. Round and rectangular wires were modeled separately. Within each parameter, different letters denote significant differences ($P < .05$) exist between wires (eg, Align A, Align B, NiTi 0.014-inch, etc.).

[b] Nitinol Classic 0.019 × 0.025-inch wires tended to flip to a flat-wise orientation during bending above 2 mm deflection. Data not presented.

[c] NiTi indicates nickel-titanium; SS, stainless steel.

* Significant difference ($P < .05$) between dry and water-stored wires of the same type/size.

below). One possible mechanism is the glass fibers in the composite wires also experienced hydrolytic degradation which made them fracture more easily or possibly the bond between the fiber and resin matrix was compromised, leading to alterations in stress transfer and local stress concentrations led to yielding/crazing of the wire.

The present findings are important as a clinical guideline for using these fiber-reinforced composite wires. The manufacturer states[14] (Table 1) that Align A, B, and C and TorQ A and TorQ B should have force values similar to 0.016-inch NiTi, 0.018-inch NiTi, 0.016-inch SS, 0.019 × 0.025-inch NiTi, and 0.019 × 0.025-inch beta-titanium, respectively. All fiber-reinforced composite wires had lower force delivery levels than the manufacturer-specified comparison except for TorQ A. Of the above comparisons, Align C had the greatest deviation from the comparison, often having over 200 g of force difference during activation compared to 0.016-inch SS. The force level of Align C would probably be more comparable to that of 0.020-inch martensitic-stabilized NiTi, instead of 0.016-inch SS. Thus, clinicians should be cognizant of the fact that the manufacturer comparisons for these composite wires are generalizations at best and should not be taken as equivalence.

Bending properties were assessed in this study by subjecting the wires to three-point bending to a deflection of 3.1 mm following ADA Specification No. 32 for Orthodontic Wires as a guide, with the exception of a support span of 14 mm instead of 12 mm. The larger span was selected due to fixture limitations and because 14 mm is the average distance between the labial center of a mandibular lateral incisor and a first premolar on the same side of the arch,[1,17] and it has been used in previous research.[1,10,17] So, although a standard procedure was followed for exploring the bending properties of the fiber-reinforced composite wires, it should be noted that the manufacturer of the composite wires provides deflection limit guidelines[14] (Table 1). However, the manufacture fails to specify the length of the span for these deflections, which is a critical piece of information since the force will vary with the distance between supports. When tested in the dry condition, Align A could be deflected up to 3 mm without crazing but after 30 days of water storage, 30% of Align A wire segments crazed around 1.39 ± 0.34 mm, which is much lower than the specified deflection guide for Align A. Based on the results of this study, to prevent wire damage, Align A probably should not be deflected more than 1 mm clinically. Consequently, although the force levels of Align A are between those of 0.014-inch and 0.016-inch martensitic-stabilized NiTi, they may not be able to be utilized the same way clinically. When tested dry, crazing of Align B and Align C occurred around 2.5 mm of deflection, whereas TorQ A and TorQ B crazed around 1.1 mm. For water-stored groups, the incidence of crazing increased for Align B and Align C, but the average deflection limits before crazing were not significantly different. For Align C, TorQ A, and TorQ B, the deflection at the time of crazing was actually greater than that suggested by the manufacturer as a deflection limit. Overall, it is apparent that water exposure increases the tendency of the fiber-reinforced composite wires to craze. Even with the crazing, the wires still exert some force, but they are much less than without crazing (Tables 2 and 3).

CONCLUSIONS

- The force level material comparisons and deflection limits for fiber-reinforced composite wires vary somewhat from those suggested by the manufacturer.
- Water immersion for 30 days was damaging to the larger fiber-reinforced composite archwires because they were more likely to craze during bending, resulting in decreased amounts of force applied at a given deflection.
- Alloy wires were not significantly affected by water storage.
- Overall, the alloy wires possessed vastly more consistent force values compared to the composite wires.

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