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Original Article

Elemental composition, corrosion resistance and mechanical properties of computer-aided design and computer-aided manufacturing fixed retainers versus conventional fixed retainers

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Abstract

Purpose: To investigate the elemental composition, corrosion resistance, and mechanical properties of computer-aided design and computer-aided manufacturing (CAD-CAM) retainers versus conventional fixed retainers (FRs).
Methods: Eight different retainer wires were investigated. Energy dispersive X-ray spectroscopy was used to determine the elemental composition. Leakage was analysed according to ISO 10271:2020 guidelines. Hardness was tested using the Vickers method with a load of 0.3 kg. The tensile force and tensile strength were evaluated. Multiple comparisons among wires of hardness, tensile force, and strength were conducted using the Welch *t*-test, with Bonferroni correction.
Results: Nickel was present in all wires. The CAD-CAM-FR wire, which contained more nickel than the other wires, had no measurable leakage. The gold-plated wires had the highest total leakage, but did not exceed the ISO standard limit. The hardness of the stainless-steel twisted wires was the highest and that of the CAD-CAM-FR wire was the lowest. The tensile strength of the CAD-CAM-FR wire was significantly lower than that of the other wires and similar to the other twisted-wire retainers.
Conclusion: The CAD-CAM-FR wire is likely to have high corrosion resistance and flexibility due to its low hardness.

Keywords: corrosion resistance, hardness, orthodontic retainer, orthodontic wire, tensile strength

Introduction

Dental arch length and width decrease throughout life [1] and, in the long term, can affect the inter-canine width [2]. Therefore, maintaining the arch form and arch width after removing orthodontic appliances such as brackets is an important factor for long-term stability. Thick, round stainless-steel wires have been used for retention, because they are considered superior for the maintenance of the arch form. However, thick wires allow less physiological tooth mobility/movement so that external force is directly transmitted to the adhesive that fixes the wires to the tooth, and thus may result in a higher risk of bond failure. In addition, these wires are somewhat uncomfortable for patients [3]. First introduced by Zachrisson in 1977 [4], thin-wire multistranded fixed retainers (FRs) that bond lingually to all anterior teeth were widely used in orthodontic practice and were the gold standard for maintaining the stability of anterior tooth alignment after treatment [4-6]. However, advances in material science and computer technology have made it possible to develop new types of FRs that may be more effective.

Recently developed computer-aided design and computer-aided manufacturing (CAD-CAM) nickel (Ni) titanium (Ti) FRs claim to deliver the utmost accuracy with great interproximal adjustment. This means that CAD-CAM technology can fit the Ni-Ti wire, which cannot be bent because of its superelastic properties, on the tooth surface. This may cause less tongue irritation and have better stability as they cannot create occlusal interference [7]. CAD-CAM-FR wires are reported to have high flexibility, which permits physiological tooth movement and may reduce the failure rate [7]. CAD-CAM-FR wires are biocompatible in terms of periodontal health, as they are resistant to microbial colonisation and plaque formation [8,9]; moreover, biomechanical properties of their superior elasticity and dimensional stability are maintained during the production process [10]. However, besides biomechanical properties obtained from bending tests, the strength of retainer wires should also be evaluated. It has been shown that early retainer failures are mainly due to bond failure, and late retainer failures are mainly due to wire fracture/breakage [11]. Aside from facilitating periodontal health by minimizing microbial colonisation and plaque formation, resistance to corrosion involving the elemental composition of the wire should also be evaluated, as the oral environment is often acidic, and the FRs are generally kept for a very long time.

Thus, the elemental composition, corrosion resistance, and mechanical properties of CAD-CAM retainers versus conventional FRs were evaluated in this study to validate the use of CAD-CAM-FR wire in terms of mechanical properties and biocompatibility.

Materials and Methods

Study materials

The retainer wires used included the following: namely, FR wires (WT; Wildcat, GAC International, Bohemia, NY, USA), (PT; Penta-one, Masel, Carlsbad, CA, USA), (GT; Penta twist retainer wires, Gold’n Braces, Lake St. Louis, MO, USA), (TT; Twistflex retainer wire, 3MUnitek, Bracknell, UK), (OC; Ortho FlexTech, Reliance Orthodontic Products, Itasca, IL, USA), (MS; Memotain, CA Digital, Hilden, Germany), (GR; Round retainer wires, Gold’n Braces), and (BR; Blue Elgiloy, Rockey Mountain Orthodontics Europe, Strasbourg, France, [control]) (Table 1). The sample size was determined prior to the experiment using statistical software (GPower ver. 3.1, Kiel University, Kiel, Germany), factoring in a power of 80% and a confidence interval of 95%, and referring to previous reports that used similar experimental methods [12].

Sample preparation

Before the samples were used for HV0.3 hardness measurements and energy-dispersive X-ray spectroscopy (EDS) analyses, the retainers were cut to suitable lengths for embedding in epoxy resin samples that had a diameter of 25 mm. Thereafter, the retainers were ground up to a #4000 using silicon carbide paper (SiC foil, Struers, Ballerup, Denmark). For tensile testing, retainers were cut to lengths to fit into the holders on the tensile machine, which were spaced at 17.5 mm apart. For the static immersion corrosion test, the retainers were cut to give a total surface area of 5 cm^2 such that they fitted into 15-mL polypropylene (PP) tubes.

Energy-dispersive X-ray qualitative analysis

The elemental composition was measured using energy-dispersive X-ray spectroscopy (EDS), analysed with ESPRIT compact software, as part of the SEM system (TM4000Plus, Hitachi, Tokyo, Japan). Some possible

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Table 1 Retainer wires used in this study

Wire group	Brand name	Wire size according to manufacturer	Type of retainer	Manufacturer
WT	WildCat	0.381 mm (0.015 in)	strand-twisted, stainless steel	GAC
PT	Penta-One	0.546 mm (0.0215 in)	twisted coaxial, stainless steel	Masel Orthodontics
GT	Penta twist retainer wire	0.546 mm (0.0215 in)	strand-twisted, gold-plated stainless steel	Gold'n Braces
TT	Twistflex retainer wire	0.813 mm (0.032 in)	strand-twisted, stainless steel	3M Unitek
OC	Ortho FlexTech	0.973 × 0.401 mm (0.0383 × 0.0158 in)	interlocking chain, stainless steel	Reliance Orthodontic Products
MS	Memotain	0.406 × 0.406 mm (0.016 × 0.016 in)	square solid(CADCAM), NiTi alloy	CA-Digital
GR	Round retainer wire	0.762 mm (0.030 in)	round solid, gold-plated stainless steel	Gold'n Braces
BR	Blue Elgiloy	0.762 mm (0.030 in)	round solid, cobalt-base alloy	Rocky Mountain Orthodontics

WT: Wildcat twisted wire; PT: Penta-one twisted wire; GT: Penta twist gold plated wire; TT: Twistflex twisted wire; OC: Ortho FlexTech chained wire; MS: Memotain square wire; GR: Round gold-plated round wire; BR: Blue Elgiloy round wire

Table 2 Elemental composition (wt%) in each wire group by EDS

Wire group	Fe	Cr	Ni	Co	Mn	Mo	Au	Ti	Al	Si
WT	72	18	7	-	1	0	-	0	2	0.5
PT	71	19	9	-	1	-	-	-	-	0.7
GT Layer	7	2.5	0	-	0	-	90	-	-	0
Matrix	70	17	9	-	1	-	3	-	-	-
TT	70	20	8	-	2	0.2	-	-	-	0.8
OC	70	18	10	-	1	1	-	-	-	0.8
MS	-	-	49	-	-	-	-	50	-	0.4
GR Layer	20	7	0	-	-	-	73	-	-	0
Matrix	72	20	8	-	-	-	0	-	-	1
BR	17	21	16	40	2	4	-	-	-	1

WT: Wildcat twisted wire; PT: Penta-one twisted wire; GT: Penta twist gold plated wire; TT: Twistflex twisted wire; OC: Ortho FlexTech chained wire; MS: Memotain square wire; GR: Round gold-plated round wire; BR: Blue Elgiloy round wire

elements, commonly used in alloys, were expected to be found (within the detection range of EDS): silver (Ag), aluminum (Al), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), niobium (Nb), nickel (Ni), rhodium (Rh), silicon (Si), Ti, and vanadium (V). Results are specified as a weighted percentage (wt%).

Static corrosion test

The standardized method for corrosion testing was applied, as described in ISO 22674:2022 [13]. ISO 10271:2020 [14] was followed, however, with some small adjustments. The retainers were immersed in a corrosion solution. According to ISO 10271, the samples should be immersed in a solution of 0.1 mol/L lactic acid ($C_3H_6O_3$) 90% and 0.1 mol/L sodium chloride (NaCl), with 1 mL solution per 1 cm^2 of sample surface. The pH should be 2.3 ± 0.1. A solution amount of 5 mL was used per retainer with a surface area of 5 cm^2. The retainers were cut to fit the test tubes. The ends of each retainer were sealed with nail polish to prevent leakage; notably, the ends are usually sealed with composite in the patient's mouth.

Eight retainer types were tested, and three sets of each were treated in an identical fashion. The retainers were kept in the solution at 37 ± 1°C for a period of 7 days, according to ISO 10271 [14]. In addition, a reference solution was made and treated identically.

The solutions from the immersion tests were sealed in PP containers and sent for analysis by inductively coupled plasma optical emission spectroscopy (ICP-OES) to detect free ions in the solution; the analysis was carried out by Sheffield Analytical Services Limited (Sheffield, UK). The results are specified in micrograms per milliliter (µg/mL).

Mechanical properties

The Vickers hardness (HV0.3) test was performed with a hardness testing machine (Duramin-40 A1 testing machine, Struers, Champigny sur Marne, France) using the Vickers method, with a load of 2.94 N (0.3 kgf). For the tensile-force measurements, six specimens in each group were tested. One measurement per specimen was recorded. The tests were performed in a universal testing machine (BZ1-MM11210.IN01, ZwickRoell, Ulm, Germany; capacity: 10 kN) at a rate of 1 mm/min, until the specimen fractured. Each retainer was clamped into two holders; the width of the tension part of the retainer was identical to the distance between the holders. The retainers were pulled until fractured. In addition, the ultimate tensile strength was calculated by dividing the ultimate tensile force by the cross-sectional area of the wire, the thickness of which was measured using a slide calliper.

Statistical analysis

Data were analysed using statistical software, based on R and R Commander (EZR on R Commander, ver.1.61; Jichi Medical University, Saitama, Japan) [15]. Normal distribution was confirmed (using the Kolmogorov-Smirnov test) and homogeneity of variance (using Bartlett's test). As a result, a parametric method that assumes heterogeneity of variance was selected. Vickers hardness, tensile force, and tensile strength data for each group were subjected to the Welch *t*-test with Bonferroni correction, which adjusted the level of significance from 0.05 to 0.00178, to enable multiple comparisons.

Results

Elemental composition

All of the retainers, except for MS, contained Cr, Mn, Fe, and Ni. In addition, BR contained Co; MS contained Ni (49 wt%) and Ti only; the gold (Au)-plated retainers GT and GR contained Fe and Cr in the matrix and Au mainly in the outer layer; Ni was present in all wires; Fe and Cr were the main elements in all other retainer wires apart from BR and MS; and in all stainless-steel wires (WT, PT, GT, TT, OC, and GR), 18 wt% Cr and 8 wt% Ni were detected (Table 2).

Corrosion resistance

The results of the ICP analyses of lactic acid test solutions, with a pH of 2.3, are shown in Table 3. The values for each element are given in µg/cm^2 per 7 days. None of the retainers had a leakage exceeding 200 µg/cm^2, which is set as a limit in ISO 22674:2022 [13]. The Au-plated retainer wires had the highest total ion leakage, together with WT. GT had three times higher leakage than GR (68.8 vs. 20.3 µg/cm^2), while PT and BR had 0.3 and 0.4 µg/cm^2, respectively. By contrast, the CAD-CAM NiTi FR wire (MS) that contained more Ni than the other wires had no measurable leakage.

Mechanical properties

The HV values of the retainers ranged from 632 HV0.3 (WT) to 317 HV0.3 (MS) (Table 4). The remaining retainers had values between 400 and 600 HV0.3. Strand-twisted wires (WT, PT, GT, and TT) had larger HV values than the other wires (OC, MS, GR, and BR). The mean HV values of OC and MS were the smallest, and the results were significant (Fig. 1). The solid wires (GR and BR) had significantly higher tensile force than the other wires, whereas OC and MS had the lowest tensile force (Table 4, Fig. 2).

No statistically significant differences were detected in tensile strength between WT, PT, GT, MS, and TT (Table 4, Fig. 3). Solid wires, GR, and BR had approximately twice the tensile strength values as the twisted ones and MS. The tensile strength of OC was the lowest among all wires.

Discussion

Although retention procedures differ from country to country, interest in retention procedures is increasing and a trend toward more fixed retention has been demonstrated [16]. Bonded retainers alone are most commonly used in the mandible, and bonded retainers in combination with removable retainers are most commonly used in the maxilla in Norway [17]. Regarding retainer-wire selection in this study, all investigated retainer wires are available and are reportedly used to different degrees by Norwegian

Table 3 Leakage of ions (μg/cm²) detected by ICP-OES in each wire group

Wire group	Au	Co	Cr	Mo	Mn	Fe	Nb	Ti	Dy	Cd	Ni	Be	Pb	Total
WT	<1	<1	4	<1	<1	28.5	<1		<1	<1	2.6	<1	<1	35.1
PT	<1	<1	<1	<1	<1	0.3	<1		<1	<1	<1	<1	<1	0.3
GT	<1	<1	10.8	<1	0.4	52.2	<1		<1	<1	5.4	<1	<1	68.8
TT	<1	<1	1.9	<1	<1	12.1	<1		<1	<1	1.1	<1	<1	15.1
OC	<1	<1	<1	<1	<1	6	<1		<1	<1	0.4	<1	<1	6.4
MS								<1		<1	<1	<1	<1	<1
GR	<1	<1	3.7	<1	<1	15.4	<1		<1	<1	1.2	<1	<1	20.3
BR	-	0.2	<0.1	<0.1	<0.1	0.2	-		-	<0.1	<0.1	<0.1	<0.1	0.4

WT: Wildcat twisted wire; PT: Penta-one twisted wire; GT: Penta twist gold plated wire; TT: Twistflex twisted wire; OC: Ortho FlexTech chained wire; MS: Memotain square wire; GR: Round gold-plated round wire; BR: Blue Elgiloy round wire

Table 4 Vickers hardness (HV0.3), tensile force (N), and tensile strength (MPa) in each wire

Wire group	HV0.3		Tensile force		Tensile strength	
WT	631.5	(8.1)	111.6	(10.7)	985.8	(95.1)
PT	530.5	(12.1)	164.7	(19.7)	723.5	(81.9)
GT	506.3	(8.6)	151.3	(11.9)	660.3	(50.9)
TT	583.9	(8.9)	451.0	(73.9)	875.7	(145.1)
OC	338.8	(29.2)	68.4	(2.5)	207.0	(7.9)
MS	317.3	(6.6)	109.1	(21.0)	720.4	(53.1)
GR	441.2	(6.3)	685.4	(10.3)	1510.0	(21.0)
BR	424.8	(23.7)	778.2	(3.5)	1535.0	(22.9)

Values are given as mean (standard deviation) all in HV0.3, force, and strength.
WT: Wildcat twisted wire; PT: Penta-one twisted wire; GT: Penta twist gold plated wire; TT: Twistflex twisted wire; OC: Ortho FlexTech chained wire; MS: Memotain square wire; GR: Round gold-plated round wire; BR: Blue Elgiloy round wire

orthodontists, the latest being the CAD-CAM retainer.

The CAD-CAM-FR wire may have high biocompatibility due to unmeasurable ion leakage; additionally, the wire showed comparatively low hardness and low tensile strength. Fixed bonded retainers are used to maintain alignment stability after treatment; however, at the same time, they should allow normal physiologic tooth mobility to prevent bonding failure. They should also be able to withstand occlusal forces and have properties sufficient to avoid permanent deformation and fracture. The retainer wire that has been suggested to be optimal for retention is a multi-stranded wire with elastic properties that allow slight mobility of individual teeth [3]. Ni-Ti wire has superior elasticity [18] and a lower elastic modulus than stainless steel and Co-Cr wires [19]. Ni-Ti alloy has superior elastic properties, and the wires cannot be bent. Nevertheless, with CAD-CAM technology and cut processing, MS wire can be perfectly fitted to the tooth surface [20,21]. The tensile force of the MS in this study was among the lowest and similar to that of the other twisted retainer wires. When converted into tensile strength, the MS and the other twisted-wire retainers behaved in a similar manner and exhibited similar properties.

The amount of ion leakage is indicative of a wire's biocompatibility. ISO 10271 [14] provides standard corrosion-test methods for metallic materials. Ion leakage was greater from the Au-plated wires than from the other wire types, contrary to the expectation that the Au layer would be protective and decrease ion leakage; the plating treatment may have led to "pitting corrosion" and this, in turn, may have reduced leakage resistance. MS, on the other hand, had the least ion leakage; this may have been attributable to high corrosion resistance due to higher ion transfer resistance to the Ti alloy, the surface of which has an oxide film layer [22]. According to ISO 22674 for metallic materials in fixed and removable restorative materials [13], the material integrity of corrosion resistance should not exceed 200 μg/cm². Despite leakage being observed from the Au-plated wires, the amount did not exceed the limit set by the study guidelines. However, wire with as little ion leakage as possible should be used for patients with metal allergies.

The Vickers hardness of Ni-Ti is generally known to be 290-440 HV, and the tensile strength is reported to be around 600 MPa [23]. The hardness of other metals is reported to be 600 HV for stainless steel [24] and 440 HV for Co-Cr [24], and the tensile strength is known to be 1850 MPa for stainless steel [25] and 1450 MPa for cobalt chromium [25]. Therefore,

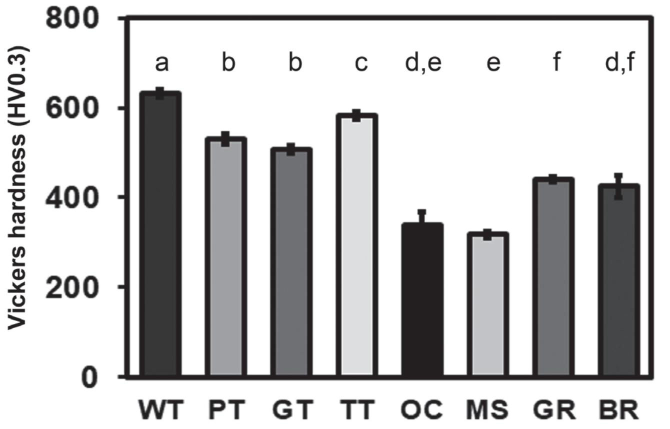

Fig. 1 Hardness according to Vickers hardness (HV0.3). Different lowercase letters above the bars indicate a significant difference ($P < 0.00178$). The hardness was higher for the twisted wires (WT, PT, GT, and TT) compared to the other wire types (OC, GR, BR, and MS).
WT: Wildcat twisted wire; PT: Penta-one twisted wire; GT: Penta twist gold plated wire; TT: Twistflex twisted wire; OC: Ortho FlexTech chained wire; MS: Memotain square wire; GR: Round gold-plated wire; BR: Blue Elgiloy round wire.

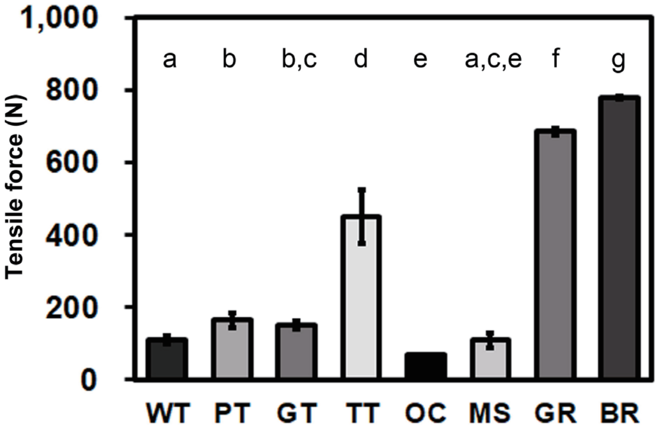

Fig. 2 Maximum tensile force. Different lowercase letters above the bars indicate a significant difference ($P < 0.00178$). The tensile forces of OC and MS were the smallest among the wires.
WT: Wildcat twisted wire; PT: Penta-one twisted wire; GT: Penta twist gold plated wire; TT: Twistflex twisted wire; OC: Ortho FlexTech chained wire; MS: Memotain square wire; GR: Round gold-plated wire; BR: Blue Elgiloy round wire.

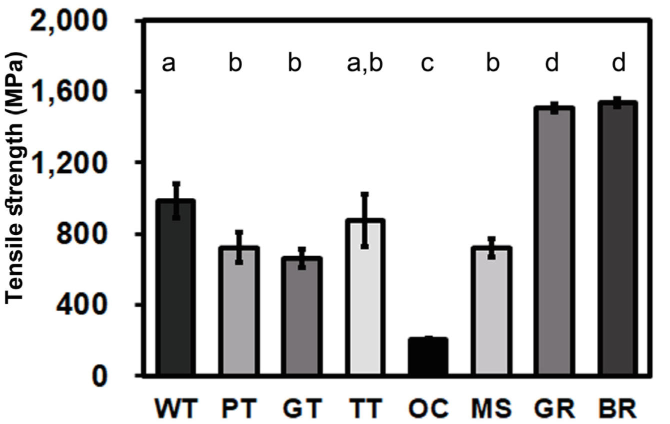

Fig. 3 Tensile strength. Different lowercase letters above the bars indicate a significant difference ($P < 0.00178$). The tensile strength of MS was similar to that of twisted wires (PT, GT, and TT).
WT: Wildcat twisted wire; PT: Penta-one twisted wire; GT: Penta twist gold plated wire; TT: Twistflex twisted wire; OC: Ortho FlexTech chained wire; MS: Memotain square wire; GR: Round gold-plated round wire; BR: Blue Elgiloy round wire.

it was confirmed that the hardness and tensile strength of the material in this study were similar to those in the previous reports.

Regarding the comparison of the hardness among retainer wires, the twisted-strand retainers tended to have higher Vickers hardness than the other wires. BR made of Co-Cr alloy and MS made of Ni-Ti alloy had lower hardness values than wires made of stainless steel. On the other hand, wire shape affected tensile strength, and the twisted-strand wires were weaker than the solid wires. However, this study demonstrated that WT, PT, GT, and MS did not significantly differ from TT. Therefore, although increased wire size is preferable for MS to obtain greater mechanical strength, such as that exhibited by GR and BR, it may not be clinically relevant due to greater discomfort. However, the clinical significance of the present results is that MS is found to have high corrosion resistance and flexibility due to its low hardness. Therefore, CAD-CAM FR (MS) can flexibly resist the force due to tooth displacement and has high anti-ion release properties.

This study had some limitations. The wires used were those commonly used in Norway, however, wires are commercially available in a variety of shapes and thicknesses. In addition, although the experiment was based on ISO standards, the results pertaining to the corrosion tests might have differed if the study had been conducted in an actual oral environment.

Conflict of interest

The authors declare that they have no conflicts of interest.

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