Arch-dimensional changes in non-extraction cases with finishing wires of a particular material, size and arch form

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Aim: This study was undertaken to assess pre- and post-treatment upper and lower arch dimensions, and changes occurring in those dimensions, during orthodontic treatment without premolar extractions, when finishing wires of a particular material, size and arch form had been used.

Methods: The records of 58 patients (31 male and 27 female) with a mean age of 13.52 (±1.60) years were selected for this study, with ethics approval gained from the Departmental Human Ethics Advisory Group of the University of Melbourne (DHEAG no: 1033997.1). All patients had been treated with fixed appliances (0.018 inch, pre-adjusted edgewise) in the early permanent dentition, without premolar extractions, by one experienced orthodontist. Pre- and post-treatment upper and lower arch dimensions were measured from study casts. Correlation coefficients were calculated between these measurements as well as pretreatment cast and vertical cephalometric measurements, gender and the amount of crowding that had been relieved.

Results: Despite the use of finishing archwires of the same material, size and arch form (0.016 x 0.022 inch, heat-treated cobalt-chromium), there was considerable variation in dimensional changes that occurred during treatment within the total sample and its various subgroups, and in the final arch dimensions. All arch width changes were found to be strongly correlated with the amount of pretreatment crowding. Post-treatment arch dimensions and changes in those dimensions were also strongly correlated with pretreatment dimensions, suggesting that the final post-treatment arch dimensions were significantly influenced by other factors rather than simply the material, size and arch form of the finishing wires. In this treated sample, no statistically significant differences were found in the resultant arch widths and arch width changes occurring in the different vertical pattern subgroups.

Conclusion: The placement of finishing wires of a particular material, size and arch form is unlikely to result in exactly matching end-of-treatment arch forms and dimensions in all orthodontic patients. Instead, whether using a 0.018 or a 0.022 inch slot system, the clinician should expect considerable individual variation in final arch form and dimension, despite the placement of apparently very similar wires. The main determinants of final arch form and dimension appear to be the original muscular and occlusally-related arch form and dimension and the amount of crowding to be relieved. Final arch forms and dimensional changes with treatment are unlikely to be directly related to patient gender, age or underlying vertical pattern. The findings indicate that clinicians must decide whether they will accept the considerable lateral and antero-posterior expansion that is likely to occur when crowding is to be relieved in the permanent dentition without premolar extractions.

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Introduction

Orthodontic diagnosis and treatment planning involves consideration of the likely three-dimensional changes in the dentition and the entire dento-facial complex. Influencing factors include the amount of pretreatment crowding, Angle’s molar classification, incisal overjet and overbite, vertical and transverse growth patterns and gender, as well as lip and tongue soft-tissue factors and breathing patterns. Historically, the use of many variable arch forms has
been proposed and the placement of standard-sized and custom-shaped finishing wires is still common in contemporary clinical practice. In addition, it has previously been proposed that patients with different underlying vertical facial patterns might present with different naturally-occurring arch forms. Historically, it has been accepted that greater changes in arch form during treatment are perhaps associated with long-term instability of the orthodontic result. The present study was therefore undertaken to assess the ranges of likely post-treatment arch dimensions, and changes in those dimensions, that might occur when finishing wires of a particular material, size and arch form were placed during early permanent dentition orthodontic treatment, without premolar extractions. It was expected that various factors influencing post-treatment arch dimensions might also be identified.

Materials and methods

Study sample

The records of 58 patients (31 male and 27 female) with a mean age of 13.52 (± 1.60) years were selected for this study. The mean ages at commencement and the duration of active treatment are presented in Table I. All patients had been treated by one orthodontist with more than 20 years’ experience and had been treated with contemporary pre-adjusted fixed appliances (0.018 × 0.028 inch slot) without premolar extractions, commencing in the early permanent dentition. No adjunctive appliances such as quad helices, functional appliances, or rapid palatal expanders had been used. Upper and lower finishing archwires of the same material, size and arch form (0.016 × 0.022 inch, heat-treated cobalt-chrome) were placed in all cases, for a minimum of six months before the removal of active appliances. The lower archwire was bent using a contemporary arch form template (3M Unitek, CA, USA), with the upper archwire then matched to the lower arch form, 3 mm wider all around (Figure 1). High quality pretreatment lateral cephalometric radiographs were available.

Cephalometric analysis

All pretreatment cephalograms were hand traced by one examiner (D.A.) and digitised using Westceft cephalometric software (customised analysis software by Mr Geoffrey West). The cephalometric measurements used in the present study are listed in Table II. The patient sample was divided into three vertical facial pattern groups on the basis of the facial axis (one measure of underlying vertical pattern and mandibular growth direction) as follows: the dolichofacial group, facial axis < 87º; the mesofacial group, facial axis between 87º and 93º; and the brachyfacial group, facial axis > 93º. For interest only, and to confirm the vertical patterns, data related to the mandibular plane angle are also included in Table I. These mandibular plane figures generally reflect the same classifications as those for the facial axis angle, with some overlap.

Study cast analysis

Pre- and post-treatment study cast measurements are listed in Table II and illustrated in Figure 2. The
Measurements were produced using an electronic digital sliding caliper to the nearest 0.1 mm (Mitutoyo Corporation, Tokyo, Japan). The amount of crowding (tooth-size – arch-length discrepancy) that had been relieved was calculated using the segmental method of Proffit and Fields, by subtracting the pretreatment segmental total from the post-treatment segmental total (Figure 3).

In order to determine measurement error, 20 randomly-selected study cast and cephalometric measurements were repeated one month later. The standard measure of error as described by Dahlberg and the coefficient of reliability were calculated. This analysis showed that there were no clinically significant differences between the two sets of measurements at the 95% confidence level.

| Age pretreatment (years) | Duration of treatment (years) | Facial axis (degrees) | Mandibular plane angle (degrees) |
|--------------------------|-------------------------------|-----------------------|----------------------------------|
|                          | N    | Mean  | SD  | Min  | Max  | Signif | N    | Mean  | SD  | Min  | Max  | Signif | N    | Mean  | SD  | Min  | Max  | Signif |
| Total sample             | 58   | 13.47 | 1.63 | 9.83 | 16.67 | -      | 2.13 | 0.60  | 0.83 | 4.17 | 9.02  | 4.46  | 79.80 | 99.08 | 25.07 | 5.84  | 13.66 | 38.05 | -       |
| Male                     | 31   | 13.81 | 1.62 | 9.83 | 16.67 | NS     | 2.12 | 0.55  | 1.17 | 3.25 | 91.50 | 4.09  | 79.80 | 97.26 | 24.52 | 5.75  | 14.23 | 35.55 | NS     |
| Female                   | 27   | 13.09 | 1.59 | 10.00| 15.58 | NS     | 2.14 | 0.67  | 0.83 | 4.17 | 90.48 | 4.87  | 80.13 | 99.08 | 25.70 | 5.98  | 13.66 | 38.05 | NS     |
| Brachyfacial             | 18   | 13.30 | 1.27 | 11.33| 15.08 | NS     | 2.15 | 0.76  | 0.83 | 4.17 | 95.76 | 1.45  | 94.26 | 99.08 | 21.26 | 4.75  | 14.23 | 29.79 | NS     |
| Mesofacial               | 29   | 13.78 | 1.74 | 9.83 | 16.67 | NS     | 2.03 | 0.52  | 1.17 | 3.00 | 90.76 | 1.66  | 87.08 | 93.67 | 24.78 | 4.87  | 13.66 | 33.82 | NS     |
| Dolichofacial            | 11   | 12.95 | 1.83 | 10.00| 15.58 | NS     | 2.36 | 0.52  | 1.67 | 3.25 | 83.97 | 2.59  | 79.80 | 86.96 | 32.06 | 3.04  | 28.97 | 38.05 | NS     |

SD = Standard deviation, Min = minimum value, Max = maximum value, NS = not significant

Table I. Sample characteristics

Measurements were produced using an electronic digital sliding caliper to the nearest 0.1 mm (Mitutoyo Corporation, Tokyo, Japan). The amount of crowding (tooth-size – arch-length discrepancy) that had been relieved was calculated using the segmental method of Proffit and Fields, by subtracting the pretreatment segmental total from the post-treatment segmental total (Figure 3).

| Measurement Definition | Arch width (mm) | Intermolar width (mm) | Inter-premolar width (mm) | Inter-molar width (mm) | Arch depth (mm) | Crowding (mm) | Mandibular plane angle (degrees) |
|------------------------|----------------|----------------------|--------------------------|-----------------------|----------------|---------------|----------------------------------|
| Arch width (mm)        | Arch width (mm) | Intermolar width (mm) | Inter-premolar width (mm) | Inter-molar width (mm) | Arch depth (mm) | Crowding (mm) | Mandibular plane angle (degrees) |
| Intermolar width (mm)  | Intermolar width (mm) | Inter-premolar width (mm) | Inter-molar width (mm) | Arch depth (mm) | Crowding (mm) | Mandibular plane angle (degrees) |
| Inter-premolar width (mm) | Inter-premolar width (mm) | Inter-molar width (mm) | Arch depth (mm) | Crowding (mm) | Mandibular plane angle (degrees) |
| Inter-molar width (mm) | Inter-molar width (mm) | Arch depth (mm) | Crowding (mm) | Mandibular plane angle (degrees) |

Table II. Cephalometric and study cast measurements.
statistics applied. Mean changes were calculated for each cephalometric and study cast variable in the total sample and the created subgroups. Significant differences were subjected to analysis of variance between the genders and the three vertical pattern groups, respectively. A t-test was applied to identify significant differences between the gender groups. Statistical significance was set at either $p \leq 0.05$ or $p \leq 0.01$. The relationships between the various study variables were also tested with Pearson’s product moment correlation coefficients.

**Results**

Pretreatment and post-treatment arch dimensions and dimensional changes are presented in Tables III to VIII. It should be noted that there was considerable individual variation for all pre- and post-treatment measurements within the total sample of young orthodontic patients and in all the sub-groups.

**Gender effect**

All mean pretreatment upper arch widths were significantly greater in males than in females, but considerable individual variation was evident (Table III). In contrast, there were no significant differences between the pretreatment male and female lower arch widths (Table IV). Following treatment, a number of male and female mean values were significantly different, although these differences were relatively small and of questionable clinical significance (Tables V and VI).

**Vertical facial pattern effect**

In the treated sample, no statistically significant differences were found in the means for either pre- or post-treatment upper and lower arch dimensions in the three vertical pattern sub-groups (Tables III to VI). Instead, there was considerable individual variation.
### Table III. Pretreatment maxillary arch dimensions

|                         | Maxillary canine width pretreatment | Maxillary premolar width pretreatment | Maxillary molar width pretreatment | Maxillary arch depth pretreatment | Maxillary crowding pretreatment |
|-------------------------|-------------------------------------|--------------------------------------|-----------------------------------|----------------------------------|--------------------------------|
|                         | N  | Mean  | SD   | Min   | Max   | Signif | N  | Mean  | SD   | Min   | Max   | Signif | N  | Mean  | SD   | Min   | Max   | Signif | N  | Mean  | SD   | Min   | Max   | Signif |
| Total sample            | 58 | 33.86 | 2.23 | 29.10 | 39.30 |        | 30.16 | 2.75 | 25.80 | 37.30 |        | 39.96 | 2.68 | 33.30 | 46.30 |        | 29.02 | 2.45 | 25.50 | 37.90 |        | 0.00 | 2.77 | 8.10 | 6.70 |        |
| Male                    | 31 | 34.71 | 2.29 | 30.10 | 39.30 | *      | 31.08 | 2.51 | 26.90 | 37.10 | *      | 40.75 | 2.83 | 33.30 | 46.30 | *      | 29.40 | 2.52 | 25.70 | 37.90 | NS    | 0.05 | 2.97 | 8.10 | 6.70 | NS    |
| Female                  | 27 | 32.89 | 1.73 | 29.10 | 36.90 | *      | 29.11 | 2.68 | 26.70 | 35.70 | *      | 39.05 | 2.20 | 35.40 | 44.50 | *      | 28.59 | 2.34 | 25.50 | 32.40 | NS    | 0.06 | 2.57 | 5.00 | 6.40 | NS    |
| Brachyfacial           | 18 | 34.07 | 3.13 | 29.10 | 39.30 | NS    | 30.55 | 3.27 | 25.90 | 37.50 | NS    | 40.57 | 3.46 | 33.30 | 46.30 | NS    | 29.41 | 2.69 | 26.20 | 37.90 | NS    | 0.23 | 2.91 | 5.00 | 6.70 | NS    |
| Mesofacial             | 29 | 34.10 | 1.71 | 31.30 | 37.70 | NS    | 30.20 | 2.43 | 25.80 | 37.10 | NS    | 39.81 | 2.11 | 35.40 | 45.30 | NS    | 28.84 | 2.25 | 25.70 | 33.60 | NS    | 0.39 | 2.80 | 8.10 | 3.80 | NS    |
| Dolichofacial         | 11 | 32.90 | 1.45 | 30.70 | 35.20 | NS    | 29.45 | 2.75 | 26.10 | 35.00 | NS    | 39.35 | 2.63 | 36.10 | 44.40 | NS    | 28.87 | 2.71 | 25.50 | 33.20 | NS    | 0.66 | 2.49 | -3.30 | 6.40 | NS    |

SD = Standard deviation, Min = minimum value, Max = maximum value, NS = not significant
* = \( p \leq 0.05 \) - test significant difference

### Table IV. Pretreatment mandibular arch dimensions

|                         | Mandibular canine width pretreatment | Mandibular premolar width pretreatment | Mandibular molar width pretreatment | Mandibular arch depth pretreatment | Mandibular crowding pretreatment |
|-------------------------|-------------------------------------|--------------------------------------|-----------------------------------|----------------------------------|--------------------------------|
|                         | N  | Mean  | SD   | Min   | Max   | Signif | N  | Mean  | SD   | Min   | Max   | Signif | N  | Mean  | SD   | Min   | Max   | Signif | N  | Mean  | SD   | Min   | Max   | Signif |
| Total sample            | 58 | 25.80 | 1.89 | 22.60 | 29.40 |        | 27.42 | 2.07 | 23.50 | 33.60 |        | 34.10 | 2.49 | 27.60 | 39.30 |        | 23.67 | 1.75 | 20.30 | 27.60 |        | 0.91 | 3.29 | -7.90 | 10.40 |        |
| Male                    | 31 | 26.12 | 1.87 | 22.60 | 29.40 | NS    | 27.82 | 2.10 | 23.50 | 33.60 | NS    | 34.40 | 2.71 | 27.60 | 39.30 | NS    | 23.57 | 1.76 | 20.30 | 26.50 | NS    | 1.74 | 3.37 | -7.90 | 10.40 | *      |
| Female                  | 27 | 25.43 | 1.87 | 22.60 | 29.40 | NS    | 26.96 | 1.97 | 23.70 | 31.10 | NS    | 33.76 | 2.21 | 29.30 | 38.70 | NS    | 23.78 | 1.76 | 20.90 | 27.60 | NS    | -0.03 | 2.98 | -6.80 | 4.30 | *      |
| Brachyfacial           | 18 | 25.87 | 2.18 | 22.60 | 29.40 | NS    | 27.72 | 2.33 | 23.50 | 31.10 | NS    | 34.48 | 2.91 | 27.60 | 38.70 | NS    | 23.97 | 1.20 | 22.40 | 26.60 | NS    | 0.88 | 2.96 | -5.30 | 4.80 | NS    |
| Mesofacial             | 29 | 25.85 | 1.87 | 23.30 | 29.40 | NS    | 27.60 | 1.92 | 24.70 | 33.60 | NS    | 34.01 | 1.97 | 30.60 | 39.30 | NS    | 23.60 | 2.06 | 20.30 | 27.60 | NS    | 1.26 | 3.86 | -7.90 | 10.40 | NS    |
| Dolichofacial         | 11 | 25.54 | 1.54 | 22.60 | 27.60 | NS    | 26.45 | 1.90 | 23.70 | 29.60 | NS    | 33.72 | 3.10 | 29.30 | 38.90 | NS    | 23.35 | 1.67 | 20.90 | 25.60 | NS    | 0.06 | 2.02 | -3.70 | 3.10 | NS    |

SD = Standard deviation, Min = minimum value, Max = maximum value, NS = not significant
* = \( p \leq 0.05 \) - test significant difference
**Table V.** Post-treatment maxillary arch dimensions.

|                      | N | Mean  | SD  | Min  | Max  | Signif | Mean  | SD  | Min  | Max  | Signif | Mean  | SD  | Min  | Max  | Signif |
|----------------------|---|-------|-----|------|------|--------|-------|-----|------|------|--------|-------|-----|------|------|--------|
| Total sample         | 58| 33.94 | 1.44| 30.30| 36.70|        | 30.59 | 1.36| 27.30| 33.30|        | 41.16 | 2.30| 36.20| 45.80|        |
| Male                 | 31| 34.26 | 1.48| 31.20| 36.70| NS     | 30.99 | 1.21| 28.80| 33.30| *      | 42.09 | 2.06| 38.40| 45.80| *      |
| Female               | 27| 33.56 | 1.33| 30.30| 35.60| NS     | 30.14 | 1.40| 27.30| 33.30| *      | 40.08 | 2.12| 36.20| 44.60| *      |
| Brachyfacial         | 18| 34.07 | 1.68| 31.20| 36.70| NS     | 30.76 | 1.19| 29.00| 33.00| NS     | 42.02 | 2.45| 37.40| 45.60| NS     |
| Mesofacial           | 29| 34.06 | 1.23| 31.30| 36.20| NS     | 30.59 | 1.48| 27.70| 33.30| NS     | 40.74 | 2.00| 36.60| 45.50| NS     |
| Dolichofacial        | 11| 33.39 | 1.54| 30.30| 35.60| NS     | 30.35 | 1.37| 27.30| 31.90| NS     | 40.85 | 2.63| 36.20| 45.80| NS     |

SD = Standard deviation, Min = minimum value, Max = maximum value, NS = not significant
* = p ≤ 0.05 - Test significant difference

**Table VI.** Post-treatment mandibular arch dimensions.

|                      | N | Mean  | SD  | Min  | Max  | Signif | Mean  | SD  | Min  | Max  | Signif | Mean  | SD  | Min  | Max  | Signif |
|----------------------|---|-------|-----|------|------|--------|-------|-----|------|------|--------|-------|-----|------|------|--------|
| Total sample         | 58| 26.66 | 1.47| 24.10| 33.20|        | 27.56 | 1.39| 24.10| 31.70|        | 35.04 | 2.08| 30.20| 40.50|        |
| Male                 | 31| 26.78 | 1.63| 24.10| 33.20| NS     | 27.88 | 1.53| 25.90| 31.70| *      | 35.75 | 2.10| 32.00| 40.50| *      |
| Female               | 27| 26.53 | 1.29| 24.40| 28.70| NS     | 27.20 | 1.14| 24.10| 28.90| *      | 34.23 | 1.77| 30.20| 37.80| *      |
| Brachyfacial         | 18| 26.72 | 1.07| 25.00| 28.40| NS     | 27.97 | 1.05| 26.10| 30.50| NS     | 35.49 | 1.92| 32.00| 38.30| NS     |
| Mesofacial           | 29| 26.98 | 1.77| 24.10| 33.20| NS     | 27.56 | 1.57| 24.10| 31.70| NS     | 34.82 | 1.88| 32.00| 40.50| NS     |
| Dolichofacial        | 11| 25.75 | 0.70| 24.40| 26.70| †      | 26.92 | 1.22| 24.90| 28.90| NS     | 34.87 | 2.82| 30.20| 39.70| NS     |

SD = Standard deviation, Min = minimum value, Max = maximum value, NS = not significant
* = p ≤ 0.05 - Test significant difference, † = p ≤ 0.05 - ANOVA significant differences in means
### Table VII. Change in maxillary arch dimensions

|                          | N   | Mean | SD  | Min | Max | Signif | Mean | SD  | Min | Max | Signif | Mean | SD  | Min | Max | Signif | Mean | SD  | Min | Max | Signif |
|--------------------------|-----|------|-----|-----|-----|--------|------|-----|-----|-----|--------|------|-----|-----|-----|--------|------|-----|-----|-----|--------|
| Total sample             | 58  | 0.07 | 1.62| -3.20| 4.00 | *      | 0.43 | 2.14| -4.80| 4.10 | *      | 1.20 | 1.54| -2.90| 5.50 | NS     | 0.46 | 0.72| -5.20| 0.70 | NS     |
| Male                     | 31  | -0.45| 1.42| -3.20| 2.00 | *      | -0.09| 2.06| -4.30| 3.90 | *      | 1.34 | 1.65| -1.80| 5.50 | NS     | 0.46 | 0.70| -5.20| 0.80 | NS     |
| Female                   | 27  | 0.67 | 1.65| -2.80| 4.00 | *      | 1.03 | 2.11| -4.80| 4.10 | *      | 1.03 | 1.42| -2.90| 3.20 | NS     | 0.63 | 0.86| -1.70| 0.70 | NS     |
| Brachyfacial             | 18  | 0.01 | 2.14| -3.20| 4.00 | NS     | 0.21 | 2.43| -4.80| 3.70 | NS     | 1.45 | 1.63| -0.70| 5.50 | NS     | 0.94 | 0.95| -5.70| 0.90 | NS     |
| Mesofacial               | 29  | -0.04| 1.26| -2.50| 1.90 | NS     | 0.39 | 2.07| -4.30| 4.10 | NS     | 0.93 | 1.34| -2.90| 3.20 | NS     | 0.38 | 0.66| -2.40| 0.90 | NS     |
| Dolichofacial            | 11  | 0.49 | 1.57| -2.00| 2.60 | NS     | 0.91 | 1.93| -3.40| 3.40 | NS     | 1.50 | 1.88| -1.80| 4.20 | NS     | 0.30 | 0.51| -0.50| 0.10 | NS     |

SD = Standard deviation, Min = minimum value, Max = maximum value, NS = not significant
* = $p \leq 0.05$ - test significant difference

### Table VIII. Change in mandibular arch dimensions

|                          | N   | Mean | SD  | Min | Max | Signif | Mean | SD  | Min | Max | Signif | Mean | SD  | Min | Max | Signif | Mean | SD  | Min | Max | Signif |
|--------------------------|-----|------|-----|-----|-----|--------|------|-----|-----|-----|--------|------|-----|-----|-----|--------|------|-----|-----|-----|--------|
| Total sample             | 58  | 0.87 | 2.03| -2.40| 6.80 | -      | 0.15 | 1.94| -4.30| 4.70 | -      | 0.94 | 1.73| -3.70| 5.70 | -      | 0.45 | 0.42| -0.50| 1.70 | -     |
| Male                     | 31  | 0.66 | 2.13| -2.40| 6.80 | NS     | 0.06 | 2.03| -4.30| 4.70 | NS     | 1.35 | 1.87| -3.70| 5.70 | NS     | 0.94 | 0.40| 0.60| 1.70 | *      |
| Female                   | 27  | 1.10 | 1.91| -2.00| 4.70 | NS     | 0.24 | 1.86| -3.90| 3.70 | NS     | 0.47 | 1.45| -2.00| 4.00 | NS     | -0.11| 0.61| 0.60| 1.20 | *      |
| Brachyfacial             | 18  | 0.84 | 1.98| -1.80| 4.20 | NS     | 0.24 | 2.10| -3.00| 4.70 | NS     | 1.01 | 2.15| -2.10| 5.70 | NS     | 0.08 | 0.31| 0.50| 0.30 | NS     |
| Mesofacial               | 29  | 1.12 | 2.29| -2.40| 6.80 | NS     | -0.04| 1.99| -4.30| 2.80 | NS     | 0.81 | 1.59| -3.70| 4.30 | NS     | 0.71 | 0.71| 0.60| 1.70 | NS     |
| Dolichofacial            | 11  | 0.22 | 1.19| -1.40| 2.00 | NS     | 0.47 | 1.58| -2.20| 2.80 | NS     | 1.15 | 1.45| -1.10| 4.00 | NS     | 0.35 | 0.82| 0.40| 1.90 | NS     |

SD = Standard deviation, Min = minimum value, Max = maximum value, NS = not significant
* = $p \leq 0.05$ - test significant difference
Changes in dimensions during treatment
The calculated mean changes occurring during treatment in all arch dimension measurements were small in all groups (generally about 1 mm). There was wide individual variation in these dimensional changes (Tables VII and VIII).

Correlations
When Pearson’s coefficients were calculated, the amount of crowding relief was shown to be strongly correlated with the observed changes in all arch dimensions ($p < 0.01$). Generally, the greater the pretreatment crowding, the greater the arch width increases generated during treatment. Interestingly, significant increases not only occurred across the canines, but also across the premolars and molars.

Dimensional changes occurring in one arch were found to be strongly correlated with the dimensional changes occurring in the opposing arch and the amount of crowding in that arch ($p < 0.01$). For instance, a strong statistically significant correlation was found between the amount of upper arch crowding and changes in lower premolar and molar arch widths. Changes in upper inter-canine width were found to be strongly correlated with changes in lower inter-canine width. Similar correlations were found for upper and lower inter-premolar width and arch depth changes.

Changes in upper and lower arch depths were also found to be significantly correlated with the amount of crowding that had been relieved ($p < 0.01$). It appears that the greater the amount of crowding to be relieved without premolar extractions, the greater the likely increase in arch depth. This highlights the fact that the observed and correlated dimensional changes occurred in the antero-posterior and transverse dimensions.

Although there was considerable individual variation, all post-treatment arch dimensional measurements were found to be strongly correlated with their original pretreatment measurements. For example, smaller pretreatment widths were found to be more likely associated with smaller post-treatment widths.

A negative correlation was found between all arch dimensional changes occurring during treatment and the original pretreatment arch width measurements ($p < 0.05$). It seemed that the further the pretreatment dimensions were from the average, the greater the likely reversion towards the mean measurement during treatment. Although pretreatment dimensions were found to be strongly correlated with post-treatment dimensions, the range of the arch width measurements across the total sample and its sub-groups was not as large after treatment. This is illustrated by the fact that the standard deviations for the post-treatment dimensions were generally smaller than those for the pretreatment dimensions.

Discussion

Limitations of this study
The patients included in this non-extraction sample were gathered from the private practice of one experienced orthodontist. Selection bias may therefore have occurred, even at the treatment planning stage. In order to avoid undesirable aesthetic and potentially unstable changes, selective extractions of premolar teeth would have been undertaken in many patients in that practice. The choice to extract teeth would have contributed to the smaller number of dolichofacial cases in this non-extraction sample. Another area of possible bias in the sample may be the relatively small amount of pretreatment crowding. This may be explained by the fact that, in many crowded cases in the practice, the clinician may have decided to use the leeway space for non-extraction treatment or to ask for the extractions of premolars, both of which were exclusion criteria for the study. These factors require consideration when results are compared of other orthodontic treatment samples. It is common practice to use auxiliary devices such as expanders, quad-helices and functional appliances to alter the dentition and its neuromuscular environment, either prior to, or as adjuncts to, fixed appliance treatment. Different dimensional changes would likely occur with the use of auxiliary devices and it should be indicated that the findings of the present study reflect changes that might occur with routine archwire placement in treatment commenced in the early permanent dentition.

Individual variation
It was found that there was considerable individual variation, not only in the morphological presentation of patients in this sample, but also in their dimensional response to treatment. However, this study was designed to examine the post-treatment arch dimensions and dimensional changes occurring during treatment, in which pre-determined sized and shaped archwires were placed. In order to address the
main study question, it was necessary that treatment had been provided as consistently as possible, especially with respect to finishing wire material, size and arch form. No other attempts were made to hide or diminish the variation in treatment response.

Gender differences
The minor gender-based arch-dimensional differences found in the present study are consistent with previous findings which determined that males had, on average, larger arch dimensions than females.4-6 More mandibular crowding was found in the male group, which is also consistent with previously published data.7 However, the clinical relevance of these findings is questionable, because a mean difference of only 1 to 2 mm between the genders was found for most of the measured arch widths. Greater differences in arch dimensions might have been found in a sample of fully-grown males and females.

Crowding
The most obvious factor influencing the amount of change in arch width with non-extraction treatment was the amount of pretreatment crowding. Although it may be obvious, it reaffirms the fact that, if non-extraction treatment is undertaken in crowded cases, it is likely to directly affect arch form and arch dimensional changes. The nature of these changes may then be an important factor to consider when planning for stability and retention.

One interesting finding was that relief of lower crowding was closely correlated with changes in inter-canine width and also with changes in the inter-premolar and inter-molar widths. Similarly, the strong correlation found between crowding relief and arch depth increases also confirms the fact that, when non-extraction treatment is undertaken, changes in all arch dimensions should be expected. Individual incisor positioning goals become important considerations for the clinician when managing crowding with or without premolar extractions.8

Maintenance of lower arch form and position
A firm view held by many is that the pretreatment form of the lower arch represents a position of muscular balance.9,10 That view suggests that the greater the change from this position during treatment, the greater the likelihood of future relapse. Previous studies support the concept that arches subjected to greater change during treatment may have a greater likelihood of later relapse.11,12 If it is accepted that the maintenance of a pretreatment lower arch form represents a state of balance, in order to ensure more stable longer term alignment and occlusion, that arch form should not be changed as a result of treatment. In addition, based on previous relapse studies, the maintenance of inter-canine width is of significant importance.9,11,13-15 Although this general tenet might be reasonable, exceptions appear to exist. For instance, lower inter-canine expansion has been shown to be better tolerated in brachyfacial Class II division 2, deep overbite patients than in more mesofacial or dolichofacial Class I and Class II division 1 patients.15,16 This variability in initial morphological presentation and likely differences in individual muscular response to treatment are other factors to be considered.

Inter-premolar width changes
It is interesting that the present study found a significant relationship in the amount of crowding to be relieved and changes in upper and lower inter-premolar width. A treatment increase in inter-premolar width has previously been shown to be potentially more stable than increases in either inter-canine or inter-molar widths.14,17-19 This potential for greater stability accompanying increases in inter-premolar width may well have implications for arch form selection.17 However, stability is only one factor to be taken into consideration alongside tissue health, function and aesthetics.20

Naturally-occurring arch development
Normal growth changes could theoretically contribute to arch dimensional changes seen during treatment. The extent of this contribution would depend on many individual factors, particularly the timing of treatment in relation to expected dental arch development. Early longitudinal growth studies revealed that only small natural changes are likely during the early permanent dentition period of treatment.21,22 Other reports have shown that maximum arch widths are likely to be reached before the eruption of the permanent canines, after which a decrease is to be expected.23,24 Adolescent orthodontic treatment which is commenced in the early permanent dentition will typically occur during a period when minimal natural width changes are to be expected.
**Vertical facial pattern and arch dimensions**

Typical descriptions of the extremes of vertical facial pattern have often included reference to different arch forms and dimensions for each vertical type. Dolichofacial individuals tend to have relatively narrower transverse facial dimensions while brachyfacial individuals tend to have relatively wider transverse facial dimensions. However, only a limited number of previous reports have involved the direct investigation of the relationship between different vertical facial patterns and either individual untreated arch widths or changes in those widths with treatment. Isaacson et al. measured inter-maxillary molar width and found that dolichofacial patients generally had narrower arches than brachyfacial patients. However, the results were less evident in a more recent study which suggested that dolichofacial patients might have narrower arch widths than brachyfacial patients, but the differences were not statistically significant. While all the implications of different underlying vertical patterns need to be taken into account, this reinforces the fact that individual treatment plans need to be determined for each patient.

**Arch form selection**

An interesting observation in the present study was that, in some cases, arch dimensions reduced with treatment. Factors that may have contributed to this possibly included the previously-outlined selection bias and the use of the relatively conservative arch form template. Not all problems with the maintenance of arch form and tooth positions after treatment occur as a result of arch expansion, although it is accepted that changes occurring in initially-spaced dentitions may also be subject to considerable post-treatment relapse. It would appear that, regardless of whether arch dimensions have been increased, maintained or reduced, long-term individual retention decisions still have to be made.

**Clinical relevance**

Current orthodontic thinking might suggest that particular, empirically-based arch forms and sizes should be used on the basis of aesthetics, function and stability. The chosen empirical arch form is often related to the original lower arch form and size. Although only one arch form and size was used in the current patient sample, the results of the present study have shown that, if the clinician placed exactly the same wires (material, size, arch form and duration of placement) in different patients, and left them to function for months, widely varying arch forms and sizes might result. This would seem consistent whether a 0.018 or a 0.022 inch slot system is used. The results of the present study indicate that, if a wire of a particular shape and size is placed and allowed to work against the surrounding musculo-occlusal forces, the resultant dental arch will not automatically conform. Other factors appear to be involved, of which the amount of crowding to be relieved and the pretreatment dimensions of the arches are significant. Ultimately, the occlusal and muscular forces acting on the dentition and the amount of pretreatment crowding will bias the teeth to move forward or laterally until arch alignment has been achieved. Even recently-developed, digitally-derived archwires will only commence three-dimensional detailing of tooth position and occlusion once the arch form has been determined following the relief of the initial crowding. That is why definitive scans for digital archwire production are usually taken several months into active treatment, when the dimensions of the uncrowded arches have become clearer. On the basis of their individual education and experience, clinicians have to decide how to best deal with a range of dento-facial problems. Factors involved will be the amount of crowding, the three-dimensional dental and skeletal relationships, the vertical and transverse facial patterns, as well as lip profile and smile characteristics. Following consideration, the clinician can decide on the advisability of expanding the arches in individual patients. That decision is likely to determine the resultant arch forms.

**Conclusions**

Taking into account the outlined limitations, the following conclusions may be drawn:

1. The placement of finishing wires of a particular material, size and arch form is not likely to lead to matching end-of-treatment dental arch forms and dimensions in all orthodontic patients. Many different final arch forms and dimensions are likely to be seen.

2. The main determinants of the final arch form and dimensions appear to be the original musculo-occlusally-related arch form and dimensions and
the amount of pretreatment crowding. Clinicians should keep this in mind when deciding whether anterior and/or lateral expansion is desirable when attempting to relieve crowding in individual patients.

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