European Journal of Orthodontics 34 (2012) 410–417
doi:10.1093/ejo/cjr011
Advance Access Publication 8 April 2011

The effect of Teflon coating on the resistance to sliding of orthodontic archwires

Giampietro Farronato*, Rolf Maijer**, Maria Paola Carìa***,****, Luca Esposito*, Dario Alberzoni* and Giorgio Cacciatore*
*Department of Surgical, Reconstructive, and Diagnostic Sciences, University of Milan, Italy, **Executive Director of the SDB Institute, Dallas, TX, USA, ***Department of Public Health Sciences, Karolinska Institutet, Stockholm, Sweden, ****Department of Clinical and Experimental Medicine, Avogadro University, Novara, Italy

Correspondence to: Professor Giampietro Farronato, Department of Surgical, Reconstructive, and Diagnostic Sciences, Fondazione IRCSS Ca' Granda—Ospedale Maggiore Policlinico, University of Milan, Via Commenda 10, 20122 Milan, Italy. E-mail: giampietro.farronato@unimi.it

SUMMARY Teflon is an anti-adherent and aesthetic material. The aim of this study was to evaluate, *in vitro*, the influence of Teflon coating on the resistance to sliding (RS) of orthodontic archwires. For this purpose, Teflon-coated archwires were examined using frictional resistance tests by means of a universal testing machine and compared with conventional uncoated wires. Twelve types of archwires with round and rectangular sections (0.014, 0.018, and 0.018 × 0.025 inches) and of different materials (stainless steel and nickel–titanium) were tested with two passive self-ligating brackets (SmartClip™ and Opal®) and one active self-ligating bracket (Quick®). Each archwire–bracket combination was tested 10 times under 8 simulated clinical scenarios. Statistical comparisons were conducted between the uncoated and Teflon-coated archwires using Wilcoxon and Mann–Whitney tests, and linear regression analysis.

For all bracket–archwire combinations, Teflon-coated archwires resulted lower friction than the corresponding uncoated archwires ($P < 0.01$). The results showed that Teflon coating has the potential to reduce RS of orthodontic archwires.

Introduction

Friction, or resistance to sliding (RS), can be defined as the resistance to motion when a solid object moves tangentially against another (Rabinowicz, 1965). RS can be divided into three components: classical friction, elastic binding, and plastic binding or physical notching. In the passive configuration, when the archwire does not contact the mesial and distal edges of the bracket slot, only classic friction contributes to RS (Kusy and Whitley, 1997). Classic friction is equal to the normal force applied by ligation multiplied by the coefficient of friction (Jastrzebski, 1976), which is determined by the nature of the material surfaces of the bracket–archwire couple. In the active configuration, when the archwire contacts the edges of the slot, binding begins to contribute to RS. The second-order angle (θ) at which the archwire first contacts both edges of the opposing slot walls is called the critical contact angle for binding (θ_c; Kusy and Whitley, 1999). At still greater θ values, the bracket may physically deform the archwire, thus adding the physical notching component to the elastic binding and classic friction components of RS (Articolo *et al.*, 2000).

Teflon or polytetrafluoroethylene (PTFE) is a material characterized by a completely fluoridated chain. This chain is responsible for its physical and chemical characteristics. From an orthodontic point of view, PTFE is an anti-adherent and aesthetic material that has excellent chemical inertia as well as good mechanical stability. Its modest mechanical properties can be improved using some fillers. The physical characteristics of Teflon are shown in Table 1. It is made through a sintering process and two forms exist: classical PTFE, not microporous (Teflon) and expanded PTFE (ePTFE), microporous (Gore-Tex). ePTFE is characterized by orientated microfibrils, kept together by solid junctions (Pietrabissa, 1996). The numerous applications of PTFE and ePTFE in medicine and dentistry are: suturing (Chiapasco, 2002), surgical application for a prolapse of the anterior mitral flap by replacing artificial chordae (Tomita *et al.*, 2005), vascular prosthesis (Liang *et al.*, 2006), vascular endothelial growth factor gene carrier (Tao and Chen, 2007), cardiac valvular prosthesis (Pietrabissa, 1996), membrane for guided tissue regeneration (Wolf *et al.*, 1986), membrane to reconstruct the orbital walls (Brusati and Chiapasco, 1999), nasal augmentation (Owsley and Taylor, 1994), duraplasty (Shimizu *et al.*, 2007), microvascular decompression (Andrychowski and Czernicki, 2001), material used to improve the anti-cariogenic properties of the composite resins (Gyo *et al.*, 2008), archwires coating (Farronato *et al.*, 1988), auricular prosthesis (Xie, 2003), filters (Bogdanovic *et al.*, 2006; Karthikeyan *et al.*, 2006), endoscopic treatment of primary vesico-ureteral reflux (Varga *et al.*, 2004), coating of metallic stents for palliation of malignant biliary disease (Hatzidakis *et al.*, 2007), artificial muscles (Tollefson and Senders, 2007), conduit for guided nerve regeneration (He *et al.*, 2003), and treatment of facial depression with facial nerve palsy (You *et al.*, 1999).

Since Teflon has a low coefficient of friction, archwires with a Teflon coating could possibly reduce RS. Typically, RS is considered during tipping (the second order of space), although rotation (the first order of space) and torque (the third order of space) also affect resistance. The aim of this study was to evaluate the effect of Teflon coating on RS of orthodontic archwires with first-, second-, and third-order angulations.

Materials and methods

Materials

Twelve types of commercially available archwires (Table 2) with round and rectangular sections (0.014, 0.018, and 0.018 × 0.025 inches) of different materials (stainless steel and nickel–titanium), with and without Teflon coating, were tested. Teflon-coated archwires (TP Italia, Gorle, BG, Italy) are made through an atomizing process with cleaned compressed air as the transport medium for the atomized Teflon particles. Stereomicrographs of uncoated and Teflon-coated archwires are shown in Figure 1. All the micrographs were obtained with a Leica $MZ12_5$ stereomicroscope (Meyer Instruments, Houston, Texas, USA).

Each type of archwire was coupled with three types of self-ligating brackets: SmartClip™ (3M Unitek, Monrovia, California, USA), Quick® (Forestadent, St. Louis, Missouri, USA), and Opal® (Ultradent Products, South Jordan, Utah, USA). The passive mechanism of the SmartClip bracket consists of two Nitinol clips that open and close through elastic deformation of the metal when the archwire exerts a force on them; the Quick active and passive bracket clip can be opened either by sliding it open from the gingival aspect or by using the hole in the clip; and the Opal bracket is characterized by a clip that opens and closes as a door (Figure 2).

Eight stainless steel plates were manufactured for each bracket type, to simulate eight different clinical scenarios *in vitro*. Three brackets were positioned on each plate with orthodontic composite (Transbond XT™ Light Cure Adhesive, 3M Unitek), to simulate upper right lateral incisor, canine, and first premolar brackets. Each plate was

Table 1 Physical characteristics of Teflon.

Properties	Value
Molecular weight	5×10^5 to 5×10^6
Density	2170 kg/m^3
Softening temperature	615 K
Fusion temperature	6000 K
Modulus of elasticity	0.41–0.55 GPa
Load at failure	14–48 MPa
Elongation at break	100–400%

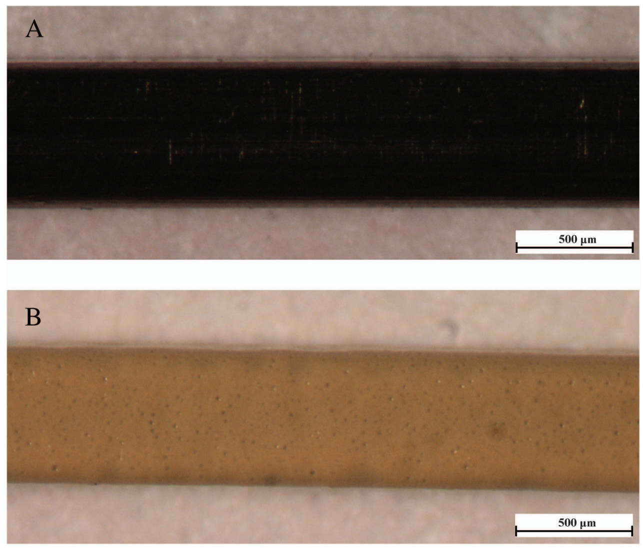

Figure 1 Stereomicrographs of uncoated (A) and Teflon-coated (B) 0.018 × 0.025 inches stainless steel archwires.

Table 2 Archwires [superelastic nickel–titanium (Ni–Ti) and stainless steel (SS)] and brackets tested in the experiment.

Product	Design	Nominal dimensions (inches)	Material	Manufacturer
Archwires				
Uncoated	Round	0.014	Ni–Ti	American Orthodontics, Sheboygan, Wisconsin, USA
Uncoated	Round	0.018	Ni–Ti	American Orthodontics
Uncoated	Rectangular	0.18 × 0.025	Ni–Ti	American Orthodontics
Teflon coated	Round	0.014	Ni–Ti	TP Italia, Gorle, BG, Italy
Teflon coated	Round	0.018	Ni–Ti	TP Italia
Teflon coated	Rectangular	0.18 × 0.025	Ni–Ti	TP Italia
Uncoated	Round	0.014	SS	American Orthodontics
Uncoated	Round	0.018	SS	American Orthodontics
Uncoated	Rectangular	0.18 × 0.025	SS	American Orthodontics
Teflon coated	Round	0.014	SS	TP Italia
Teflon coated	Round	0.018	SS	TP Italia
Teflon coated	Rectangular	0.18 × 0.025	SS	TP Italia
Brackets				
SmartClip	Two clips	0.022	SS	3M Unitek, Monrovia, California, USA
Quick	One clip	0.022	SS	Forestadent, St. Louis, Missouri, USA
Opal	One clip	0.022	SS	Ultradent Products, South Jordan, Utah, USA

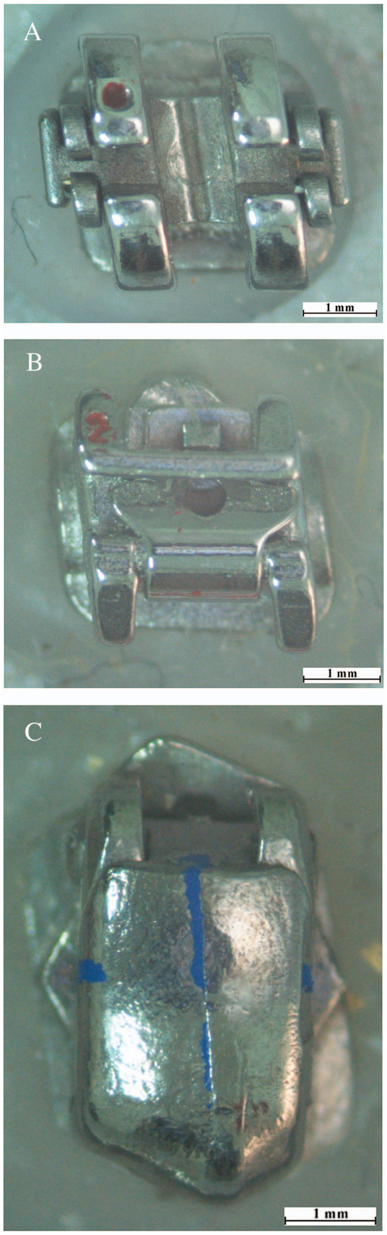

Figure 2 Stereomicrographs of the tested brackets. SmartClip brackets (A) have two clips, and Quick (B) and Opal (C) brackets have one clip.

Table 3 Simulated clinical scenarios.

Scenarios	Displacement (mm)	In–out (mm)	Torque (°)
1	0	0	0
2	0	0	5
3	1	0	0
4	1	0	5
5	1	0	10
6	1	1	0
7	2	0	0
8	2	1	0

different from the others for the displacement, and in–out and torque values of the canine bracket: a summary of the values for the various plates is shown in Table 3. The distance from the centre of the brackets was always 8.5 mm. Stainless steel templates were constructed to position the brackets correctly on the plates. The precision of the templates was 100 mm, with 0.2–0.3 per cent tolerance. Only 0.014 and 0.018 inch archwires were tested with plates 3–8, while 0.018 × 0.025 inch archwires were tested with plates 1–6. It was considered that the choice was appropriate to simulate the most usual clinical situations in orthodontic practice.

Frictional testing

The RS of each bracket–archwire–plate combination was tested 10 times by passing the wire through the test brackets at a rate of 10 mm minute^{-1}, with a frictional testing apparatus, mounted on the crosshead of a universal testing machine (Model LR30K Plus, Lloyd Instruments, Fareham, Hants, UK). A loop was made at the mesial end of the archwire and a 3-0 suture was passed through it. The suture was attached to a 50-N load cell and the plate was fixed to the lower grip of the machine (Figure 3). All materials were cleaned with 95 per cent ethanol before testing, and only new sections of wire were used. Nexigen Plus software (Lloyd Instruments) was used to register the RS values (1000 measurements were collected per minute). The collected RS data related to kinetic friction. Static friction was not considered.

Statistical analysis

In order to discard the values registered during suture tension, the data for the present study included only the last 500 frictional values measured in each test. As each combination was tested 10 times, descriptive statistics, including the mean and standard deviation (SD), were calculated for each combination of bracket, archwire,

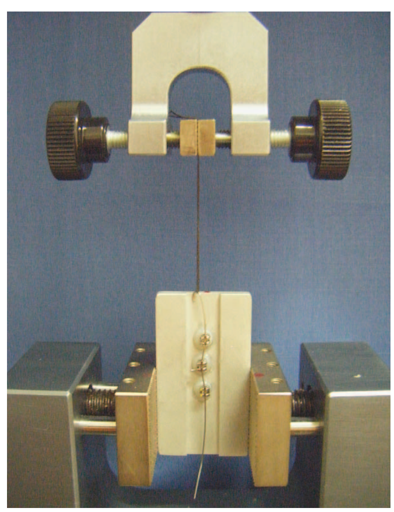

Figure 3 Photograph of the testing apparatus.

and plate. Wilcoxon and Mann–Whitney tests were used to determine significant frictional differences between Teflon-coated and uncoated archwires, and between stainless steel and nickel–titanium archwires. Kruskal–Wallis tests were carried out to determine significant frictional differences among bracket types, archwire sizes, and plates. The level of significance for all tests was set at $P < 0.05$.

A multivariate linear regression model was fitted to evaluate the effect of Teflon coating, type of bracket, type of plates, wire material, and wire size, assumed to be possible predictors, on the dependent variable 'friction'. The model was corrected for heteroscedasticity, using the estimator proposed by Davidson and MacKinnon (1993). All analyses were performed using the Stata statistical package version 10 (Stata Corp., College Station, Texas, USA).

Results

The mean and SD of RS for each bracket–archwire–plate combination are presented in Tables 4, 5, and 6. Wire size, material, and type of bracket and plate had a significant influence on friction (Wilcoxon, Mann–Whitney, and Kruskal–Wallis test results not shown). In general, less friction was elicited by archwires with a smaller size, by Ni-Ti archwires and by Quick brackets.

Table 7 shows the comparison of the mean frictional values by type of coating under separate experimental conditions. Teflon-coated archwires had, on average, significantly lower friction value (mean = 2.55 N) than uncoated archwires (mean = 5.30 N; Figure 4A). The same comparison showed a decrease of RS with Teflon coating, within each examined subgroup of wire size, wire material, type of bracket, and type of scenario (Figure 4B–E). Teflon-coated archwires produced less friction than uncoated archwires under all tested conditions. All differences were statistically significant. When the influences of all factors were considered simultaneously in a multivariate linear regression model, the adjusted estimated coefficient for Teflon coating on friction was −2.75 and still statistically significant ($P < 0.01$; 95 per cent confidence interval: –2.95, –2.56). Thus, a 2.75 unit decrease in friction was predicted for the Teflon-coated archwires compared with the uncoated archwires, holding all other variables constant in the study (archwire material, archwire size, type of brackets, and type of plates; Table 8).

Table 4 Mean and standard deviation (SD) of all kinetic data of resistance to sliding (Newton) for SmartClip brackets.

	Superelastic nickel–titanium				Stainless steel			
	Uncoated		Teflon coated		Uncoated		Teflon coated	
Scenarios	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.014 inches								
1	—		—		—		—	
2	—		—		—		—	
3	0.30	0.04	0.11	0.02	1.33	0.08	0.45	0.15
4	0.44	0.08	0.27	0.07	1.71	0.11	0.63	0.22
5	0.45	0.06	0.13	0.04	1.61	0.16	0.48	0.19
6	0.73	0.11	0.34	0.15	1.83	0.14	0.62	0.14
7	1.96	0.12	0.79	0.30	5.09	0.22	2.24	0.33
8	2.73	0.24	1.42	0.68	5.88	0.25	2.76	0.61
0.018 inches								
1	—		—		—		—	
2	—		—		—		—	
3	2.11	0.20	0.87	0.18	5.61	0.19	3.97	1.29
4	2.44	0.16	1.66	0.37	6.36	0.41	4.39	0.54
5	2.77	0.14	1.37	0.27	6.13	0.37	3.92	1.24
6	3.43	0.55	2.16	0.48	8.01	0.26	6.02	0.76
7	5.08	0.46	3.58	0.31	15.05	2.63	9.47	1.29
8	8.10	0.41	3.79	0.91	19.54	2.53	12.49	1.09
0.018 × 0.025 inches								
1	0.10	0.03	0.00	0.00	0.17	0.05	0.10	0.15
2	0.11	0.03	0.02	0.01	0.30	0.28	0.22	0.04
3	5.45	1.79	1.40	0.10	13.37	0.44	5.40	0.90
4	9.80	0.51	1.89	0.21	16.30	0.72	7.99	1.85
5	9.94	0.58	2.23	0.39	16.49	1.38	8.79	1.53
6	12.08	0.75	7.27	1.60	18.20	0.51	10.30	1.66
7	—		—		—		—	
8	—		—		—		—	

—: Not tested.

Table 5 Mean and standard deviation (SD) of all kinetic data of resistance to sliding (Newton) for Quick brackets.

	Superelastic nickel–titanium				Stainless steel			
	Uncoated		Teflon coated		Uncoated		Teflon coated	
Scenarios	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.014 inches								
1	—		—		—		—	
2	—		—		—		—	
3	0.22	0.07	0.05	0.03	0.47	0.16	0.06	0.03
4	0.21	0.08	0.10	0.01	0.67	0.17	0.13	0.04
5	0.33	0.10	0.13	0.04	1.14	0.26	0.16	0.06
6	0.54	0.14	0.18	0.06	1.13	0.14	0.19	0.09
7	1.65	0.19	0.33	0.12	3.57	0.35	1.63	0.40
8	2.06	0.19	0.67	0.19	4.28	0.50	2.08	0.66
0.018 inches								
1	—		—		—		—	
2	—		—		—		—	
3	1.41	0.29	0.31	0.09	4.76	0.29	1.91	0.51
4	2.12	0.24	0.96	0.18	5.45	0.33	3.26	0.35
5	2.55	0.16	1.29	0.30	6.55	0.51	4.20	0.65
6	2.17	0.22	1.62	0.18	4.80	0.67	2.85	0.35
7	5.88	0.91	1.80	0.44	11.16	2.16	8.97	1.23
8	6.54	0.67	2.22	0.35	13.37	1.51	11.06	1.05
0.018 × 0.025 inches								
1	1.15	0.19	0.25	0.14	1.63	0.33	0.84	0.51
2	1.22	0.38	0.26	0.09	2.09	0.55	1.70	0.36
3	5.72	0.89	0.91	0.16	10.32	0.88	5.15	1.16
4	7.63	0.58	2.16	0.91	13.73	1.41	6.30	1.39
5	9.31	0.78	3.69	1.33	14.98	1.19	7.42	0.81
6	—		—		—		—	
7	—		—		—		—	
8	—		—		—		—	

—: Not tested.

Discussion

There are several ways to reduce RS by improvement of the material surface of the archwire: Teflon coating (Farronato *et al.*, 1988; Husmann *et al.*, 2002), ion implantation (Kusy *et al.*, 1992, 1993; Husmann *et al.*, 2002), diamond-like carbon coating (Kusy *et al.*, 1993, 1997), plasma deposition (Kusy *et al.*, 1993), unidirectional fibre-reinforced polymer composite coated with poly(chloro-*p*-xylylene; Zufall *et al.*, 1998; Zufall and Kusy, 2000), and coating with nickel–phosphorous electroless film impregnated with inorganic fullerene-like nanoparticles of tungsten disulphide (Redlich *et al.*, 2008).

Teflon coating of wire results in frictional losses ranging from 22.2 to 6.1 per cent (Husmann *et al.*, 2002). Teflon-coated ligatures also produced lower friction than elastomeric ligatures (De Franco *et al.*, 1995). With ion implantation, the measured frictional losses ranged from 45.9 to 23.4 per cent (Husmann *et al.*, 2002). Ion implantation of titanium into polycrystalline alumina surfaces and nitrogen into beta-titanium wires reduced the static and kinetic coefficients from 0.50 and 0.44 before implantation to 0.20 and 0.25 respectively after implantation (Kusy *et al.*, 1997).

Diamond-like carbon coating provided the best frictional results for the polycrystalline alumina/β-titanium couple when both contacting surfaces were coated (Kusy *et al.*, 1993, 1997). On the other hand, plasma deposition performed the best for the polycrystalline alumina/stainless steel couple when only one surface was coated, with values of coefficient of friction as low as 0.08 (Kusy *et al.*, 1993).

The characteristics of unidirectional fibre-reinforced polymer composite are well known (Zufall *et al.*, 1998). The most important advantages of unidirectional fibre-reinforced polymer composite archwires are their tooth-coloured appearance as well as the capability to vary their stiffness through control of reinforcement and matrix composition without changing the wire size. However, at high normal forces or angulations, the reinforcement fibres of the wire surface tend to wear. Although poly(chloro-*p*-xylylene) coating has been used to maintain water adsorption and hydrolytic stability of uncoated wires, it failed to lower the values of the coefficient of friction (Zufall and Kusy, 2000).

Coating performed through the impregnation of stainless steel wires into electroless solutions of nickel–phosphorus and inorganic fullerene-like nanoparticles of tungsten disulphide produced a significant reduction in friction. Namely, the friction coefficient changed from 0.25 to 0.08, while the friction forces decreased by up to 54 per cent (Redlich *et al.*, 2008).

Table 6 Mean and standard deviation (SD) of all kinetic data of resistance to sliding (Newton) for Opal brackets.

	Superelastic nickel–titanium				Stainless steel			
	Uncoated		Teflon coated		Uncoated		Teflon coated	
Scenarios	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.014 inches								
1	—		—		—		—	
2	—		—		—		—	
3	0.31	0.08	0.07	0.03	1.21	0.10	0.40	0.11
4	0.35	0.08	0.09	0.04	1.41	0.17	0.50	0.34
5	0.35	0.05	0.10	0.02	1.15	0.13	0.38	0.06
6	0.72	0.08	0.15	0.04	2.29	0.47	0.53	0.21
7	1.73	0.10	0.30	0.07	5.04	0.56	2.29	0.41
8	2.40	0.23	0.39	0.09	5.49	0.41	2.54	0.79
0.018 inches								
1	—		—		—		—	
2	—		—		—		—	
3	1.79	0.11	0.50	0.14	6.93	0.50	3.72	0.46
4	2.33	0.26	0.75	0.30	7.41	0.35	3.27	0.29
5	2.80	0.34	1.09	0.33	7.68	0.60	3.67	0.28
6	4.81	0.58	1.57	0.35	12.36	0.78	6.82	0.52
7	5.91	0.42	2.26	0.22	13.33	1.61	9.32	1.17
8	6.75	0.41	2.44	0.41	15.73	3.08	10.15	2.03
0.018 × 0.025 inches								
1	0.10	0.07	0.06	0.01	0.21	0.11	0.18	0.06
2	0.13	0.04	0.06	0.02	0.33	0.06	0.18	0.09
3	7.17	0.94	1.23	0.17	15.65	0.50	6.56	0.97
4	8.26	0.47	1.59	0.69	17.66	0.59	7.24	1.33
5	9.22	0.44	2.11	0.41	20.57	1.13	8.10	0.43
6	—		—		—		—	
7	—		—		—		—	
8	—		—		—		—	

—: Not tested.

Table 7 Comparison of means and standard deviation (SD) of frictional resistance (N) for uncoated and Teflon-coated archwires in different experimental conditions.

	Uncoated archwires			Teflon-coated archwires				
	*n**	Mean	SD	*n*	Mean	SD	*z*	*P* value
All	1040	5.30	5.30	1040	2.55	3.06	13.52	<0.01
Wire sizes								
0.014 inches	360	1.74	1.60	360	0.66	0.82	12.57	<0.01
0.018 inches	360	6.65	4.50	360	3.88	3.30	10.08	<0.01
0.018 × 0.25 inches	320	7.79	6.58	320	3.18	3.32	8.50	<0.01
Wire materials								
Nickel–titanium	520	3.34	3.25	520	1.17	1.37	12.31	<0.01
Stainless steel	520	7.26	6.16	520	3.92	3.61	8.71	<0.01
Brackets								
SmartClip	360	5.86	5.75	360	3.04	3.39	6.78	<0.01
Quick	340	4.44	4.25	340	2.20	2.74	8.59	<0.01
Opal	340	5.58	5.64	340	2.37	2.93	8.26	<0.01
Scenarios								
1	60	0.56	0.63	60	0.24	0.35	3.72	<0.01
2	60	0.70	0.79	60	0.41	0.61	2.76	<0.01
3	180	4.67	4.56	180	1.84	2.14	7.06	<0.01
4	180	5.79	5.47	180	2.40	2.56	6.40	<0.01
5	180	6.34	5.98	180	2.74	2.84	6.19	<0.01
6	140	5.22	5.29	140	2.90	3.27	4.91	<0.01
7	120	6.29	4.47	120	3.58	3.46	5.56	<0.01
8	120	7.74	5.51	120	4.33	4.21	6.20	<0.01

*Number of tests executed.

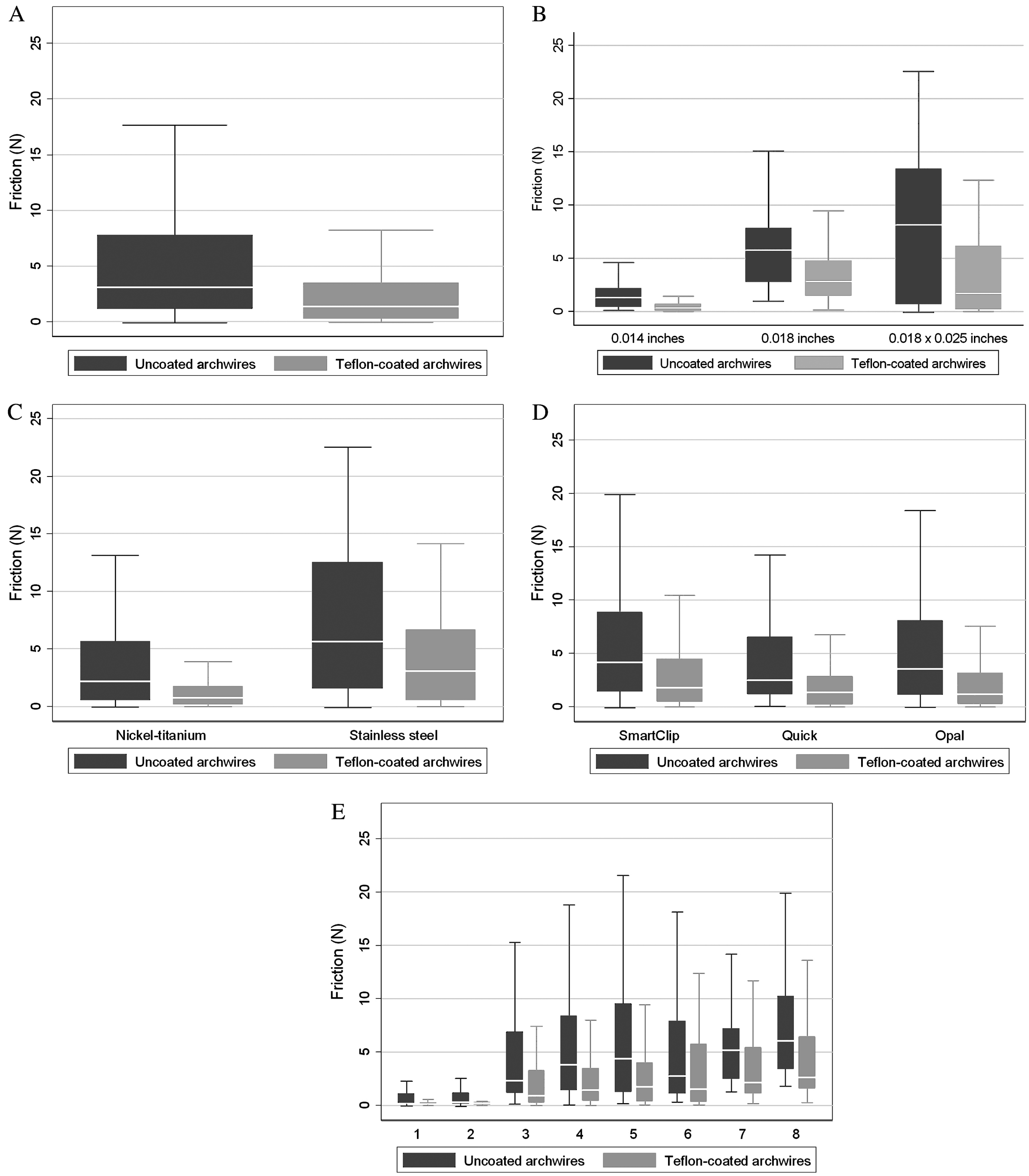

Figure 4 Comparison of frictional values (N) between uncoated and Teflon-coated archwires (A), according to archwire sizes (B), archwire material (C), type of bracket (D), and various combinations (E).

In the present study, several clinical conditions were simulated *in vitro*. For all comparisons, Teflon-coated archwires produced lower friction than the corresponding uncoated archwires ($P < 0.01$). The best frictional results were registered with a combination of Teflon-coated archwires and Quick brackets. This reduction in adverse forces has positive implications for future clinical applications. The findings suggest that coating orthodontic archwires with Teflon has the potential to decrease RS. The practical relevance of this finding might be interesting, given that coating with Teflon has excellent aesthetic properties: the tooth-like colour of Teflon-coated archwires, together with their improved frictional performance, may lead to widespread use of this type of archwire in future orthodontic practice. Clinical studies are however needed to confirm these findings *in vivo*.

Conclusions

Teflon-coated archwires produced lower frictional levels than their corresponding uncoated archwires. Coating

Table 8 Adjusted* regression coefficients (β), *P* value, and 95% confidence interval (95% CI) to determine the association among Teflon coating, type of bracket, and friction.

	β	*P* value	95% CI
Teflon coating			
No	—		
Yes	–2.75	<0.01	–2.95, –2.56
Type of bracket			
Quick	—		
Opal	0.66	<0.01	0.41, 0.90
SmartClip	0.81	<0.01	0.57, 1.05

*Adjusted also for wire size, wire material, and various combinations.

archwires with Teflon may be a possible way to reduce RS. The best frictional results were found with a combination of Teflon-coated archwires and Quick brackets.

Acknowledgements

The authors wish to thank the Department of Human Morphology and Biomedical Sciences of the University of Milan for the support provided in the realization of the stereomicrographs.

References

Andrychowski J, Czernicki Z 2001 Application of the insulating material Teflon—pladgets (Genzyme-USA) during the microvascular decompression. Neurologia i Neurochirurgia Polska 5: 26–29

Articolo L C, Kusy K, Saunders C R, Kusy R P 2000 Influence of ceramic and stainless steel brackets on the notching of archwires during clinical treatment. European Journal of Orthodontics 22: 409–424

Bogdanovic J, De Pater A J, Doekes G, Wouters I M, Heederik D J 2006 Application of porous foams for size-selective measurements of airborne wheat allergen. The Annals of Occupational Hygiene 50: 131–136

Brusati R, Chiapasco M 1999 Elementi di chirurgia oro-maxillo-facciale. Màsson, Milano

Chiapasco M 2002 Manuale illustrato di chirurgia orale. Màsson, Milano

Davidson R, MacKinnon J G 1993 Estimation and inference in econometrics. Oxford University Press, New York

De Franco D J, Spiller R E Jr, Von Fraunhofer J A 1995 Frictional resistances using Teflon-coated ligatures with various bracket-archwire combinations. The Angle Orthodontist 65: 63–72

Farronato G P, Casiraghi G, Giannì A B, Salvato A 1988 The use of PTFE in orthodontics. Mondo Ortodontico 13: 83–89

Gyo M, Nikaido T, Okada K, Yamauchi J, Tagami J, Matin K 2008 Surface response of fluorine polymer-incorporated resin composites to cariogenic biofilm adherence. Applied and Environmental Microbiology 74: 1428–1435

Hatzidakis A, Krokidis M, Kalbakis K, Romanos J, Petrakis I, Gourtsoyiannis N 2007 ePTFE/FEP-covered metallic stents for palliation of malignant biliary disease: can tumor ingrowth be prevented? Cardiovascular and Interventional Radiology 30: 950–958

He F C *et al.* 2003 Long-term result of guided nerve regeneration with an inert microporous polytetrafluoroethylene conduit. Chinese Journal of Traumatology 6: 145–151

Husmann P, Bourauel C, Wessinger M, Jäger A 2002 The frictional behavior of coated guiding archwires. Journal of Orofacial Orthopedics 63: 199–211

Jastrzebski Z D 1976 The nature and properties of engineering materials. Wiley-Interscience, New York

Karthikeyan S, Joshi U M, Balasubramanian R 2006 Microwave assisted sample preparation for determining water-soluble fraction of trace elements in urban airborne particulate matter: evaluation of bioavailability. Analytica Chimica Acta 576: 23–30

Kusy R P, Whitley J Q 1997 Friction between different wire-bracket configurations and materials. Seminars in Orthodontics 3: 166–117

Kusy R P, Whitley J Q 1999 Influence of archwire and bracket dimensions on sliding mechanics: derivations and determinations of the critical contact angles for binding. European Journal of Orthodontics 21: 199–208

Kusy R P, Keith O, Whitley J Q, Saunders C R 1993 Coefficient of friction characterization of surface-modified polycrystalline alumina. Journal of the American Ceramic Society 76: 336–342

Kusy R P, Tobin E J, Whitley J Q, Sioshansi P 1992 Frictional coefficients of ion-implanted alumina against ion-implanted beta-titanium in the low load, low velocity, single pass regime. Dental Materials 8: 167–172

Kusy R P, Saunders C R, Whitley J Q 1997 Improving arch mechanics through surface chemistry. In: Nanda R (ed). Biomechanics in clinical orthodontics W B Saunders Company, Philadelphia, pp. 50–64

Liang Z, Hong Y, Lin P 2006 The arteria reconstruction of the carotid artery involved with advanced head and neck cancer. Lin Chuang Er Bi Yan Hou Ke Za Zhi 20: 257–258

Owsley T G, Taylor C O 1994 The use of Gore-Tex for nasal augmentation: a retrospective analysis of 106 patients. Plastic and Reconstructive Surgery 94: 241–248

Pietrabissa R 1996 Biomateriali per protesi e organi artificiali. Pàtron, Bologna

Rabinowicz E 1965 Friction and wear of materials, 2nd edn. Wiley-Interscience, New York

Redlich M, Katz A, Rapoport L, Wagner H D, Feldman Y, Tenne R 2008 Improved orthodontic stainless steel wires coated with inorganic fullerene-like nanoparticles of WS(2) impregnated in electroless nickel-phosphorous film. Dental Materials 24: 1640–1646

Shimizu S, Koizumi H, Kurita M, Utsuki S, Oka H, Fujii K 2007 Duraplasty in the posterior fossa using a boat-shaped sheet of expanded polytetrafluoroethylene. Neurologia Medico-Chirurgica 47: 379–381

Tao S F, Chen L 2007 Application of polytetrafluoroethylene as VEGF gene carrier. Zhejiang Da Xue Xue Bao Yi Xue Ban 36: 61–65

Tollefson T T, Senders C W 2007 Restoration of eyelid closure in facial paralysis using artificial muscle: preliminary cadaveric analysis. Laryngoscope 117: 1907–1911

Tomita Y *et al.* 2005 Surgical application for a prolapse of the anterior mitral leaflet by replacing artificial chordae with polytetrafluoroethylene grafts. Surgery Today 35: 812–818

Varga J, Zivković D, Dobanovaćki D, Petrović S 2004 Possibilities of endoscopic treatment of primary vesicoureteral reflux. Medicinski Pregled 57: 159–163

Wolf H F, Rateitschank E M, Rateitschank K H 1986 Parodontologia. Màsson, Milano

Xie N P 2003 Preparation and clinical application of Teflon-wire piston and stapes height measurer. Di Yi Jun Yi Da Xue Xue Bao 23: 790–791

You X B, Cao W A, Fu R 1999 The application of expanded polytetrafluoroethylene in the treatment of facial depression with facial nerve palsy. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi 13: 95–98

Zufall S W, Kusy R P 2000 Sliding mechanics of coated composite wires and the development of an engineering model for binding. The Angle Orthodontist 70: 34–47

Zufall S W, Kennedy K C, Kusy R P 1998 Frictional characteristics of composite orthodontic archwires against stainless steel and ceramic brackets in the passive and active configurations. Journal of Materials Science: Materials in Medicine 9: 611–620