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Which orthodontic archwire sequence? A randomized clinical trial

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SUMMARY The aim of this study was to compare three orthodontic archwire sequences. One hundred and fifty-four 10- to 17-year-old patients were treated in three centres and randomly allocated to one of three groups: A = 0.016-inch nickel titanium (NiTi), 0.018 × 0.025-inch NiTi, and 0.019 × 0.025-inch stainless steel (SS); B = 0.016-inch NiTi, 0.016-inch SS, 0.020-inch SS, and 0.019 × 0.025-inch SS; and C = 0.016 × 0.022-inch copper (Cu) NiTi, 0.019 × 0.025-inch CuNiTi, and 0.019 × 0.025-inch SS. At each archwire change and for each arch, the patients completed discomfort scores on a seven-point Likert scale at 4 hours, 24 hours, 3 days, and 1 week. Time in days and the number of visits taken to reach a 0.019 × 0.025-inch SS working archwires were calculated. A periapical radiograph of the upper left central incisor was taken at the start of the treatment and after placement of the 0.019 × 0.025-inch SS wire so root resorption could be assessed.

There were no statistically significant differences between archwire sequences A, B, or C for patient discomfort ($P > 0.05$) or root resorption ($P = 0.58$). The number of visits required to reach the working archwire was greater for sequence B than for A ($P = 0.012$) but this could not be explained by the increased number of archwires used in sequence B.

Introduction

The aim of this study was to evaluate three orthodontic archwire sequences in terms of patient discomfort, root resorption, and time to working archwire. This is important because the aim is to reach the working archwire not only efficiently but also in physiologically sound archwire steps (Burstone and Koenig, 1974; Waters *et al*., 1975; Burstone, 1981; Rock and Wilson, 1988; Tidy, 1989; Waters, 1992). However, a balance should be made between the potential benefits of a more rapid progression to working wires and risks such as root resorption (Remmington *et al*., 1989; Linge and Linge, 1991) and patient discomfort (Ngan *et al*., 1989; Wilson *et al*., 1989).

There is a lack of *in vivo* data to support the choice of archwire sequence because of the difficulty in evaluating intra-oral force levels. Rock and Wilson (1988) suggested using clinical success factors as outcomes, including rate of tooth movement, absence of iatrogenic damage, and patient acceptance. The rate of tooth movement or time in initial aligning archwires has been evaluated (O'Brien *et al*., 1990; Jones and Chan, 1992; West *et al*., 1995). However, archwire sequence past initial aligning wires has not been investigated and thus provided the focus for this trial. The null hypothesis tested was as follows:

There is no difference in (1) patient discomfort (2) root resorption, and (3) time to working archwire between three archwire sequences: A = 0.016-inch nickel titanium (NiTi), 0.018 × 0.025-inch NiTi, and 0.019 × 0.025-inch stainless steel (SS); B = 0.016-inch NiTi, 0.016-inch SS, 0.020-inch SS, and 0.019 × 0.025-inch SS; and C = 0.016 × 0.022-inch copper (Cu) NiTi, 0.019 × 0.025-inch CuNiTi, and 0.019 × 0.025-inch SS.

Methods

Sample size calculation

Reuker (1979) reported a mean treatment time for the straightwire appliance system of 1.8 years with a standard deviation (SD) of 4 months. It was hypothesized in the present investigation that if the time to reach the working archwire were 3 months shorter for one archwire sequence, with a SD of 4 months, this would be clinically significant in terms of efficiency. When the sample size in each of the three groups was 40, a one-way analysis of variance (ANOVA) would have a 99 per cent power to detect, at the 0.05 level, a difference in means characterized by a variance of means of 3 months assuming the common SD is 4 months. This gave a total sample size for the trial of 120. One hundred and fifty-four patients were registered to allow for a drop-out rate of just over 20 per cent.

Ethical approval was obtained from the Central Manchester Local Research Committee (No. CEN/00/185) and written parent and child consent taken for patients at the University Dental Hospital of Manchester, Hope Hospital

(Salford), and a specialist orthodontic practice (Crewe, UK). Patients with pain from any other medical or dental condition that may have affected their reported discomfort scores were excluded. The inclusion criteria were <18 years, upper and lower pre-adjusted edgewise appliance (0.22-inch slot), and non-extraction or up to four premolar extractions.

Patients reporting a history of trauma (crown fracture or avulsion and re-implantation), central incisor root filling, or pre-existing root resorption (identified as radiographic blunting of the root apex of the upper left central incisor) were not excluded, but these factors were taken into account in the statistical analysis.

Randomization was carried out by throwing an unweighted die where 1 and 2 = archwire sequence A, 3 and 4 = sequence B, and 5 and 6 = sequence C. A restricted randomization was used in blocks of 12 to ensure equal allocation of patients to the treatment groups. Random allocation was concealed in thick opaque envelopes. Only when the patient was registered was the next consecutive envelope opened, ensuring that the clinician and patient were blind to the treatment allocation until the patient was registered in the trial.

Intervention and outcome measures

The planned intervention was one of three archwire sequences used to reach the working archwire (0.019 × 0.025-inch SS). All archwires were manufactured by Ormco (Amersfoort, The Netherlands), including 35 degrees thermoactive CuNiTi.

All archwires were left in place until they were passively engaged in all bracket slots before proceeding to the next archwire in the sequence. Since this was a 'realistic' study, it was left to clinical judgement whether to use elastic or wire ligatures and canine lacebacks. As a result of the randomization process, variables such as method and extent of ligation, lacebacks, push coil, and duration of time between appointments were divided with equal probability between groups A, B, and C.

Full or partial engagement of the initial aligning wires was not thought to influence discomfort levels because of the nature of the hysteresis curve exhibited by the NiTi archwires, whereby an increased wire deflection does not result in a proportional increase in force levels. However, the clinicians were asked not to place a palatal arch, quadhelix, or headgear at the same visit as the initial archwire so that discomfort from the former appliances did not influence archwire discomfort scores.

Three outcome measures were assessed: (1) patient discomfort at each archwire change and total discomfort for each archwire sequence, (2) root resorption (root length) of an upper left central incisor (in mm), and (3) time to reach upper and lower working archwire (0.019 × 0.025-inch SS) in months, and also the number of visits.

The following baseline data were collected: age and gender, operator level (staff or postgraduate student), type of malocclusion, extraction or non-extraction treatment, upper and lower labial segment crowding, irregularity index (Little, 1975) for upper and lower labial segments, and start of treatment periapical of the upper left central incisor.

When the archwires were changed, the patients recorded their discomfort on a seven-point Likert scale at 4 hours, 24 hours, 3 days, and 1 week for the upper and lower arches separately (Ngan *et al*., 1989; Wilson *et al*., 1989). The patients were given discomfort data sheets, as required, at the end of their adjustment appointment and asked to return them at the following visit.

The upper left central incisor was used as an indicator of likely root resorption and root length measurements were recorded by two authors (SD and MA-O) who were previously calibrated to use dial callipers (Mitutoyo, Andover, Hampshire, UK) accurate to a 10th of a millimetre. An upper incisor was chosen because it has been suggested that these are at most risk of root resorption (Remmington *et al*., 1989). The length of the crown from the cemento-enamel junction to the incisal tip was measured from a periapical radiograph taken at the start of treatment (C1) and after the working archwire was placed (C2). A correction factor for enlargement between the start and end-point radiograph was calculated as C1/C2. Apical root resorption was measured as root length at the start of treatment (R1) minus root length at the end of alignment (R2) and multiplied by the correction factor (Linge and Linge, 1991):

$$\text{Apical root resorption} = R1 - R2 \times (C1/C2).$$

Labial segment crowding was assessed by one author (NAM) by calculating the difference between the sum of the mesio-distal widths of the incisors and canines and the arch space available between the distal contact points of the canines. The latter was measured by summing the distance between the distal contact point of the canine and the mesial contact point of the central incisor on both sides of the arch. Labial segment irregularity was recorded according to the irregularity index (Little, 1975). Intra-examiner reliability was assessed by remeasuring 20 cases at least 1 week later.

At the end-point of the trial, when 0.019 × 0.025-inch SS wire had been passively placed in both arches for at least 4 weeks, a second periapical radiograph of the upper left central incisor was taken. The time taken and the number of visits to reach the working archwire were recorded from the patient notes.

At the end of the trial, the case notes were checked for any other protocol violations i.e. designated archwire sequence not being used, and the reasons for this were recorded. Such patients were still included in the intention to treat analysis. For some patients, 0.016 × 0.022-inch

CuNiTi was ineffective for severely rotated premolars. Therefore, if 0.016 × 0.022-inch CuNiTi was ineffective and had been in place >6 months, it was agreed to keep the patient in the study but change the initial aligning wire to 0.016-inch NiTi.

Method error

Systematic error was reduced by ensuring that the examiner was blind to the archwire allocation when labial segment crowding, Little's index, and root resorption were measured. In addition, root resorption measurements were made in a random order so that patients' start and end-point radiographs were not measured consecutively. It was not possible to blind either the treating clinicians or the examiner (SW) who recorded time to working archwire from the patient notes.

Random error was reduced by taking measurements twice and calculating a mean score for root lengths, labial segment crowding, and Little's index.

Statistics

Summary statistics were calculated and the data checked for normality. ANOVA was used to compare archwire sequence groups for the main outcome measures. Intra-examiner reliability for the dial calliper measurement was assessed using intra-class correlation coefficients (ICCs). Systematic error was quantified by examination of the difference and 95 per cent confidence intervals.

Results

Table 1 shows the number of patients in each group and the reasons for any dropouts. There was no apparent systematic error for any of the outcomes, as the differences between means were very small and the 95 per cent confidence limits narrow. ICC revealed high intra-examiner reliability for Little's index (0.99), labial segment crowding (0.96), and root length (0.98).

The characteristics of the patients in each archwire sequence group are summarized in Tables 2 and 3. Up to one-third of patients had reported upper incisor trauma. There were more females than males, which reflects the uptake of orthodontic treatment, with the exception of group A where 60.8 per cent of patients were male. The distribution of the type of malocclusion and extraction/non-extraction cases was similar between the archwire sequence groups. ANOVA revealed no statistically significant differences between archwire sequences for labial segment crowding ($P = 0.56$) or Little's index ($P = 0.46$). An intention to treat statistical analysis was carried out, whereby data for patients who did not receive the correct allocated archwires were included in the analysis ($n = 4$).

The influence of operator experience on outcome variables

T-tests were used to evaluate whether operator experience influenced any of the outcome variables. In summary, reported discomfort at 24 hours (maximum discomfort) was similar for postgraduate ($n = 8$) and staff ($n = 2$) patients ($P > 0.05$) except for lower arch/sequence C where mean discomfort was 3.3 for staff and 5.2 for postgraduates ($P = 0.015$). Root resorption was not statistically significantly different for staff or postgraduates ($P = 0.41$). Postgraduates took a slightly longer time to reach the upper working archwire only ($P = 0.022$) and more visits to reach upper and lower working archwires ($P < 0.05$). Therefore, operator experience was factored into the analysis for time and number of months to working archwire.

Archwire sequence and patient discomfort

Mean discomfort scores at different time intervals for each archwire sequence are shown in Table 4. For example, the score at 4 hours for sequence A indicates the mean discomfort experienced for the whole archwire sequence at 4 hours (0.016-inch NiTi, 0.018 × 0.025-inch NiTi, and 0.019 × 0.025-inch SS). ANOVA did not reveal any statistically significant difference in reported discomfort between archwire sequences A, B, or C (F ratio, $P > 0.05$). In addition, there was no statistically significant difference between the proportion of patients who returned/did not return discomfort data in groups A, B, or C [chi-square value 0.49, $P = 0.79$, 2 degrees of freedom (df)]. This suggested that there was no evidence of bias towards patients returning data as potentially they may have experienced more discomfort.

Table 1 Trial profile.

	Archwire sequence		
	Sequence A	Sequence B	Sequence C
Received standard intervention	51	50	53
Protocol violations	0	2*	2*
Followed up	41	44	44
Withdrawn (total)	10	6	9
Reasons for withdrawal			
Lost for follow-up (failed appointments)	7	4	5
Patient requested appliance removal	2	0	2
Obtained treatment elsewhere	0	1	0
Operator stopped treatment			
Repeated breakages	1	0	1
Poor oral hygiene	0	1	1
Completed trial	41	44	44

*Patients with protocol violations in sequence B and C were still included in the analysis as an 'intention to treat' statistical analysis was used.

Table 2 Descriptive statistics for each archwire sequence for the patients enrolled in the trial.

	Archwire sequence		
	A	B	C
Mean age in years (SD)	13.8 (1.6)	14.4 (1.9)	14.4 (1.8)
Gender (%)			
Male	31 (60.8)	13 (26.0)	18 (34.0)
Female	20 (39.2)	37 (74.0)	35 (66.0)
History of incisor trauma (%)			
Yes	14 (27.5)	6 (12.0)	11 (20.8)
No	37 (72.5)	44 (88.0)	42 (79.2)
Root filled upper left central incisor (%)			
Yes	1 (2.0)	0 (0)	0 (0)
No	50 (98.0)	50 (100)	53 (100)
Pre-existing root resorption upper left central incisor (%)			
Yes	1 (2.0)	0 (0)	0 (0)
No	50 (98)	50 (100)	53 (100)

Table 3 Occlusal descriptives according to archwire sequence for patients enrolled in the trial.

	Archwire sequence		
	A	B	C
Type of malocclusion (%)			
Class I	13 (25.5)	13 (26.0)	19 (35.8)
Class II division 1	18 (35.3)	18 (36.0)	17 (32.1)
Class II division 2	12 (23.5)	9 (18.0)	6 (11.3)
Class III	8 (15.7)	10 (20.0)	11 (20.8)
Extraction/non-extraction (%)			
Extraction	32 (68.1)	35 (70.0)	37 (71.2)
Non-extraction	15 (31.9)	15 (30.0)	15 (28.8)
Mean labial segment crowding [mm (SD)]			
Upper	4.01 (4.3)	3.77 (4.71)	3.20 (4.26)
Lower	3.26 (2.63)	3.10 (2.36)	3.55 (2.66)
Little's index [mm (SD)]			
Upper	10.70 (6.10)	10.48 (6.54)	9.60 (6.40)
Lower	6.49 (5.05)	5.72 (4.31)	6.05 (4.75)

Archwire sequence and root resorption

Mean root resorption for archwire sequence A was 0.96 mm (SD 1.0 mm), sequence B 1.39 mm (SD 1.8 mm), and sequence C 1.19 mm (SD 1.5 mm). ANOVA revealed no statistically significant difference between archwire sequences, for upper left central incisor root resorption (F ratio, $P = 0.58$). However, this should be interpreted with caution as the SDs were large. There was also no statistically significant difference between the proportion of patients with/without root resorption data between archwire sequences (chi-square value 5.0, $P = 0.80$, 2 df). Additionally, reported history of incisor trauma was not associated with increased root resorption (t-test: $P = 0.59$).

Archwire sequence and time to 0.019 × 0.025-inch SS working archwire

The mean time taken and the number of visits to reach 0.019 × 0.025-inch SS working archwire are shown in Tables 5 and 6. Operator experience was factored into the ANOVA for this variable. Although there was a trend for sequence B to take longer, there was no statistically significant difference between archwire sequences for time taken (F ratio, $P > 0.05$). However, sequence B required statistically significantly more visits, before the working archwire was placed, compared with sequence A (F ratio, $P = 0.007$ for upper arch and $P < 0.001$ for lower arch).

There was no statistically significant difference between the proportion of patients with complete/incomplete data for this variable (chi-square value 0.70, $P = 0.71$, 2 df).

Discussion

This trial showed that no archwire sequence tested was more effective than another, in terms of reported patient discomfort or upper incisor root resorption. However, clinicians may choose a NiTi sequence with the aim of reducing the number of visits to reach the working archwire. There are other factors that influence the choice of archwire progression, such as personal preference and cost, and these should be considered equally alongside the clinical evidence presented.

Importantly, the archwire sequences investigated do not appear to cause unacceptable iatrogenic root resorption or high levels of patient discomfort.

It is difficult to compare this data with the previous literature as other archwire trials evaluated initial aligning wires only (O'Brien *et al*., 1990; Jones and Chan, 1992; West *et al*., 1995). However, it would seem that an efficient archwire sequence of 0.016-inch NiTi, 0.018 × 0.025-inch NiTi, and 0.019 × 0.025-inch SS suggested by Tidy (1989) is now clinically supported.

When separate outcomes are considered, root resorption in this study was similar to that reported by Linge and Linge (1991) of 1.54 mm. Additionally, when clinically significant root loss is considered as >2.5 mm, the results are also comparable with Linge and Linge (1991) reporting 16.5 per cent of patients affected and this trial 18.1 per cent. It may be that the present results underestimate root resorption as the data only record up to the passive placement of working archwires and not to the end of treatment. In addition, although baseline risk variables such as the presence of a root filling were recorded, these were small in number and statistical analysis was not carried out.

A previous trial by Jones and Chan (1992) showed no statistically significant differences in discomfort between 0.015-inch twistflex and 0.014-inch Japanese NiTi. Although different archwires and sequences of archwire were compared, the results of this trial support their data in that patient discomfort was not influenced by the type of archwire.

Table 4 Mean discomfort scores over time for each archwire sequence*.

Sequence	Mean discomfort at 4 hours (SD)		Mean discomfort at 24 hours (SD)		Mean discomfort at 3 days (SD)		Mean discomfort at 1 week (SD)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
A	2.9 (1.8)	3.5 (2.1)	2.9 (1.6)	3.3 (1.7)	1.9 (1.1)	2.2 (1.8)	1.2 (0.4)	1.3 (0.9)
B	3.8 (1.7)	3.9 (2.0)	4.2 (1.8)	4.0 (1.8)	2.3 (1.2)	2.3 (1.0)	1.5 (0.9)	1.4 (0.6)
C	3.6 (1.6)	3.3 (1.7)	4.0 (1.6)	3.6 (1.5)	2.7 (1.1)	2.5 (1.3)	1.5 (0.4)	1.7 (0.8)

Likert scale 1–7: 1 = no discomfort at all, 7 = significant discomfort.
*No statistically significant difference between archwire sequences (ANOVA; F ratio, $P > 0.05$).

Table 5 Mean time taken to placement of 0.019 × 0.025-inch SS working archwire according to archwire sequence.

Archwire sequence	Mean time taken to placement of working archwire in months (SD)	Mean number of visits to placement of working archwire (SD)
A		
Lower	6.8 (2.5)	5.7 (2.1)
Upper	6.7 (3.5)	5.4 (2.1)
B		
Lower	9.3 (4.4)	7.5 (1.9)
Upper	7.9 (3.5)	7.1 (2.6)
C		
Lower	8.3 (4.2)	6.4 (2.2)
Upper	7.1 (3.4)	5.9 (2.8)

Table 6 ANOVA (Bonferroni correction) comparing the number of visits to placement of working archwire.

Dependent variable	Archwire sequence		Mean difference	Standard error	P value	95% confidence interval
Number of visits to upper working wire	A	B	−1.6	0.5	0.007	−2.9 to −0.4
	B	C	−0.5	0.5	1.00	−1.8 to 0.8
		C	1.1	0.5	0.10	−0.15 to 2.4
Number of visits to lower working wire	A	B	−1.8	0.4	<0.001	−3.0 to −0.7
	B	C	−0.7	0.5	0.34	−1.8 to 0.4
		C	1.1	0.4	0.06	−0.02 to 2.1

As this study did not find any clinical factors that may influence the choice of archwire, consideration may be given to cost. It is also clinically important to note that two patients receiving sequence C had severe premolar rotations where 0.016 × 0.022-inch CuNiTi was ineffective. This was because it could not be tied in adequately due to a very short interbracket span. It may therefore be more advantageous to use another aligning archwire in these instances.

Table 7 Number of patients with complete data for main outcomes.

Outcome	Archwire sequence	Number or range of subjects with complete data	Number of subjects registered in trial	Number of subjects completing trial
Pain	A	Range 15–22	51	41
	B	Range 11–16	50	44
	C	Range 15–16	53	44
Root resorption	A	28		
	B	29		
	C	37		
Time/months to working archwire				
Upper	A	41		
	B	41		
	C	39		
Lower	A	35		
	B	40		
	C	34		

Numbers in archwire groups are based on an 'intention to treat analysis' where patients not receiving the allocated treatment are still included in the statistical analysis. The number of patients remaining in the trial, in each group, is included in the table for reference.

Missing data

There was some missing data in this trial mostly because of patients not returning their discomfort scores, inadequate or illegible information in the notes, and radiographs not showing the root apex of the upper incisor. Table 7 shows the number of patients with complete data for each outcome. However, analysis suggested that there was no statistically significant difference, and therefore no bias, between the proportion of patients for whom data were or were not available.

It is possible that patients not returning discomfort sheets experienced less pain than those who returned data. However, as the reported discomfort was low, non-returners experiencing less discomfort are likely to be clinically insignificant.

Conclusions

The archwire sequences investigated were not statistically significantly different in terms of patient discomfort and

upper incisor root resorption. However, clinicians may choose sequence A to minimize the number of visits to the working archwire.

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