Journal of Orthodontics, Vol. 40, 2013, 307–312

SCIENTIFIC SECTION

An *in vivo* study on the incidence and location of fracture in round orthodontic archwires

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Objective: The main objective of this *in vivo* study was to determine the incidence and location of fracture in round nickel–titanium (NiTi) and round stainless steel orthodontic archwires, both commonly used in orthodontics. Secondarily, this study sought to determine if there is any correlation between archwire fracture and gender, diameter of the archwire, arch type (maxillary/mandibular) or bracket used.

Design: In vivo study.

Materials and methods: One thousand orthodontic patients (1434 archwires) were evaluated during regular treatment visits to assess archwire fracture and location. The patient's gender, age, type of archwire (round NiTi and round stainless steel), diameter of the archwire, arch type, location of fracture (anterior or posterior) and period of service before fracture were recorded.

Statistical analysis: Chi-square statistical test was utilized to address the frequency and the correlation between the different variables. Level of statistical significance (α) was set at 0.05.

Results: Twenty-five archwire failures were reported (1.7%) of the total sample size. All fractured archwires were NiTi, and 76% of the fractures were located in the posterior region. No statistical significance was found between archwire fracture and gender, arch type (maxillary/mandibular), archwire diameter or bracket type.

Conclusion: The frequency of archwire fracture during regular orthodontic visits is very low. The most common archwire fracture site is the posterior region. NiTi wires are the most commonly fractured archwire. No statistically significant correlation exists between archwire fracture and gender, arch type, bracket type or diameter of archwire.

Key words: Incidence of archwire fracture, location of archwire fracture, incidence and location of wire fracture, an *in vivo* study

Received 13 August 2012; accepted 24 April 2013

Introduction

Several wire alloys with a variety of mechanical properties are used in orthodontics. The search for an 'ideal archwire' that provides predictable and efficient orthodontic treatment has been of clinical interest since the inception of the specialty. Esthetics, biocompatibility, friction, formability, weldability, resilience and springback are some of the characteristics and properties that an ideal archwire would have. Currently, four archwire alloys are now commonly available; stainless steel, cobalt–chromium, nickel–titanium (NiTi) and beta-titanium.[1–3]

During orthodontic treatment, archwire fracture can be experienced. There is limited evidence indicating the frequency of wire fracture, and the location of such failures. The posterior segment of the arch has been proposed by many as the most common location for fracture.[4,5] In the literature, there are varying views as to whether archwire fracture results from deterioration in the mouth, manufacturing flaws or a combination of these factors. Alteration in the surface and grain size, such as delamination, pitting and crevice corrosion defects in retrieved archwires have all been recorded utilizing scanning electron microscopy (SEM).[6–9] This technique has revealed surface defects and non-metallic inclusions in fractured NiTi archwires.[6] Indeed, surface layers of used archwires are covered by contaminants causing discoloration, with these contaminants being identified as mainly KCl crystals.[7] In addition, undulated surfaces with manufactural scratches and crevices

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DOI 10.1179/1465313313Y.0000000062

Table 1 Frequency of archwire failure and distribution by material and size.

Archwire size	0.012	0.014	0.016	0.018	0.020
Number of NiTi failure	1	13 (1%)	4 (0.3%)	7 (0.5%)	0
Number of SS failure	NA	0	0	0	0

are also seen on the wire surface.[8] Interestingly, a different surface topography has been observed on archwires from different manufacturers.[9] The surface composition and topography of the wire alloy is considerably altered by the irreversible formation of precipitates and the development of microcrystalline NaCl, KCl and CaP deposits.[10] Engagement of the archwire into the bracket slot, particularly on rotated or angulated teeth coupled with masticatory forces can exert significant loading on an archwire and has the potential to change the microstructure of the alloy, manifesting a reduction in grain size at the site of compression.[6,11,12] A conclusive relationship between temperature variation within the mouth and the force level delivered by NiTi archwire has not yet been established.[13]

Other studies have analysed flexural properties of archwires, using both control and corroded archwire samples, and have demonstrated that occasional failure of NiTi orthodontic archwires are not the result of corrosion but are rather due to the presence of surface defects generated during wire manufacturing.[11] NiTi archwires under clinical conditions, as compared to stainless steel archwires, demonstrate identical surface characteristics and no perceivable corrosion products.[14] The elevated oxygen levels on both archwires (stainless steel and NiTi), after intra-oral use, suggest that an adherent 'passive' (without corrosion products) oxide layer forms as a result of exposure to an aqueous environment, and the development of this layer is dependent to some degree on surface characteristics.[14] *In vitro* studies have also demonstrated that once titanium alloys have absorbed an amount of hydrogen beyond a certain critical value, a sudden decrease in tensile strength can be observed, resulting in brittle fracture. This effect was considered as a possible factor in the degradation of NiTi archwires.[15–17] However, some contradicted hydrogen embrittlement as a cause of wire fracture.[6]

Therefore, the aim of this *in vivo* study was to determine the incidence and location of fracture in round NiTi and stainless steel orthodontic archwires. Secondarily, this study sought to determine if there is any correlation between archwire fracture and gender, diameter of archwire, arch type (maxillary/mandibular) or bracket used.

Materials and methods

One thousand orthodontic patients (1434 archwires) were evaluated during regular treatment visits to assess archwire fracture and location. The study was approved by our Institutional Review Board.

Patient's gender, age, type of archwire (round superelastic NiTi and round stainless steel), location of fracture (anterior or posterior), type of brackets and period of treatment before fracture were all recorded. Any fracture located in the incisor or canine area was considered a fracture in the anterior region and any fracture located in the premolar and molar region was considered a facture in the posterior region. The round wires ranged in size from 0.012 to 0.020 inch. Rectangular archwires (NiTi or stainless steel) were excluded from the study.

Table 2 Arch type and wire failure cross-tabulation.

			Wire failure			
			No	Yes	Total	Chi-square
Arch type	Max	Count	799	14	813	NS
		% within arch type	98.3%	1.7%	100.0%	
		Std. residual	0.00	0.00		
	Mand	Count	610	11	621	NS
		% within arch type	98.2%	1.8%	100.0%	
		Std. residual	0.0	0.1		
Total		Count	1409	25	1434	NS
		% within arch type	98.3%	1.7%	100.0%	

Journal of Orthodontics jor11-260.3d 10/10/13 17:55:46
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Table 3 Bracket type and wire failure cross-tabulation.

			Wire failure			
			No	Yes	Total	Chi-square
Bracket type	Victory 3M Unitek	Count	797	20	817	
		% within bracket type	97.6%	2.4%	100.0%	NS
		Std. residual	−0.2	1.5		
	MiniTwin American	Count	172	1	173	
		% within bracket type	99.4%	0.6%	100.0%	NS
		Std. residual	0.2	−1.2		
	Lewis GAC	Count	135	3	138	
		% within bracket type	97.8%	2.2%	100.0%	NS
		Std. residual	−0.1	0.4		
	Innovation R GAC	Count	141	0	141	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	.2	−1.6		
	SmartClip 3M Unitek	Count	45	0	45	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.1	−0.9		
	Transcend 3M Unitek	Count	19	0	19	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.1	−0.6		
	Clarity 3M Unitek	Count	33	0	33	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.1	−0.8		
	Innovation C GAC	Count	19	0	19	NS
		% within bracket type	100.0%	0.0%	100.0%	
		Std. residual	0.1	−0.6		
	T3 American	Count	4	0	4	NS
		% within bracket type	100.0%	0.0%	100.0%	
		Std. residual	0.0	−0.3		
	Damon Ormco	Count	15	0	15	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.1	−0.5		
	Synergy RMO	Count	12	1	13	
		% within bracket type	92.3%	7.7%	100.0%	NS
		Std. residual	−0.2	1.6		
	Omni Arch GAC	Count	2	0	2	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.0	−0.2		
	Integra Advanced Ortho systems	Count	4	0	4	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.0	−0.3		
	Alexander Ormco	Count	3	0	3	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.0	−0.2		
	Lotus Ortho Technology	Count	4	0	4	
		% within bracket type	100.0%	0.0%	100.0%	NS
		Std. residual	0.0	−0.3		
	Innovation L GAC	Count	4	0	4	NS
		% within bracket type	100.0%	0.0%	100.0%	
		Std. residual	0.0	−0.3		
Total		Count	1409	25	1434	
		% within bracket type	98.3%	1.7%	100.0%	

Journal of Orthodontics jor11-260.3d 10/10/13 17:55:46
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Table 4 Archwire size and wire failure cross-tabulation.

	Wire failure			
NT wire size	No	Yes	Total	Chi-square
0.012 NT count	63	1	64	
% within size	98.4%	1.6%	100.0%	
Std. residual	0.0	−0.1		NS
0.014 NT count	452	13	465	
% within size	97.2%	2.8%	100.0%	
Std. residual	−0.2	1.7		NS
0.016 NT count	237	4	241	
% within size	98.3%	1.7%	100.0%	
Std. residual	0.0	−0.1		NS
0.018 NT count	453	7	460	
% within size	98.5%	1.5%	100.0%	
Std. residual	.0	−0.4		NS
0.020 NT count	61	0	61	
% within size	100.0%	0.0%	100.0%	
Std. residual	0.1	−0.1		NS
0.014 SS count	12	0	12	
% within size	100.0%	0.0%	100.0%	
Std. residual	0.1	−0.5		NS
0.016 SS count	24	0	24	
% within size	100.0%	0.0%	100.0%	
Std. residual	0.1	−0.6		NS
0.018 SS count	99	0	99	
% within size	100.0%	0.0%	100.0%	
Std. residual	0.2	−1.3		NS
0.020 SS count	8	0	8	
% within size	100.0%	0.0%	100.0%	
Std. residual	0.0	−0.4		NS
Total count	1409	25	1434	
% within size	98.3%	1.7%	100.0%	

A Chi-square statistical test was utilized to address the frequency and the correlation between the different variables. The level of statistical significance (α) was set at 0.05. Standardized residuals within the context of Chi-square were utilized to represent the absolute difference between the expected and observed cell frequencies. The null hypothesis stated that there was no difference between the expected and observed values. Computing standardized residuals enables the identification of cells with major contributors to significant Chi-square values. PASW Statistics software (Predictive Analytics Software version 17, Chicago, IL, USA) was use for data analysis.

Results

Of the total sample of 1434 archwires, 813 maxillary arches and 621 mandibular arches were examined. Based on gender, the sample was distributed into 586 male patients and 848 female patients with ages ranging from 9 to 67 (mean ages: 16.19 and 17.60 years, respectively). The distribution based on archwire material was 1279 for NiTi round wires and 155 for stainless steel round wires. This represents 89.2% and 10.8% of the total sample size, respectively. A total of sixteen different bracket types were identified. In this sample, the Victory MBT (3M Unitek) was the most commonly used, representing 57% of the total sample.

Only 25 archwires from a total sample of 1434 were recorded as having failed (1.7%). Of the 25 archwires that failed, all were NiTi (Table 1). As to location, 16 archwires (76%) fractured in the posterior region (premolar and molar region), while only 9 (24%) failures were found in the anterior region (incisor and canine region).

Analysis of the correlation between arch type (maxillary/mandibular) and archwire failure was not found to be significant (Table 2). Of the 25 archwire fractures, 13 were found in males and 12 were found in females. Twenty patients with Victory MBT brackets, one with MiniTwin brackets, three with Lewis brackets and one with Synergy brackets reported archwire fracture.

Cross tabulation of archwire failure and bracket type was not statistically significant (Table 3). Also, cross tabulation of archwire failure and archwire size demonstrated no statistical significance, either (Table 4).

The 25 patients who had fractured archwires were further analysed to evaluate any relationship between archwire fracture and clinical presentation, such as the specific location of the fracture, large span of unsupported wires, rotation of more than 30°, mandibular plane angle, molar and canine relationship, type of dentition, known cause, skeletal classification, ANB and finally the Wits appraisal (Table 5). Twenty exhibiting wire failure presented with a normodivergent facial pattern. Eleven patients had an end-on molar occlusion on the affected side. Of the remaining 14 patients, 10 patients had class I, one had class II, 1 had Class III and in 2 patients, the first permanent molar was not present. Thirteen subjects presented with an end-on canine relationship, seven had class I, and in five subjects, the canines were unerupted. Nineteen patients had permanent dentition, while six patients presented in the late mixed dentition.

Discussion

The goal of this *in vivo* study was to determine the frequency and location of archwire fracture. The results of this study found that the frequency of archwire fracture during regular orthodontic visits was minimal

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Table 5 Archwire fracture and clinical presentation.

Subject	Location	Situation	MPA	Molar	Canine	Dentition	Cause	Skeletal	ANB	Wits
1	DUR2	Span 2-E	Norm	EO EO	EO EO	LMIX	UKN	II	4	0.8
2	MLR6		Hyper	EO III	I X	PERM	PLAY	III	8	4
3	MLR6 MLL6		Norm	I I	EO EO	PERM	CHEW	II	8	−0.2
4	MLR6 MLL6		Norm	I I	EO EO	PERM	CHEW	II	8	−0.2
5	L3-3	Span 3-3	Norm	EO EO	EO EO	L MIX	CHEW	II	6	4
6	LR6		Norm	I X	EO EO	PERM	CHEW	II	4	−4
7	LR6		Norm	I X	EO EO	PERM	CHEW	II	4	−4
8	MLL7		Norm	I X	EO EO	PERM	CHEW	II	4	−4
9	MLL7		Norm	I X	EO EO	PERM	CHEW	II	4	−4
10	DUL3	Span D to 3	Norm	EO EO	EO EO	PERM	UKN	II	4	−1.3
11	DLR2	Unerupted 3	Hypo	EO EO	X X	L MIX	UKN	I	.4	−3
12	DLR2	Unerupted 3	Hypo	EO EO	X X	L MIX	UKN	I	.4	−3
13	MLL6		Norm	II EO	EO EO	PERM	UKN	II	4	4
14	MLL6		Norm	II EO	EO EO	PERM	UKN	II	4	4
15	MLR1	Deep bite	Norm	I I	I I	L MIX	CHEW	II	2	−2
16	MUR6		Norm	I I	EO EO	PERM	UKN	II	6	6
17	DLR4	Rotated LR3	Norm	EO EO	X X	PERM	PLAY	II	4	2
18	DLR4	Rotated LR3	Norm	EO EO	X X	PERM	PLAY	II	4	2
19	MUR1		Hypo	EO EO	EO EO	PERM	UKN	II	5	3
20	MLR6		Norm	III I	I I	PERM	CHEW	I	1	−6
21	MLR6		Norm	III I	I I	PERM	CHEW	I	1	−6
22	DL3		Norm	III I	I I	PERM	CHEW	II	1	−6
23	MLR6		Norm	I X	I I	PERM	UKN	II	5	−1
24	DUR2		Hypo	II II	X X	L MIX	PLAY	II	3	3
25	MLR6		Norm	I X	I I	PERM	UKN	II	5	−1

Abbreviations:
Location: DUR (distal upper right), DLR (distal lower right), MLR (mesial lower right), MLL (mesial lower left), DL (distal lower), L (lower).
MPA: Norm (Normodivergent), Hyper (Hyperdivergent), Hypo (Hypodivergent).
Molar: Canine: I (class I), II (class II), III (class III), EO (end-on), X (missing).
Dentition: L MIX (Late mixed dentition), PERM (Permanent dentition).
Cause: UKN (Unknown), Chew (Chewing), PLAY (Playing).

(1.7%) with most of the failures occurring in the posterior region (76%), probably due to the high magnitude of masticatory forces in this region or greater inter-bracket distance in the posterior teeth. All archwire fractures occurred in NiTi wires. It appears that continuous advancements in orthodontics wires are improving archwire properties and are minimizing wire fracture.

It is not surprising that none of the stainless steel wires fractured, since these wires are the strongest orthodontic wires.[18] Increased strength increases stiffness and reduces range, and therefore, most clinicians prefer NiTi archwires for initial leveling and aligning stage.[18] Statistically, the correlation between archwire fracture, gender, arch type, bracket type and diameter of archwire was not significant. Out study included a very large sample size, and investigated a potential problem that has not been widely measured. However, it was limited to round orthodontic archwire fracture. Further exploration of rectangular orthodontic archwires fracture can be beneficial.

It can be concluded that archwire fracture is not a major clinical concern during orthodontic treatment. However, it may be occasionally encountered, especially in non-cooperative patients. Aside from the clinical significance of these findings, archwire fracture is not of such clinical significance that it needs to be discussed from an informed consent perspective.

Conclusions

- The frequency of archwire fracture during regular orthodontic visits is very low.
- The most common archwire fracture site is the posterior region.
- Nickel-titanium wires are the most commonly fractured archwires.
- No significant correlation exists between archwire fracture and gender, arch type, bracket type and diameter of archwire.

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