The effect of cross-sectional dimensional variations of square and rectangular chrome-cobalt archwires on torsion

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Chrome-cobalt and stainless steel archwires have similar mechanical properties within the elastic range,[1] but the advantage of chrome-cobalt is the special heat-treatment that it can be given. Chrome-cobalt wires are easy to bend in the soft condition, and through heat-treatment, become much stronger. The age-hardening temperature range is 260° to 650° C, with 482° C suggested for 7 to 12 minutes in an electric furnace.[1] Heat treatment increases the yield strength but decreases the ductility of chrome-cobalt wires. They have excellent corrosion resistance and are easily soldered. These properties have made chrome-cobalt popular as an orthodontic wire material. Originally offered by only one vendor, several suppliers can now be found. It is therefore of interest to evaluate the variations in cross-sectional dimensions and the mechanical properties of these wires when tested in torsion.

Orthodontic wires and brackets are generally sold without exact information about tolerances for height and width dimensions. Meling et al.[2] studied 40 different sizes and types of square and rectangular stainless steel wires commonly used in the .018 inch edgewise technique supplied by

Abstract

The purpose of this investigation was to study the control of cross-sectional dimensions and edge bevel by various manufacturers in the production of chrome-cobalt archwires and its effect on transmitting torque through an .018 inch slot bracket system. Twenty-seven different square and rectangular chrome-cobalt wires commonly used in the edgewise technique supplied by five different manufacturers were studied with respect to dimensions, edge bevel, and mechanical properties in torsion. The mechanical study simulated application of torque to an individual tooth. Standard brackets with .018 inch slot heights were used. The results show that variation in cross-sectional dimension and edge bevel leads to variable torsional play (third-order clearance). As an example, .016 × .016 wires have a mean torsional play of as much as 26.8 degrees, with a range of 21.0 to 32.3 degrees. When using .016 × .016 wires, one must apply from 34.8 to 48.6 degrees of twist to get 20 N-mm of torsional moment. This variation is primarily due to the rather wide range in torsional play. As a result, the prediction by which a predetermined torsional moment can be delivered becomes uncertain. The results also show that because the working range in torsion of chrome-cobalt wires is somewhat limited due to high torsional stiffness, precise delivery of torsional moment based on the condition present in the oral cavity is difficult. The torsional stiffness varies between manufacturers within the various dimensional groups as a result of differences in cross-sectional geometry and material properties.

Key Words

Orthodontic wires • Materials testing • Edge bevel • Torsional strength • Chrome-cobalt

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Table 1
Wires used in investigation

Producer	Type	Dimensions .016 × .016	.016 × .022	.018 × .025
Dentaurum	Remaloy soft	X	X	X
Forestadent	Forestaloy blue	X	X	X
Forestadent	Forestaloy yellow	X	X	X
GAC	Bioloy blue	X	X	X
GAC	Bioloy yellow	X	X	X
Masel	Masiloy blue	X	X	X
Masel	Masiloy yellow	X	X	X
RMO	Elgiloy blue	X	X	X
RMO	Elgiloy yellow	X	X	X

Values for dimensions are given in 1/1000"
For metric values, 0.016"= 0.4064 mm, 0.017"= 0.4318 mm
.018" = 0.4572 mm, .022" = 0.5588 mm and .025" = 0.6350 mm

five different manufacturers, and found that most wires were within ±0.0005 inches (±0.0127 mm).

With respect to edge bevel, no information is given by the manufacturers. It has been suggested by Sernetz[3] that edge bevel radius should be at least 0.04 mm (0.0016 inches) for patient comfort. An investigation by Meling et al.[2] demonstrated that the majority of the tested stainless steel wires had considerably more edge bevel than 0.04 mm and that edge bevel varied considerably.

Deviations from stated wire dimensions and edge bevel can strongly influence torsional play.[2,4,5] Using a novel formula that includes the effect of edge bevel on torsional play,[4] Meling et al.[2] published a table on the amount of rotational play based on mean measured wire size and edge bevel findings.

Deviations from stated wire dimensions and edge bevels also influence torsional stiffness.[5] Stiffness is represented by the slope of the load-deflection diagram or the moment per degree of twist delivered by the appliance. Low stiffness makes a lower rate of deactivation possible and allows greater ease and accuracy in applying a given moment.[6,7]

The purpose of this investigation was to study various square and rectangular chrome-cobalt wires supplied by several manufacturers as to their behavior in torsion as related to torsional play (third order clearance) and torsional stiffness.

Materials and methods

Square and rectangular chrome-cobalt wires commonly used in 0.018 inch edgewise technique were tested in an as-received condition. Five manufacturers supplied a total of 27 different wires (Table 1). The wires were supplied in straight lengths, 10 pieces of each. Some manufacturers supplied wires with the same dimension in various qualities. Three major suppliers from the United States and two from Germany were selected.

Five-centimeter lengths were cut from each wire. Heights and widths were measured to the nearest 1/1000 mm using a digital micrometer accurate to ±1μm (model 293-521, Mitutoyo Corp, Tokyo, Japan). Several readings were taken along each segment. The results are shown in Table 2.

The results from edge bevel measurements according to the method described by Meling et al.[2,5] are given in Table 2. Edge bevel was estimated from cross-sectional cuts from each specimen magnified 720× onto a monitor (Zeiss Axioscope, Hamamatsu CCD, combined with a Sony 14' Trinitron color screen). Using a clear acetate template with a series of quarter-circles where the radius varied in 1/100 mm increments, an estimate was made of the rounding of the corners. All four corners were measured and the mean was used in subsequent calculations. This method has been shown to have a low intra- and interindividual error.

The accuracy and precision to which the various manufacturers make their wires have been evaluated. The results are given in Tables 3 and 5.

Ten test pieces cut from separate lengths of each wire type were tested in a torque-measuring instrument with an interbracket distance of 4 mm. This instrument has been described previously[5,8] and is a further development of an apparatus reported earlier.[9,10] A regression line was fitted to the linear portion of the torsional moment versus angle of twist diagram using the least square method. The line's intercept with the abscissa represents the amount of torsional play between wire and bracket. The slope of the line represents torsional stiffness. A mean diagram for 10 test pieces was then estimated. The results are presented in Table 4, and the torque-twist diagrams for the various dimensions are shown in Figures 1, 2, and 3. As the diagrams of some wires were very close, only one wire diagram from each manufacturer is shown for each dimension.

The torsional play was also estimated using the formula given by Meling et al.[4,5] When applying

Table 2
Results of wire measurements

Wire producer and quality	Dimensions Height 1/100 mm	Dimensions Width 1/100 mm	Measured values Height 1/100 mm	Measured values Width 1/100 mm	Difference Height 1/100 mm	Difference Width 1/100 mm	Bevel Radius 1/100 mm
Dentaurum							
Remaloy soft	40.64	40.64	41.53 ±0.14	41.64 ±0.14	0.89	1.00	2.08 ±0.58
Remaloy soft	40.64	55.88	41.04 ±0.31	55.74 ±0.14	0.40	-0.14	4.88 ±0.53
Remaloy soft	45.72	63.50	45.44 ±0.05	63.91 ±0.09	-0.28	0.41	1.98 ±0.33
Forestadent							
Forestaloy blue	40.64	40.64	40.22±0.11	40.18 ±0.15	-0.42	-0.46	1.86 ±0.41
Forestaloy blue	40.64	55.88	40.25 ±0.17	55.21 ±0.21	-0.39	-0.67	2.52 ±0.73
Forestaloy blue	45.72	63.50	45.14 ±0.14	63.00 ±0.18	-0.58	-0.50	3.45 ±0.79
Forestaloy yellow	40.64	40.64	40.25 ±0.17	40.22 ±0.16	-0.39	-0.42	2.71 ±0.64
Forestaloy yellow	40.64	55.88	40.22 ±0.16	55.03 ±0.13	-0.42	-0.85	3.23 ±0.88
Forestaloy yellow	45.72	63.50	44.97 ±0.13	63.02 ±0.09	-0.75	-0.48	3.53 ±0.66
GAC							
Bioloy blue	40.64	40.64	40.86 ±0.07	40.81 ±0.07	0.22	0.17	4.88 ±0.46
Bioloy blue	40.64	55.88	40.72 ±0.10	56.18 ±0.13	0.08	0.30	4.19 ±0.34
Bioloy blue	45.72	63.50	45.38 ±0.10	63.85 ±0.20	-0.34	0.35	6.19 ±0.62
Bioloy yellow	40.64	40.64	40.62 ±0.21	40.69 ±0.18	0.20	0.05	5.03 ±0.32
Bioloy yellow	40.64	55.88	40.68 ±0.06	56.36 ±0.07	0.04	0.48	4.69 ±0.36
Bioloy yellow	45.72	63.50	45.33 ±0.05	63.60 ±0.00	-0.39	0.10	4.75 ±0.36
Masel							
Masiloy blue	40.64	40.64	40.18 ±0.16	40.20 ±0.12	-0.46	-0.44	9.03 ±0.20
Masiloy blue	40.64	55.88	40.61 ±0.37	55.80 ±0.55	-0.03	-0.08	3.30 ±1.11
Masiloy blue	45.72	63.50	45.15 ±0.17	62.90 ±0.08	-0.57	-0.60	3.66 ±0.54
Masiloy yellow	40.64	40.64	40.62 ±0.22	40.60 ±0.29	-0.02	-0.04	6.23 ±0.63
Masiloy yellow	40.64	55.88	40.82 ±0.23	55.50 ±0.42	0.18	-0.38	2.26 ±0.82
Masiloy yellow	45.72	63.50	45.25 ±0.11	63.42 ±0.08	-0.47	-0.08	3.64 ±0.52
RMO							
Elgiloy blue	40.64	40.64	40.14 ±0.43	40.46 ±0.52	-0.50	-0.18	2.37 ±0.36
Elgiloy blue	40.64	55.88	40.03 ±0.25	55.40 ±0.24	-0.61	-0.48	2.51 ±0.39
Elgiloy blue	45.72	63.50	45.34 ±0.45	63.51 ±0.31	-0.38	0.01	9.92 ±0.95
Elgiloy yellow	40.64	40.64	39.78 ±0.08	39.80 ±0.13	-0.86	-0.84	1.76 ±0.34
Elgiloy yellow	40.64	55.88	39.90 ±0.23	54.79 ±0.09	-0.74	-1.09	2.53 ±0.45
Elgiloy yellow	45.72	63.50	45.42 ±0.22	63.20 ±0.16	-0.30	-0.30	8.46 ±0.61

All measurements were made to the nearest 1/1000 mm. The values given are means with ±1 standard deviation. *Dimension* denotes the dimensions stated by the manufacturers. *Difference* refers to the difference between the stated and the measured dimensions. 0.4064 mm = 0.016", 0.4318 mm = 0.017", 0.4572 = 0.018", 0.5588 = 0.022", and 0.6350 = 0.025".

torque to a tooth, the torsional play that has to be negated will be the play from a central position to one extreme in two brackets. The first method will give this total torsional play, whereas the formula will give the amount of torsional play from a central position to one extreme in one bracket. The latter value has therefore been multiplied by two in Table 2.

The amount of torsional moment was measured through activation. To test whether the deactivation curve for chrome-cobalt wires would closely follow the activation curve until the departure from linearity, three different wire dimensions of Masel Masiloy yellow were tested (Masel, Bristol, Penn). Ten test pieces cut from separate lengths of each sample wire were subjected to loading and unloading.

Statistical analysis

Means and standard deviations were calculated where applicable. The method error was esti-

Table 3
Accuracy of producer

Producer	Height ± SD	Width ± SD	Bevel ± SD
Dentaurum	0.34 ± 0.52	0.42 ± 0.49	2.98 ± 1.44
Forestadent	-0.49 ± 0.20	-0.56 ± 0.21	2.88 ± 0.91
GAC	-0.07 ± 0.25	0.24 ± 0.20	4.95 ± 0.74
Masel	-0.23 ± 0.36	-0.27 ± 0.37	4.69 ± 2.39
RMO	-0.57 ± 0.35	-0.48 ± 0.47	4.59 ± 3.34

Accuracy denotes the mean difference between measured and stated value with respect to height, width, and edge bevel (in 1/100 mm). With respect to height, ANOVA and Scheffe tests demonstrated that, apart from Forestadent and RMO, all producers were significantly different from each other ($p<0.01$). With respect to wire width, no difference was noted between Forestadent and RMO ($p<0.01$), or between Dentaurum and GAC ($p<0.01$). The analysis of edge bevel measurements demonstrated that the producers were divided into two statistically significant different groups, with Forestadent and Dentaurum in one group and the other manufacturers in the other.

mated using double measurements and the Dahlberg formula.[11] System errors were tested using a paired *t*-test. ANOVA with Scheffé test was used to analyze differences between wires and manufacturers.

Results

The results from the wire measurements are given in Table 2 with standard deviations. *Difference* denotes the mean difference between stated and measured values for wire height and width. The stated and mean measured values differed significantly for the majority of the wires tested. However, all but two wires were within ±0.0005 inch (0.0127 mm) of the stated values with respect to height. One wire did not fulfill this requirement with respect to width.

Results from the analysis of accuracy with respect to wire height, width, and edge bevel are given in Table 3. *Accuracy* refers to the average deviation from the stated value. A Scheffé test demonstrated that, apart from RMO (RMO Inc, Denver, Colo) and Forestadent (Forestadent, Pforzheim, Germany), all producers were significantly different from each other with respect to height. No differences in width were noted between RMO and Forestadent, or between GAC (GAC, Central Islip, NY) and Dentaurum (Dentaurum, Pforzheim, Germany). ANOVA with Scheffé test demonstrated that the producers were divided into two statistically significant different groups with respect to edge bevel, with Forestadent and Dentaurum in one group and the other manufacturers in the other.

Table 4 presents the results from the torque experiments. The mean slope of the linear portion of the torque-twist diagram (torsional stiffness), the degree of twist at 20 N-mm of torsional force, the working range, the calculated torsional play, and the intercept (torsional play based upon the torque-twist diagrams) along with standard deviations are provided. Differences between calculated torsional play and intercepts are given.

The precision with which manufacturers make their wires was evaluated (Table 5). *Precision* refers to the standard deviation around the observed mean for each sample. To get a general impression of the precision, mean standard deviations for the stability of the wire height, width, edge bevel, torsional play and stiffness, as well as the degree of twist at 20 N-mm, were calculated for each manufacturer based upon the total variance. From a clinical point of view, the latter value may be considered the most important.

A summary of wire dimensions and torque measurements for the various dimensional groups of wires with their corresponding ranges is found in Table 6.

Torsional moment was measured through activation in this study, but has also been tested in unloading (unpublished results). The linear portion of the activation curve corresponded closely to the linear portion of the deactivation curve. The data and the torque-twist diagrams can therefore be used to evaluate the situation taking place in the delivery of torque. This is in accordance with the previous study on stainless steel wires.[5]

Torsional play was estimated in two different ways, and the differences between the two estimates of torsional play were subjected to a paired *t*-test. The mean difference between the two estimates for 270 wires was -0.16 degrees, which was not statistically significant ($p=0.09$).

Discussion

Wire cross-section

A wire's performance in torsion experiments depends on its composition and cross-sectional geometry. Furthermore, manufacturers differ in their ability to control accuracy and precision.[2,5] Generally, orthodontic wires have an edge bevel that significantly influences both the torsional play[2,5,12] and the polar moment of inertia. The latter is also affected by deviations in height and width from the stated, nominal values. Since the amount of torsional play between wire and bracket is dependent on the difference between

Table 4
Results of torque experiments

Wires	Wire quality	Torsional stiffness Nmm/degree	Angle of twist at 20 N-mm degrees	Working range degrees/Nmm	Calculated play([4]) degrees	Intercept degrees	Difference calc.-int. degrees
Dentaurum							
0.016 x 0.016	Remaloy Soft	1.43 ±0.11	34.80 ±0.50	6.91 ±0.47	19.56	20.99 ±0.79	-1.43
0.016 x 0.022	Remaloy Soft	2.81 ±0.30	23.41 ±0.40	3.42 ±0.36	16.61	16.58 ±0.38	0.03
0.018 x 0.025	Remaloy Soft	3.00 ±0.11	10.50 ±0.08	3.31 ±0.09	3.69	3.88 ±0.15	-0.19
Forestadent							
0.016 x 0.016	Forestaloy blue	1.20 ±0.11	41.08 ±0.74	8.28 ±0.74	25.45	24.52 ±1.09	0.93
0.016 x 0.022	Forestaloy blue	2.65 ±0.27	24.68 ±0.50	3.74 ±0.42	17.19	17.19 ±0.47	0.00
0.018 x 0.025	Forestaloy blue	2.43 ±0.12	11.96 ±0.23	3.91 ±0.18	4.58	4.14 ±0.23	0.44
0.016 x 0.016	Forestaloy yellow	1.20 ±0.08	41.60 ±0.46	8.20 ±0.48	26.74	25.20 ±0.72	1.54
0.016 x 0.022	Forestaloy yellow	2.52 ±0.29	25.60 ±0.47	4.03 ±0.45	17.86	17.54 ±0.57	0.32
0.018 x 0.025	Forestaloy yellow	2.44 ±0.11	12.17 ±0.36	3.94 ±0.20	4.95	4.28 ±0.18	0.67
GAC							
0.016 x 0.016	Bioloy blue	1.37 ±0.05	43.11 ±0.53	7.36 ±0.30	27.50	28.40 ±0.49	-0.90
0.016 x 0.022	Bioloy blue	2.75 ±0.09	24.19 ±0.12	3.59 ±0.10	16.78	17.02 ±0.23	-0.24
0.018 x 0.025	Bioloy blue	3.67 ±0.14	9.54 ±0.16	2.65 ±0.09	4.44	4.23 ±0.23	0.21
0.016 x 0.016	Bioloy yellow	1.45 ±0.07	42.77 ±0.33	6.97 ±0.32	29.20	28.82 ±0.75	0.38
0.016 x 0.022	Bioloy yellow	2.58 ±0.08	26.12 ±0.09	3.81 ±0.12	17.20	18.50 ±0.24	-1.30
0.018 x 0.025	Bioloy yellow	3.82 ±0.05	9.62 ±0.05	2.56 ±0.03	4.33	4.49 ±0.05	-0.16
Masel							
0.016 x 0.016	Masiloy blue	—	—	—	48.79	—	—
0.016 x 0.022	Masiloy blue	2.75 ±0.31	24.86 ±0.69	3.24 ±0.31	16.60	18.38 ±0.83	-1.78
0.018 x 0.025	Masiloy blue	3.80 ±0.21	10.58 ±0.33	2.59 ±0.13	4.60	5.40 ±0.25	-0.80
0.016 x 0.016	Masiloy yellow	1.27 ±0.25	48.55 ±1.37	8.12 ±1.83	32.46	32.31 ±2.64	0.15
0.016 x 0.022	Masiloy yellow	2.04 ±0.17	26.21 ±0.59	4.60 ±0.32	15.48	17.01 ±0.69	-1.53
0.018 x 0.025	Masiloy yellow	2.57 ±0.17	12.96 ±0.29	3.88 ±0.24	4.34	5.20 ±0.35	-0.86
RMO							
0.016 x 0.016	Elgiloy blue	1.26 ±0.27	42.08 ±1.97	8.18 ±1.47	26.41	25.72 ±1.44	0.69
0.016 x 0.022	Elgiloy blue	2.27 ±0.07	26.55 ±0.44	4.29 ±0.13	17.67	17.96 ±0.39	-0.29
0.018 x 0.025	Elgiloy blue	3.50 ±0.37	11.32 ±1.13	2.83 ±0.23	5.35	5.65 ±0.77	-0.30
0.016 x 0.016	Elgiloy yellow	1.15 ±0.05	45.20 ±0.29	8.55 ±0.24	27.44	28.11 ±0.63	-0.67
0.016 x 0.022	Elgiloy yellow	2.34 ±0.03	25.93 ±0.41	4.11 ±0.04	18.26	17.71 ±0.46	0.55
0.018 x 0.025	Elgiloy yellow	3.22 ±0.27	11.29 ±0.43	2.95 ±0.21	4.84	5.38 ±0.33	-0.54

The values given are means with ±1 standard deviation. *Calculated play* denotes the torsional play calculated using the formula developed by Meling et al.[4] Intercept denotes tosional play based on the abscissal intercept of a regression line fitted to the linear portion of the torsional stress/strain diagram. *Difference calc.-int.* refers to the difference between calculated torsional play and the measured actual intercept. Some values for Masel Masiloy blue .016 × .016 could not be calculated and are omitted.

slot height and wire dimensions as well as the degree of wire rounding,[4] a reduction in wire size results in poorer fit in the bracket slot and may lead to less control during tooth movement.

On average, the chrome-cobalt wires tested were thinner than their nominal values (Table 2). This contrasts with previous findings for stainless steel wires, where lighter wires were thicker than stated and heavier wires were thinner,[5] although the chrome-cobalt wires from Dentaurum demonstrated this pattern. Within a dimensional group, the chrome-cobalt wires were also thinner than their stainless steel counterparts. The wires from GAC were closest to their stated heights (Table 3). This is in accordance with a previous study of stainless steel wires.[5] On average, the wires from GAC were also closest to the stated widths (Table 3) and had the highest level of dimensional precision (Table 5).

Table 5
Precision of producers. The average variation around the mean value, expressed by the standard deviation, for each producer with respect to height, width, and edge bevel

Producer	Wire height	Wire width	Wire edge bevel	Torsional stiffness	Angle at 20 N-mm	Torsional play
Dentaurum	±0.192	±0.121	±0.475	±0.188	±0.359	±0.495
Forestadent	±0.142	±0.151	±0.670	±0.176	±0.662	±0.597
GAC	±0.107	±0.123	±0.405	±0.082	±0.259	±0.384
Masel	±0.216	±0.300	±0.666	±0.219	±0.729	±1.236
RMO	±0.292	±0.269	±0.535	±0.211	±0.940	±0.734

Table 6
Summary of wire measurements and torque experiments

		.016 × .016		.016 × .022		.018 × .025	
		Mean	Range	Mean	Range	Mean	Range
Wire height	0.010 mm	40.47	39.78 - 41.53	40.47	39.90 - 41.04	45.27	44.97 - 45.44
Wire width	0.010 mm	40.51	39.80 - 41.64	55.56	54.79 - 56.36	63.38	62.90 - 63.91
Edge bevel	0.010 mm	3.99	1.76 - 9.03	3.35	2.26 - 4.88	5.06	1.98 - 9.92
Torsional stiffness	Nmm/degree	1.29	1.15 - 1.45	2.52	2.04 - 2.81	3.16	2.43 - 3.82
Angle of twist at 20 N-mm	Degrees	42.40	34.80 - 48.55	25.28	23.41 - 26.55	11.20	9.54 - 12.96
Working range	Degrees	7.82	6.91 - 8.55	3.87	3.24 - 4.60	3.19	2.56 - 3.94
Intercept	Degrees	26.76	20.99 - 32.31	17.54	16.58 - 18.50	4.84	3.88 - 5.65

With respect to edge bevel, there was little intrasample variation (Table 2). However, a large intermanufacturer variation in edge bevel for similar wire dimensions was observed, being highest for the .018 × .025 wires (range 0.079 mm) and lowest for the .016 × 0.022 wires (range 0.026 mm) (Table 6).The Forestadent and Dentaurum wires had the least amount of edge bevel (Table 3). The chrome-cobalt wires had, on average, somewhat less edge bevel than previously reported for stainless steel wires.[5] The precision levels varied little between manufacturers (Table 5).

Wire stiffness

The torsional stiffnesses of the .016 × .016 and .018 × .025 wires were less than those observed for stainless steel wires.[5] This could be due to differences in wire dimensions, edge bevel, or modulus of rigidity. The chrome-cobalt wires were, as noted above, both smaller and less beveled than their stainless steel counterparts, the effects of which will counteract each other. The .016 × .022 chrome-cobalt and stainless steel wires had identical torsional stiffnesses. The former wires were smaller and had approximately half as much edge bevel. Thus, either the effects of wire dimension and edge bevel balanced out, or the chrome-cobalt wires had a higher modulus of rigidity.

The variation in torsional stiffness is mainly related to variations in cross-sectional dimension. However, since no existing formula for the polar moment of inertia takes into consideration the effect of edge bevel,[13] an exact evaluation of the effect of cross-sectional variation on the torsional stiffness is not feasible and must be approximate. A comparison between the two chrome-cobalt qualities (yellow and blue) revealed that for three of the manufacturers, the difference between the two qualities could be largely explained by differences in cross-sectional dimension. Of the .016 × .022 wires, the

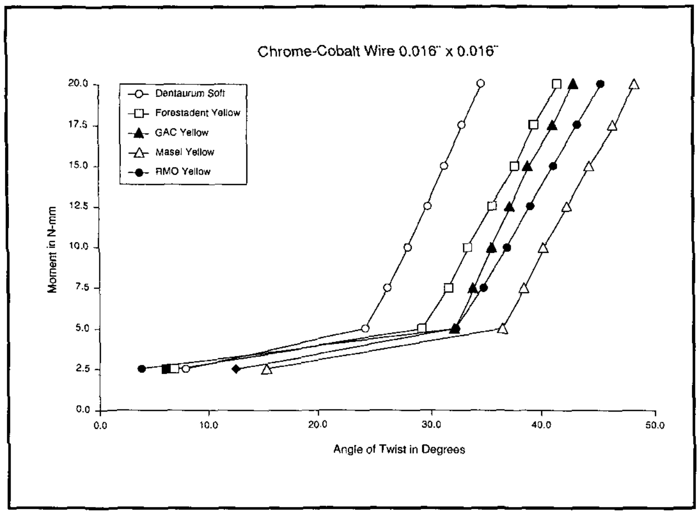

Figure 1

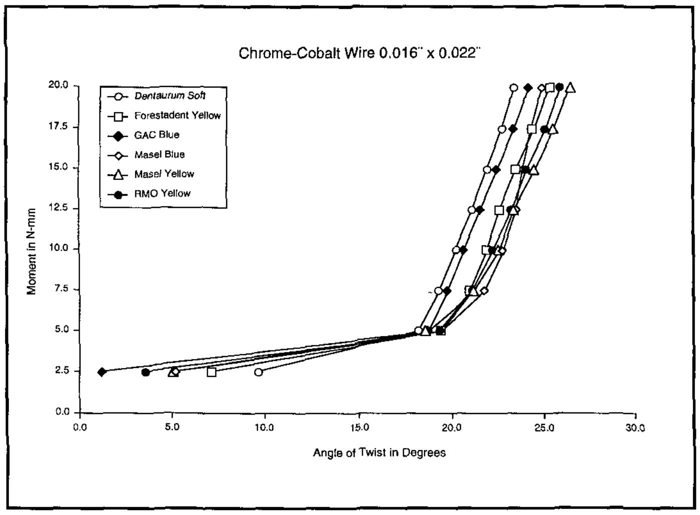

Figure 2

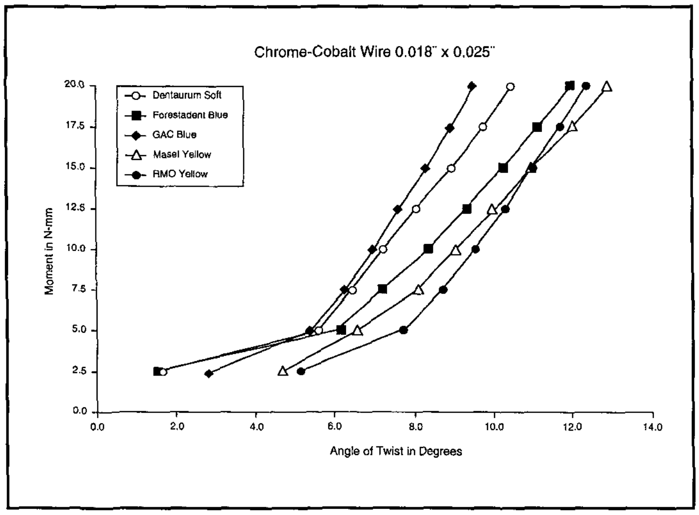

Figure 3

Figure 1
Torque-twist diagrams for nine different .016 × .016 wires from five different manufacturers

Figure 2
Torque-twist diagrams for nine different .016 × .022 wires from five different manufacturers

Figure 3
Torque-twist diagrams for nine different .018 × .025 inch wires from five different manufacturers

RMO wires had, on average, the least torsional stiffness, but also the smallest dimensions. Dentaurum wires were the stiffest, but also the largest. The Masiloy yellow wire had less torsional stiffness than the blue variety, but this difference could not be explained by variations in cross-section alone. The results suggest differences in material qualities leading to differences in the modulus of rigidity in this case.

The .018 × .025 wires showed some marked differences. The wires could be divided into two main groups with respect to torsional stiffness, with intragroup differences attributable to differences in cross-section. The wires supplied by GAC and RMO and the Masel blue wire had high torsional stiffness values relative to their cross-sections, while the wires supplied by Forestadent and Dentaurum and the Masel yellow had low stiffness values. This difference in rigidity is most likely due to differences in material characteristics.

The Masel blue .016 × .016 wire was notable for its small wire dimensions and large edge bevel, leading to a very flexible wire. The calculated torsional play was significantly larger than the other .016 × .016 wires, and the wire could only be tested up to 12.5 N-mm in torsion before plastic deformation occurred. Furthermore, it had a torque-twist diagram that did not allow for calculation of torsional stiffness, working range, or intercept.

Tables 4 and 6 show the degree of twist necessary to produce 20 N-mm of torsional moment. For the .016 × .022 wires, the angle of twist at 20 N-mm ranged from 23.4 to 26.6 degrees. The variability is the result of several factors; wire dimensions and edge bevels vary, leading to changes in torsional play and stiffness, and variations in the modulus of rigidity also influence results.

The precision in torsional stiffness and degree of twist at 20 N-mm differed between various manufacturers (Table 5). Overall, the GAC wires were more precise.

Torsional play

Most wires showed little intrasample variation for both play and angle of twist at 20 N-mm, with the exception of Masiloy yellow .016 × .016 wire. Therefore, the observed variation is mainly due to variation between producers.

The .016 × .016 wires as a group had a mean torsional play of as much as 26.8 degrees. The range was from 21.0 to 32.3 degrees, while at 20 N-mm the range was 34.8 to 48.6 degrees (Table 6). This indicates that most of the variation at 20 N-mm is caused by variations in torsional play (90%).

The .016 × .022 wires had a mean torsional play of 17.5 degrees and a range from 16.6 to 18.5 degrees. This is less than for stainless steel wires.[5] As the range in angle of twist at 20 N-mm was 23.4 to 26.6 degrees, approximately 60% of the variation at 20 N-mm is due to torsional play. The remainder is attributable to variations in torsional stiffness as a result of cross-section and material properties.

Finally, the .018 × .025 wires have a mean torsional play of 4.8 degrees and a range of 3.9 to 5.7 degrees. At 20 N-mm the range is 9.5 to 13.0 degrees. For this wire dimension, about 50% of the variation at 20 N-mm is due to variation in torsional play.

Precise control of torque application is difficult with chrome-cobalt wires. For lighter wires, the major problem is related to the large intermanufacturer variation between different wires. For heavier wires, it is related to the high torsional stiffness, which makes it difficult to apply torque to a segment of an archwire with sufficient accuracy.

Overall, the GAC wires were the most precise with respect to torsional play (Table 5). This is probably due to stability in the cross-sectional dimensions of these wires (Table 5).

Torsional play was estimated in two different ways, and there was no significant difference between the experimental data and the theoretical calculations for the different wire dimensions. Thus, the method used to estimate the degree of bevel is reasonably accurate.

The present investigation simulated the application of torque to a single tooth. Assume, for the sake of discussion, that 1500 g-mm or 15 N-mm is an ideal moment for faciolingual root movement of a single tooth, and 20 N-mm and 5 N-mm are the upper and lower limits, respectively. Since the mean torsional stiffness was 1.3 N-mm/degree for .016 × .016 wires and 3.2 N-mm/degree for .018 × .025 wires (Table 6), the working range in degrees will be 11.5 and 4.7 degrees, respectively, at a working range of 15 N-mm. As this is similar to the observed range in torsional play for the two wire dimensions, torque application with a desirable degree of certainty is difficult.

Product accuracy and precision

Unfortunately, manufacturers do not state their tolerances nor give any information about edge bevel. Previous articles by Meling et al.[2,5] illustrated that deviations from stated dimensional values exist for stainless steel wires, and that there are both significant inter- and intramanufacturer variations. The manufacturers also delivered various wire qualities with different tolerances. The results of this investigation demonstrate that differences exist between wire manufacturers and between wire qualities with respect to chrome-cobalt wires. These differences are due to deviations from stated dimensional values, edge bevel, and variation in the material properties. It should be kept in mind that the variation observed in this experiment is based on deviations in wire properties alone. The uncertainty by which a wire can deliver a given torsional moment will be further increased by variations in bracket-slot dimension.[4]

Clinical importance

Quality control in orthodontics concerns not only the correct placement of teeth to obtain a pleasing result, but also the correct application of moments to minimize side effects. There are important differences between manufacturers and between wire samples with respect to accuracy and precision that lead to a wide range in the torsional play and twist needed to produce 20 N-mm of torsional moment. Thus, for correct application of torque, the orthodontist should be given enough information by the manufacturer to estimate the amount of torsional play in the appliances. This study shows that when using .016 × .022 wires, one must apply from 23.4 to 26.6 degrees of twist to get 20 N-mm of torsional moment, and this variation is mostly due to a rather wide range in torsional play. If an orthodontist changes from wires with small dimensions and beveled edges to wires with larger dimensions and sharper edges, excessive torsional moments could result.[5]

Finally, when the ratio between the working range in degrees and the observed range in torsional play is small, it becomes difficult to apply the torsional moment accurately. One solution is to use more flexible wires to increase the working range.

Conclusions

1. The chrome-cobalt wires tested were, on average, thinner than their stated dimensional values. Within a dimensional group, the chrome-cobalt wires were also thinner than their stainless steel counterparts.

2. The wires had a significant edge bevel and a marked intersample variation in edge bevel. The chrome-cobalt wires had, on average, somewhat less edge bevel than that previously reported for stainless steel wires.

3. The amount of torsional play (third order clearance) is significant. The intrasample variation is low, but there is considerable variation between manufacturers. The observed variation in torsional play between the producers is the result of deviations from stated dimensional values and variable edge bevel.

4. Torsional stiffness varies considerably between producers within the various dimensions, but intrasample variation is low.

5. The degree of twist required to produce a 20 N-mm torsional moment showed a marked intermanufacturer variation for the .016 × .016 wires, while differences were smaller for the other two sizes. Most of this variation is due to variation in the torsional play. Intrasample variation was higher for the .016 × .016 wires than for the other two dimensions.

6. If an acceptable range for torque lies between 10 and 20 N-mm, these results indicate that the working range for the rectangular chrome-cobalt wires is narrow and that it can be difficult to apply physiologic torsional moments with a satisfactory degree of accuracy.

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