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Structure, Composition, and Mechanical Properties of Australian Orthodontic Wires

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Original Article

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ABSTRACT

Objective: To investigate the surface morphology, structure, elemental composition, and key mechanical properties of various sizes and tempers of Australian wires.

Materials and Methods: Three types of Australian wire were used: 0.016″ regular, 0.018″ regular+, and 0.018″ special+ (A.J. Wilcock, Whittlesea, Victoria, Australia). Each type of wire was subjected to scanning electron microscopy (SEM) analysis, x-ray energy dispersive spectroscopy (EDS) investigation, Vickers hardness testing, and tensile testing. The modulus of elasticity and ultimate tensile strength were determined. Hardness, modulus, and strength data were analyzed with one-way analysis of variance (ANOVA) and Tukey testing at the .05 level of significance.

Results: All three types of Australian wire were found to possess considerably rough surfaces with striations, irregularities, and excessive porosity. All three wire types had high levels of carbon and a similar hardness, which ranged within 600 VHN (Vickers hardness number), and a similar modulus of elasticity (173 to 177 GPa). The 0.018″ special+ had a significantly lower tensile strength (1632 MPa) than the 0.016″ regular and the 0.018″ regular+ wire (2100 MPa).

Conclusions: Australian wires did not show variation implied by the size or temper of the wires. (*Angle Orthod.* 2009;79:97–101.)

KEY WORDS: Australian wire; Stainless steel; SEM; EDS; Hardness; Modulus of elasticity

INTRODUCTION

Although Australian wire, a distinctive type of steel used in various techniques and treatment philosophies, has been included in the orthodontic armamentarium for quite some time, a review of the published literature reveals a lack of information on fundamental physical and mechanical properties. Investigation of key physical and mechanical properties of wires may provide a basis for their intraoral performance and may assist the clinician in selecting optimum handling and application in mechanotherapeutical configurations.

Historically, Australian wire was developed by Begg, the father of the Begg technique, and Wilcock. Begg was seeking a light, flexible, stainless steel wire with high resiliency and toughness to use in his newly developed Begg technique.[1,2]

Australian wire is available in sizes ranging from 0.012″ to 0.024″ round wire and as regular, regular+, special, special+, premium, premium+, and supreme grades.[3] The wires are graded according to their resiliency, with resiliency increasing from regular to supreme.[4] Regular and regular+ Australian wire is often used in situations that require significant bending or loop forming of the arch wire. Special and special+ wires are stronger and are not suitable for bending. These wires are often used in the treatment of deep

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bites because of their increased resistance to permanent deformation. The remaining grades are very resilient but are not appropriate for situations that require that sharps bends be placed in the archwire, because of their brittle nature. These high resiliency grades are often used as auxiliaries.[3]

A significant body of literature[4–8] has addressed the study of the mechanical and structural properties of traditional stainless steel orthodontic wire. These wires were the first to be adopted in the treatment of malocclusions following Angle's gold archwires, and their long-lasting application has led to numerous research efforts to characterize the mechanical properties of various sizes and tempers. Therefore, to provide a meaningful discussion of the properties of Australian wires, and in light of the scarcity of evidence in the field, this paper will use values of standard stainless steel properties to provide a comparison with corresponding data on Australian wires. This will assist the clinician in determining the appropriateness of wire for specific applications, such as leveling, aligning, and/or sliding mechanics among others.

The purpose of this study was to investigate selected physical and mechanical properties of Australian wire and to correlate the evidence derived from this investigation with the temper and size of wires.

MATERIALS AND METHODS

Three types of Australian wire were analyzed in this study: 0.016″ regular, 0.018″ regular+, and 0.018″ special+—all from the same manufacturer (A.J. Wilcock, Whittlesea, Victoria, Australia). Ten specimens 120 mm long of each type were prepared; long specimens were chosen to minimize stress incorporation in the central part of the specimen, which was the area of analysis. These segments were carefully handled as they were uncoiled from the spools and were subjected to the following tests.

Morphology, Structure, and Composition

The surface morphology and elemental composition of materials tested were determined by scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) analysis. A scanning electron microscope (Quanta 200; FEI, Hilsboro, Ore) coupled with an EDS unit (Sapphire CDU; EDAX, Mahwah, NJ) equipped with a super–ultra thin Be window was used in the study. Spectra were obtained under the following conditions: 5.1×10^{-6} Pa vacuum, 25 kV accelerating voltage, 100 μA beam current, 500× original magnification with a 0.26 × 0.26 mm sampling window, 100 second acquisition time, and 30% to 40% dead time. Quantitative analysis of the %wt concentration of probed elements was performed via nonstandard analysis and ZAF correction, with the use of Genesis 5.1 software (EDAX).

Vickers Hardness

Five wire specimens of each type were embedded in epoxy resin at a direction perpendicular to their longitudinal axes. Specimens were ground with 220 to 2000 grit size SiC papers under water cooling, were polished up to 0.05 μm with alumina suspensions (Bueler, Lake Bluff, Ill) in a grinding/polishing machine (Ecomet II; Bueler), and were cleaned in an ultrasonic water bath for 5 minutes. The Vickers hardness (HV) of wires was assessed by using a microhardness tester (HMV-2000; Shimadzu, Tokyo, Japan) under a 500 g load and testing time of 15 seconds.

Tensile Testing

Tensile testing until fracture of the wires was conducted with a universal tensile testing machine (Monsato; Tensometer 10, Weltshie, UK). The tensile testing was performed with a gauge length of 90 mm and a crosshead speed of 0.5 mm/min. From each stress-strain curve, the modulus of elasticity and ultimate tensile strength were calculated.

Statistical Analysis

Results of quantitative measurements (ie, hardness, modulus, and ultimate tensile strength) were statistically analyzed through one-way analysis of variance (ANOVA), with wire type serving as a predictor. Additional group differences were investigated with Tukey HSD (honestly significant difference) testing at the .05 level.

RESULTS

The topography of the wires showed rough surfaces with characteristic striations derived from the drawing process, along with excessive porosity and irregularities. Figure 1a depicts the surface of a 0.016″ regular wire, which demonstrates reduced porosity and surface irregularities relative to the other two types. Figure 1b shows a 0.018″ regular+ wire with the surface revealing increased roughness and porosity. In Figure 1c, the microscopic appearance of a 0.018″ special+ wire is shown, indicating a rough surface and an abundance of irregularities.

The elemental composition of the wires (Figures 2a through 2c) indicates higher carbon content for all wire specimens (quantitative data not shown), whereas different tempers did not show variation in the composition of alloys.

Table 1 shows the statistical analysis of the Vickers hardness testing results. No difference was found with

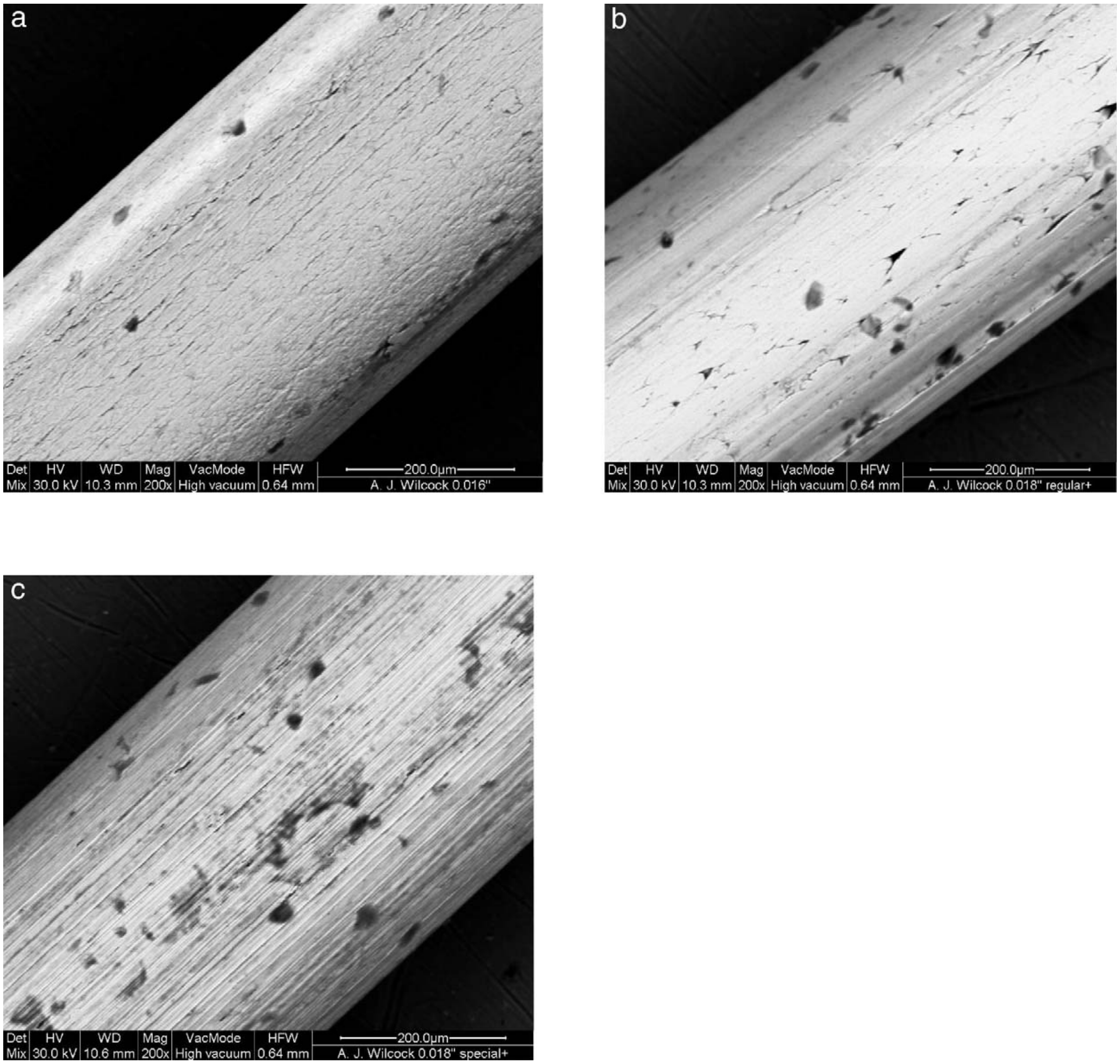

Figure 1. Representative secondary electron image of (a) 0.016″ regular, (b) 0.018″ regular+, and (c) 0.018″ special+ wires (Original magnification ×200).

respect to hardness, which ranged in the order of 660 HV_{500} for all wire types.

In Table 2, results of the modulus of elasticity of wire specimens are demonstrated. No effect of wire size or temper on the modulus of wire was observed, whereas this variable was found to range around 170 GPa for all three wire types.

Results of the ultimate tensile strength of specimens are shown in Table 3. A statistically significant reduction is indicated for the 0.018″ special+ wire, and the other groups showed values on the order of 2100 MPa.

DISCUSSION

A search of the orthodontic literature yielded only a handful of studies pertinent to the analysis of surface characteristics, elemental composition, and mechanical properties of conventional stainless steel orthodontic wires. Moreover, very little information has been presented on Australian orthodontic wires. Meanwhile, the introduction of different sizes and tempers makes application of the full range of these wires a highly empirical task, with notable lack of justification of specific selection. The clinical question behind the present investigation relates to the extent of differentiation of wire properties with regard to temper or size.

All wire specimens were found to possess rough and irregular surfaces, along with excessive porosity. Surface inspection of the images showed that irregularity and porosity increased with higher grades of the Australian wire. Previous studies[9–12] on Australian wires also found increased roughness, along with nu-

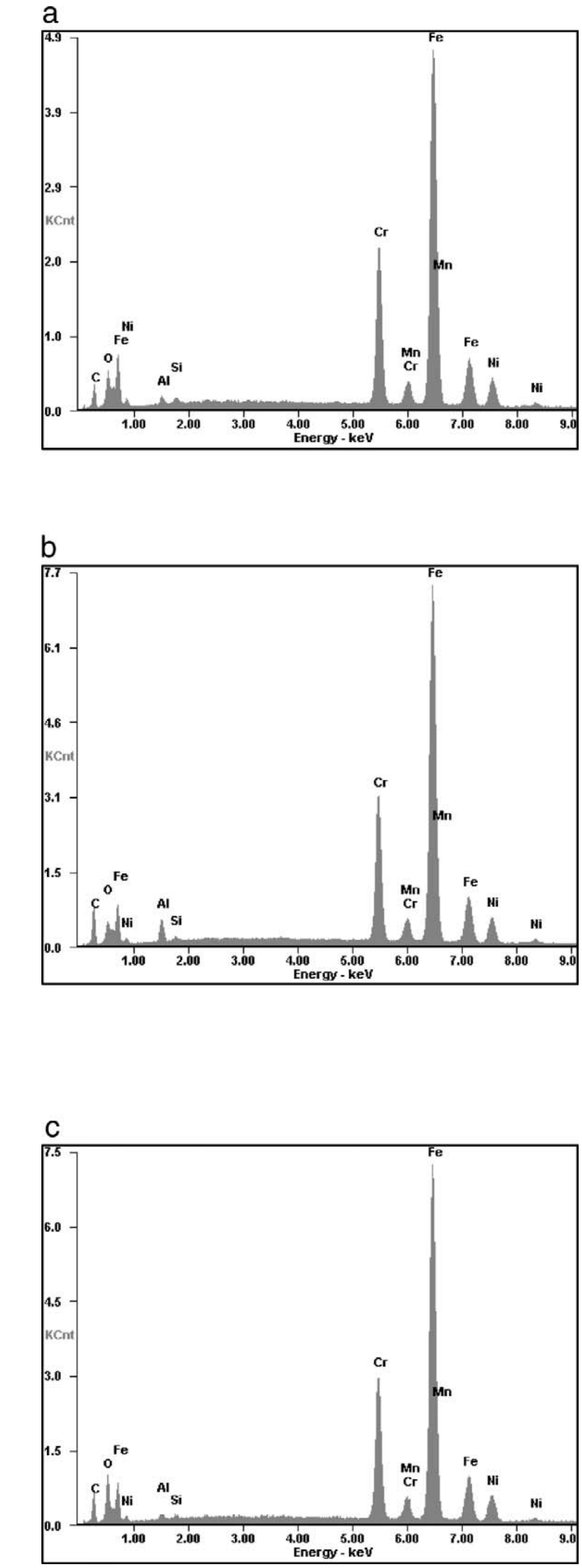

Figure 2. Energy dispersive spectroscopy (EDS) spectra of (a) 0.016″ regular, (b) 0.018″ regular+, and (c) 0.018″ special+ wires.

Table 1. Vickers Hardness of Australian Wires Included in the Study

Wire	VHN_{500} Mean (SD)[a]	Tukey Grouping*
.016″ Regular	644 (31)	A
.018″ Regular+	640 (36)	A
.018″ Special+	664 (24)	A

[a] SD indicates standard deviation; VHN_{500}, Vickers hardness number.

* Means with the same letters are not statistically different at the .05 level.

Table 2. Modulus of Elasticity of the Australian Wires Included in the Study (GPa)

Wire	Mean, GPa (SD)[a]	Tukey Grouping*
.016″ Regular	173 (4)	A
.018″ Regular+	173 (5)	A
.018″ Special+	177 (9)	A

[a] GPa indicates modulus of elasticity; SD, standard deviation.

* Means with the same letters are not statistically different at the .05 level.

Table 3. Ultimate Tensile Strength of the Wires Included in the Study (MPa)[a]

Wire	Mean, MPa (SD)[a]	Tukey Grouping*
.016″ Regular	2194 (79)	A
.018″ Regular+	2123 (68)	A
.018″ Special+	1682 (166)	B

[a] MPa indicates tensile strength; SD, standard deviation.

* Means with the same letters are not statistically different at the .05 level.

merous impurities plugged on the surface.[11] These authors reported a striated appearance, most probably attributed to the drawing process that occurs during manufacture of the wire.

Almost all orthodontic stainless steel wires are from the type 300 series, which implies that chromium contents account for 17% to 25%, and nickel 8% to 12%.[4–8] These traditional stainless steel wires are often manufactured to an 18/8 composition, which indicates around 18% chromium and 8% nickel.[5] This composition allows a chromium oxide layer to form and the alloy to remain in the austenite form, which leads to better corrosion resistance.[4] The carbon content is intentionally kept at below 0.20% to reduce the formation of chromium carbides, which can lead to corrosion of the austenitic form of stainless steel.[4] A study of Australian and stainless steel wires[11] found that A.J. Wilcock Australian wires were of the 18/8 stainless steel type but made no note of the carbon content. Therefore, it could be assumed that the carbon content was within the 0.20% range of traditional stainless steel wires. Semiquantitative elemental analysis of Australian wires as reported in the present investigation indicates that the carbon content is well above the values reported for typical 18/8 stainless steel wire. Although EDS cannot be used to quantify light elements such as carbon, and thus the results should not be used on an absolute basis, data from this analysis reveal carbon content that is almost 10 times higher than the standard value. This increased carbon content could account for the rough, irregular, and excessively porous surfaces noted in our SEM images of the wires. This may account for the impurities noted on the surfaces of Australian wires in previous studies and may explain the propensity for higher grades of Australian wires to not accept bends clinically.[1,3]

Hardness of stainless steel wires[9] has been shown to vary within the 235 to 300 range. However, others have reported values within the order of magnitude found in this study, which are much higher.[13] Tempering of high carbon alloys is associated with increasing hardness caused by clustering of carbon atoms and precipitation of carbides.[14] Thus, higher hardness values could be attributed to increased carbon content in the Australian wire, along with the manufacturing process. In addition, this increased hardness may cause Australian wire to be more brittle than traditional stainless steel wire and consequently may adversely affect the ability of the wire to withstand bending. The increased hardness of Australian wire may also adversely affect orthodontic mechanics, specifically, sliding mechanics. The Vickers hardness value (VHN) for commonly used titanium brackets ranged from 165 in the base to 372 in the tie wings.[15] The large difference in hardness between Australian wire and titanium brackets may cause the wire to bind and not slide as well through the bracket slot as stainless steel wire, which has VHN numbers that are more comparable with bracket VHN numbers.

With respect to mechanical properties, previous investigations of both round[6,7] and rectangular stainless steel wire[9,10] found that the range of modulus of elasticity and ultimate tensile strength did not differ significantly. Stainless steel wire presented modulus around 170 GPa in one study[10] and from 160 to 180 GPa in another,[5] whereas the ultimate tensile strength reported was 2100 MPa.[10] The modulus of elasticity and ultimate tensile strength testing on Australian wire performed in this study yielded results consistent with those of traditional stainless steel wire, except for the ultimate tensile strength of 0.018″ special+ Australian wire, which was found to be significantly less than values for the 0.016″ regular and 0.018″ regular+ Australian wires. It is interesting to note that this wire presented the roughest and most irregular surface among the three tested, and these features are probably related to this effect.

Porosity and rough surface may contribute to the tendency of higher grade wires to break during clinical bending. The higher carbon content may also contribute to the hardness of Australian wire. This increased hardness may lead to fracture during clinical bending and possibly to adverse affects during orthodontic mechanotherapy.

CONCLUSIONS

- The present investigation does not support an effect of temper or size on hardness and, most importantly, modulus of elasticity in Australian wires.
- Therefore, different tempers do not imply an elevation in specific properties; actually, some properties may be related to reduced strength.

REFERENCES

1. Begg PR, Kesling PC. *Begg Orthodontic Theory and Technique.* Philadelphia, Pa: WB Saunders; 1977:94–96.
2. Begg PR. Light arch wire technique. *Am J Orthod.* 1961;47: 30–48.
3. World Famous A.J. Wilcock Australian Wire, G&H Wire Company. Available at: http://www.ghwire.com/orstore/sa1.aspx. Accessed January 2, 2008.
4. Kusy RP. A review of contemporary archwires: their properties and characteristics. *Angle Orthod.* 1997;67:197–207.
5. Brantley WA. Orthodontic wires. In: Brantley WA, Eliades T, eds. *Orthodontic Materials: Scientific and Clinical Aspects.* Stuttgart, Germany: Thieme; 2001:78–103.
6. Khier SE, Brantley WA, Fournelle RA. Structure and mechanical properties of as-received and heat treated stainless steel orthodontic wires. *Am J Orthod Dentofacial Orthop.* 1988;93:206–212.
7. Asgharnia MK, Brantley WA. Comparison of bending and tension tests for orthodontic wires. *Am J Orthod.* 1986;89: 228–236.
8. Kusy RP. Orthodontic biomaterials: from the past to the present. *Angle Orthod.* 2002;72:501–512.
9. Verstrynge A, Humbeeck JV, Willems G. In-vitro evaluation of the material characteristics of stainless steel and beta-titanium orthodontic wires. *Am J Orthod Dentofacial Orthop.* 2006;130:460–470.
10. Krishnan V, Kumar KJ. Mechanical properties and surface characteristics of three archwire alloys. *Angle Orthod.* 2004; 74:825–831.
11. Acharya KA, Jayade VP. Metallurgic properties of stainless steel orthodontic archwires: a comparative study. *Trends Biomater Artif Organs.* 2005;18:125–136.
12. Birkenkamp S, Pancherz H. Comparison of three brands of round stainless steel wires used in the Begg and Tip-Edge techniques. *Aust Orthod J.* 2004;20:65–69.
13. Hunt NP, Cunningham SJ, Golden CG, Sherif M. An investigation into the effects of polishing on surface hardness and corrosion of orthodontic archwires. *Angle Orthod.* 1999;69: 433–440.
14. Reed-Hill RE, Abbaschian R. *Physical Metallurgy Principles.* Boston, Mass: PWS Publishing Company; 1994:664–670.
15. Zinelis S, Annousaki O, Eliades T, Makou M. Metallographic structure and hardness of titanium orthodontic brackets. *J Orofac Orthop.* 2003;64:426–433.