Original Article

An Occlusal and Cephalometric Analysis of Maxillary First and Second Premolar Extraction Effects

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Abstract: The purpose of this study was to examine dimensional changes in the maxillary arch following the extractions of maxillary first or second premolars. Pre- and posttreatment records of 71 patients treated by one experienced orthodontist were randomly selected from completed premolar extraction cases. Forty-five patients involved the extraction of maxillary first premolars; of these, 15 also had extractions of mandibular first premolars and 30 had extractions of mandibular second premolars. Twenty-six patients involved the extraction of maxillary second premolars, and all of these also had extractions of mandibular second premolars. Pretreatment factors that seemed to suggest a basis for the extraction choice in this sample included incisal overjet, molar relationship, and maxillary incisor protrusion. Mean reductions with treatment in the anteroposterior arch dimension were similar within all premolar extraction groups. There was evidence of greater mean maxillary intermolar-width reduction following the extractions of maxillary second premolars than following extractions of maxillary first premolars. Greater mean maxillary incisor retraction was found in the maxillary first premolar extraction group than in the maxillary second premolar group. A wide range of individual variation in incisor and molar changes did, however, accompany treatment involving both maxillary premolar extraction sequences. (*Angle Orthod* 2001;71:90–102.)

Key Words: Premolar extractions; Arch dimensions; Incisor retraction

INTRODUCTION

The role of extractions in orthodontic treatment has been historically controversial.[1–5] This controversy continues today and, with the exception of whether or not to actually undertake treatment at all, the extraction decision is still the most critical decision made by orthodontists when planning treatment.[6] This is further complicated by the fact that the relative efficacy of extraction or nonextraction strategies, in either the short or long term, has yet to be fully established.[7]

A number of previous workers have documented that premolars are the most commonly extracted teeth for orthodontic purposes.[8–10] Conveniently located between the anterior and posterior segments, premolar extractions would seem to allow for the most straightforward relief of crowding or the correction of an unacceptable interincisor relationship.[11] It has been suggested that improvements in techniques for controlling movements of teeth in 3 dimensions and improvements in the correlation of these movements with anticipated facial growth changes have both increased the number of extraction options.[12] In fact, different authors, for various reasons, have recommended variations in extraction sequences, including maxillary and mandibular first and/or second premolars.[12–16]

It is well accepted that, during orthodontic treatment involving the extraction of teeth, arch dimensional changes occur and that these dimensions continue to change following active treatment.[17–21] Quantification of these changes in the maxillary arch, however, has only recently been provided.[22] Furthermore, the ability for maxillary extraction spaces to be used in a predictable fashion has not yet been widely presented in the literature.[23–25] In one such study, Williams and Hosila[24] found that, in cases involving the extraction of 4 first premolars, approximately 66.5% of the available extraction space was taken up by the retraction of the anterior segment. In cases involving extractions of maxillary first and mandibular second premolars, 56.3% of the available extraction space was taken up by the retraction of the anterior segment.

Since it is generally accepted that a strong relationship exists between root surface area and anchorage potential, the choice of teeth to be extracted should have a direct influence on the amount of anterior segment retraction.[15,16,26] For instance, Creekmore[16] stated, as a rule-of-thumb, that

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when first premolars are extracted, one can expect the posterior teeth to move forward approximately one-third of the space, leaving two-thirds of the space for the relief of crowding and incisor retraction. When second premolars are extracted, one can expect the posterior teeth to move forward approximately half the extraction space, leaving the remaining half for the relief of crowding and the retraction of anterior teeth.[16]

Some authors have reported definite correlations between incisor movements and changes in the overlying soft tissue profile.[27–31] Others have shown that changes in tooth position are not necessarily followed by proportional changes in that soft tissue profile.[25,32–37] Variations in factors such as lip morphology, the type of treatment, gender, and age have all been held responsible for individual differences in soft tissue response. While it has been claimed by some that extraction treatment is likely to have a detrimental effect on the facial profile, it has now also been shown that the decision to extract teeth in orthodontic treatment does not have to compromise posttreatment esthetics if the decision is based on sound diagnostic criteria.[17,18,25,38–43]

Stability following orthodontic treatment continues to challenge all orthodontists.[44–46] The ability to maintain long-term alignment following orthodontic treatment involving the extraction of premolars has unfortunately also been unpredictable.[20,21,47–50] Controversy still surrounds the question of whether better long-term results are achieved with extraction or nonextraction treatment, with different studies producing conflicting results.[17,21,51–53]

With all this in mind, it is obvious that there are some differences in the dental and facial effects of extraction and nonextraction treatment. The influence, however, of various extraction sequences in these areas has been largely derived from anecdotal clinical observations, and there still seems to be little scientific evidence to support the choice of one sequence over another. It was, therefore, the purpose of the present study to investigate the differences in maxillary arch dimensional and positional changes following orthodontic treatment involving the extraction of either maxillary first or second premolars.

MATERIALS AND METHODS

Experimental sample

Pre- and posttreatment records of 71 premolar extraction cases treated by an experienced orthodontist with preangulated Edgewise appliances (0.018 × 0.028 inches) were obtained for this study. The cases were selected according to the following criteria:

1. All patients had 4 premolar extractions as part of their comprehensive orthodontic treatment plan. Patients with asymmetric premolar extractions within the dental arches were excluded.
2. None of the patients had any adjunctive appliances such as headgears, transpalatal arches, quad helices, functional appliances, or rapid maxillary expanders, as part of their orthodontic treatment. Interarch elastics were used as necessary.
3. All cases included a minimum of pre- and posttreatment lateral cephalograms, study casts, and treatment history records.

TABLE 1. Experimental Sample

Group[a]	n	Age at Commencement (Months) Mean	SD	Duration of Active Treatment (Months) Mean	SD
Total	71	163.9	15.6	26.4	5.7
Males	34	167.2	15.2	27.2	6.0
Females	37	160.9	15.6	25.7	5.4
Exo maxillary 4s	45	165.0	16.0	26.7	6.1
4/4	15	162.9	16.6	27.3	3.6
4/5	30	166.1	15.9	26.3	7.1
Exo maxillary 5s, 5/5	26	162.0	14.9	25.9	5.1

[a] 4/4, maxillary and mandibular first premolars; 4/5, maxillary first and mandibular second premolars; 5/5, maxillary and mandibular second premolars.

The age at commencement, the duration of active treatment, and the numbers of subjects in the various extraction subgroups are shown in Table 1. The average duration of fixed-appliance treatment was 26.4 months, with a range of 14 to 44 months.

Several pretreatment variables were evaluated so that changes due to any initial group differences could be distinguished from actual treatment effects (Table 2). The 3 extraction subgroups were compared statistically and the differences quantified using a one-way analysis of variance (ANOVA). Four measurements were identified as significantly different among the groups at the 95% confidence level. These variables included 2 study cast measurements (incisal overjet and Class II molar relationship) and 2 cephalometric measurements (incisor angulation and position in relation to the APog reference line). The 4/4 group required treatment of moderate amounts of overjet and Class II molar correction. The 4/5 group had the largest mean overjet (6.1 mm) and a Class II molar relationship. The 5/5 group had a mean overjet identical to the 4/4 group but a mean Class I molar relationship. Relative to the APog line, the mean maxillary incisor position was further forward in all 3 groups than the average reported by Ricketts.[54] Among the subgroups, however, the 5/5 group had the least mean incisor protrusion.

Cephalometric and occlusal analysis

The cephalometric measurements used in this study are described in Table 3 and are illustrated in Figures 1 through 3. All lateral cephalograms had been taken using the same

TABLE 2. Pretreatment Variables[a]

Variable	4/4 (n = 15)		4/5 (n = 30)		5/5 (n = 26)		Post Hoc Comparisons (*P* Values)		
	Mean	SD	Mean	SD	Mean	SD	4/4 vs 4/5	4/4 vs 5/5	4/5 vs 5/5
Age (months)	162.9	16.6	166.1	15.9	162.0	14.9			
Treatment time (months)	27.3	3.6	26.3	7.1	25.9	5.1			
ANB (°)	4.0	3.0	4.1	1.2	3.6	2.0			
Overjet (mm)	4.6***	1.7	6.1***	2.1	4.6***	1.4	0.028	1.000	0.008
Overbite (mm)	3.2	2.2	3.8	1.6	4.1	1.2			
Molar relationship (mm)	1.9*	3.1	2.5*	3.8	0.2*	2.9	1.000	0.350	0.034
FA (°)	88.1	3.7	89.1	3.6	88.6	3.7			
SNMP (°)	35.2	5.6	35.3	4.6	35.3	6.1			
11,21-APog (°)	32.8**	8.0	32.5**	7.1	27.2**	5.1	1.000	0.032	0.011
11,21-APog (mm)	8.8*	2.5	7.9*	2.8	6.7*	2.0	0.778	0.030	0.195
11,21-ANS, PNS (°)	111.2	5.8	114.0	6.6	110.2	4.6			
Crowding (mm)	5.1	4.9	3.1	4.7	3.1	2.9			

[a] ANOVA: *, $P < .05$; **, $P < .01$; ***, $P < .005$. See Tables 3 and 4 for definitions.

TABLE 3. Cephalometric Measurements

No.	Measurement	Definition
1	ANB (°)	Angle formed by the intersection of nasion point A and nasion point B lines.
2	SNMP (°)	Angle formed by the intersection of sella-nasion line and the gonion-menton line.
3	FA (°)	Angle formed by the intersection of the basion-nasion line and the facial axis.
4	IIA (°)	Angle formed by the intersection of the long axes of the maxillary and mandibular central incisors.
5	11,21-ANS, PNS (°)	Angle formed by the intersection of the long axis of the maxillary incisor and the palatal plane.
6	11,21-APog (mm)	Horizontal distance from the maxillary incisor tip to the point A pogonion line.
7	11,21-APog (°)	Angle formed by the intersection of the long axis of the maxillary incisor and the point A pogonion line.
8	ML (mm)	Distance between articulare and pogonion.
9	Incisal tip change (mm)	From superimposition on the palatal plane at ANS—the horizontal distance between maxillary incisor tip initial and final, measured perpendicular to the pterygomaxillary vertical line.

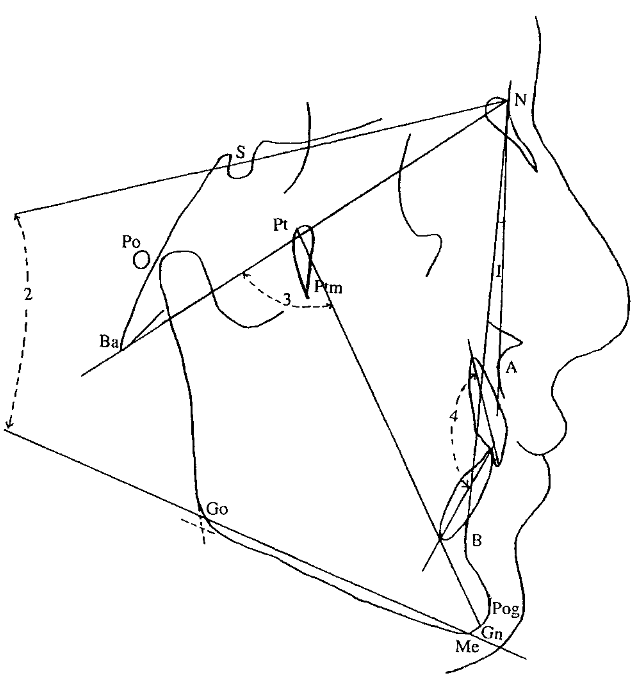


FIGURE 1. Cephalometric measurements (numbers 1–4, Table 3).

calibrated cephalostat and were traced under the same viewing conditions, ie, in a darkened room using a light box with extraneous light blocked out. Measurements were made using the Westcef program (a customized research cephalometric analysis program written for The University of Melbourne by Mr Geoffrey West), which automatically rotates the digitized landmarks so that the pterygomaxillary (PM) vertical line through sphenoethmoidale is in fact vertical (Figure 2). The use of the PM line as a vertical reference plane for anteroposterior changes has previously been suggested.[55] Absolute horizontal and vertical distances between landmarks were measured relative to the *X* and *Y* coordinates of those landmarks. To evaluate maxillary incisal changes, tracings were superimposed on the palatal plane registered at anterior nasal spine (ANS), as described by Ricketts,[56] a method that has previously been shown to be acceptable.[57] The PM line was transferred from the pretreatment tracing to the posttreatment tracing to provide a consistent reference plane for evaluating changes. Incisal changes were then measured perpendicular to the PM vertical reference plane, with forward movement of the incisal tip assigned a positive value. Linear cephalometric mea-

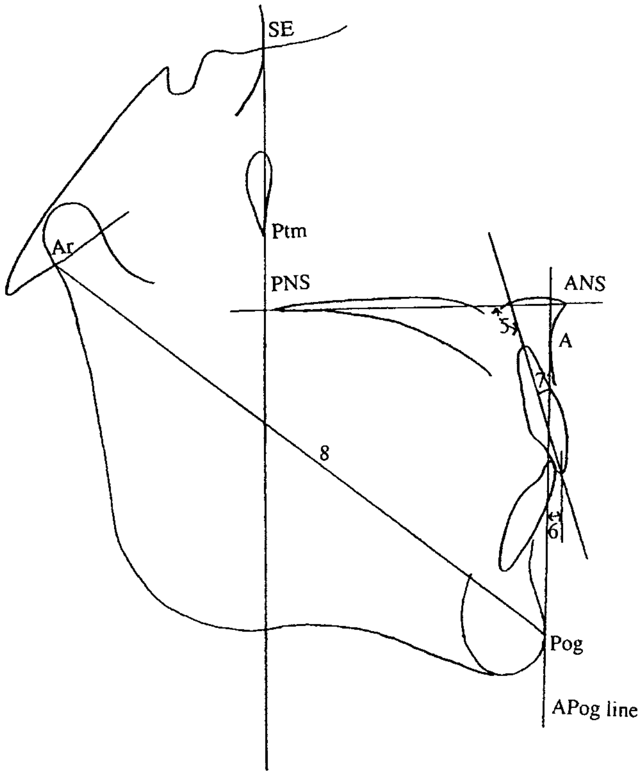


FIGURE 2. Cephalometric measurements (numbers 5–8, Table 3).

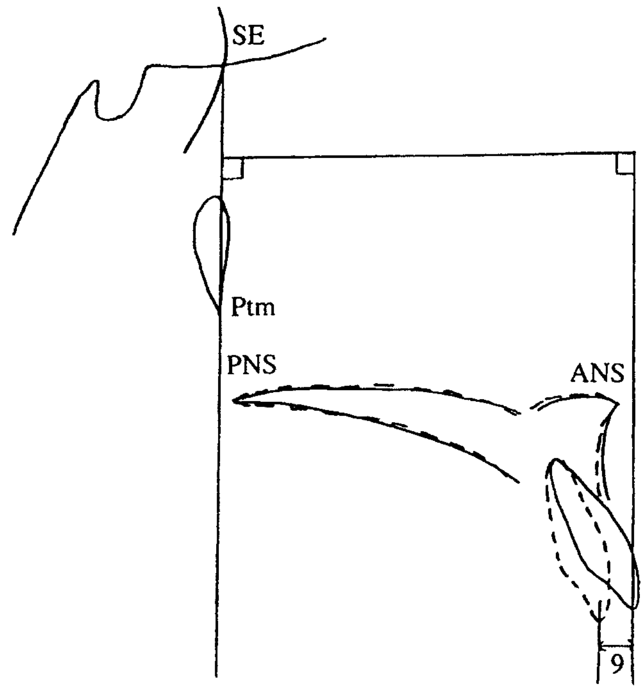


FIGURE 3. Maxillary incisor tip change (superimposition on palatal plane at ANS; number 9, Table 3).

surements were multiplied by a factor of 0.92 to take into account the 9% enlargement factor.

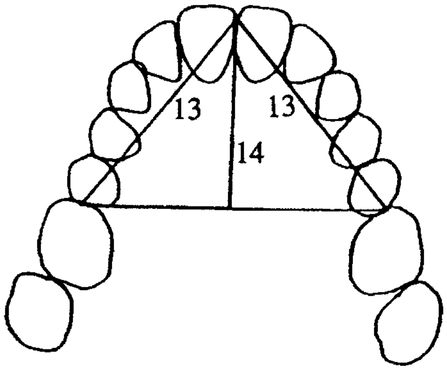
The study cast measurements used in this study are described in Table 4. Where appropriate, they are further illustrated in Figures 4 and 5. An electronic digital sliding caliper (Mitutoyo Corporation, Tokyo, Japan) was used to measure the distances between occlusal landmarks to the nearest 0.1 mm.

The amount of crowding was determined using Proffit and Fields'[58] segmental method, ie, by subtracting the pretreatment segmental total from the posttreatment segmental total and then adding back in the actual mesiodistal widths of the 2 extracted premolars. The residual space was calculated by subtracting the amount of crowding from the sum of the mesiodistal widths of the extracted maxillary premolars.

Mean changes for the cephalometric and study cast var-

TABLE 4. Study Cast Measurements

No.	Measurement	Definition
10	Overbite (mm)	Vertical overlap of the maxillary and mandibular incisors measured perpendicular to the occlusal plane.
11	Overjet (mm)	Horizontal distance between the maxillary and mandibular incisors measured parallel to the occlusal plane.
12	Crowding (mm)	Space required for crowding relief and leveling, calculated using Proffit and Field's segmental method,[58] ie, by subtracting the pretreatment segmental total from the posttreatment segmental total, then adding back in the mesiodistal widths of the 2 extracted premolars.
13	Chordal arch length (mm)	Distance from the mesial contact points of the maxillary first molars to the contact point of the maxillary central incisors.
14	Arch depth (mm)	Perpendicular distance from the line joining the mesial contact points of the maxillary first molars to the contact point of the maxillary central incisors.
15	Interpremolar width (mm)	Horizontal distance between the palatal cusp tips of the most anterior maxillary premolars.
16	Intermolar width (mm)	Horizontal distance between the mesiopalatal cusp tips of the maxillary first molars.
17	Arch segments (mm)	Distance between the lines perpendicular to the contact points of a segment of teeth; between the first molar and the distal surface of the lateral incisor and between that distal surface and the mesial surface of the central incisor.
18	Molar relationship (mm)	Distance between the mesiobuccal cusp tip of the maxillary first molar and the buccal groove of the mandibular first molar measured parallel to the occlusal plane.



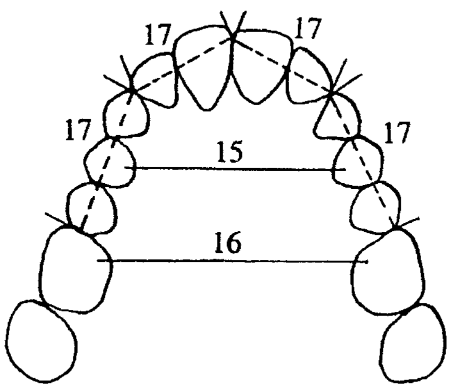


FIGURE 4. Arch dimensional measurements (numbers 13–17, Table 4).

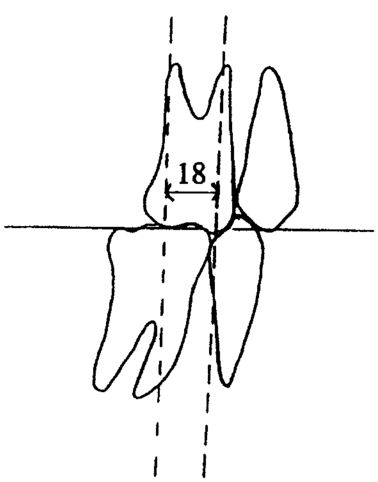


FIGURE 5. Molar relationship measurement (number 18, Table 4).

TABLE 5. Posttreatment Variables[a]

Variable	4/4 (n = 15)		4/5 (n = 30)		5/5 (n = 26)	
	Mean	SD	Mean	SD	Mean	SD
ANB (°)	3.4	1.9	3.1	1.8	3.1	2.1
Overjet (mm)	2.4	0.6	2.9	0.7	2.5	0.6
Overbite (mm)	2.2	0.6	2.6	0.7	2.6	0.9
Molar relationship (mm)	−1.9	1.9	−1.5	1.8	−2.2	1.5
FA (°)	87.1	4.0	88.4	3.8	87.8	4.1
SNMP (°)	35.2	5.3	35.6	5.0	35.7	6.5
11,21-APog (°)	24.6	4.1	24.3	6.0	23.8	5.4
11,21-APog (mm)	4.6	1.5	4.3	1.8	4.3	1.8
11,21-ANS, PNS (°)	107.0	4.6	109.0	7.8	108.6	4.9

[a] No significant differences among groups. See Tables 3 and 4 for definitions.

iables were calculated, and analysis of variance was used to identify any statistically significant differences in the changes observed within the 3 subgroups. Pearson's product moment correlation coefficients (r) were also calculated to determine whether any association existed between maxillary incisor changes and any other variables.

Error study

To evaluate tracing and measurement error, the records of 10 patients (20 sets of study casts and 20 cephalograms) were selected at random and the experimental procedure repeated. Results of the paired-samples t-test showed no significant differences between the first and second sets of measurements at the 95% confidence interval.

RESULTS

At the end of active treatment, all 3 extraction subgroups showed mean Class I incisor and molar relationships. In relation to the APog line, the mean posttreatment maxillary incisor position and angulation were also similar among the 3 extraction subgroups (Table 5).

Arch dimensional changes

The maxillary arch dimensional changes for all groups are summarized in Table 6. Since there was no statistical evidence of sexual dimorphism, each of the extraction subgroups was not further divided into male and female subgroups. As expected, mean reductions in arch depth and chordal arch length were noted in all groups. The mean reductions were, however, similar in all groups. In all groups, there was a mean increase in maxillary arch width across the most anterior premolars. The only statistically significant difference among the groups was for the reduction in intermolar width. Mean reductions of 1.5 mm (±1.7), 2.6 mm (±2.3) and 3.3 mm (±2.2) were observed in the 4/4, 4/5, and 5/5 groups, respectively.

TABLE 6. Maxillary Arch Dimensional Changes With Treatment (mean ± SD)[a]

Group	n	Arch Depth (mm)	Chordal Arch Length (mm)	Interpremolar Width (mm)	Intermolar Width (mm)
Total	71	−6.6 ± 2.4	−11.3 ± 4.0	+3.0 ± 2.3	−2.6 ± 2.2
Males	34	−6.4 ± 2.5	−11.2 ± 4.5	+3.1 ± 2.5	−2.8 ± 2.6
Females	37	−6.7 ± 2.2	−11.4 ± 3.4	+2.8 ± 2.2	−2.5 ± 1.9
Exo 4s	45	−6.8 ± 2.6	−11.4 ± 4.5	+3.4 ± 2.3	−2.2 ± 2.2
4/4	15	−6.2 ± 2.7	−10.2 ± 4.3	+3.7 ± 2.4	−1.5 ± 1.7*
4/5	30	−7.1 ± 2.6	−12.0 ± 4.6	+3.2 ± 2.3	−2.6 ± 2.3*
Exo 5s, 5/5	26	−6.2 ± 1.8	−11.1 ± 2.8	+2.3 ± 2.2	−3.3 ± 2.2*

[a] ANOVA: *, $P < .05$.

TABLE 7. Maxillary Incisor Position and Angulation Changes With Treatment (mean ± SD)[a]

Group	n	11,21-APog (mm)	11,21-APog (°)	11,21-ANS, PNS (°)	IIA (°)	Incisal Tip Change (Superimposition) (mm)
Total	71	−3.3 ± 2.2	−6.4 ± 6.7	−3.8 ± 6.4	+5.3 ± 10.5	−2.1 ± 1.7
Males	34	−3.7 ± 2.1	−6.7 ± 7.0	−3.3 ± 6.8	+6.2 ± 10.2	−2.3 ± 1.7
Females	37	−2.9 ± 2.2	−6.1 ± 6.4	−4.2 ± 6.1	+4.4 ± 10.8	−1.9 ± 1.6
Exo 4s	45	−3.9 ± 2.3	−8.2 ± 7.3●●	−5.0 ± 7.1●	+8.0 ± 11.2	−2.5 ± 1.9●
4/4	15	−4.2 ± 2.3*	−8.2 ± 8.6	−4.9 ± 6.9	+9.4 ± 14.6*	−2.4 ± 1.5
4/5	30	−3.7 ± 2.3*	−8.2 ± 6.6	−5.0 ± 7.4	+7.3 ± 9.2*	−2.5 ± 1.6
Exo 5s	26	−2.3 ± 1.7*	−3.3 ± 3.9●●	−1.6 ± 4.3●	+0.5 ± 7.1*	−1.6 ± 1.6●

[a] Student's *t* test; ●, $P < .05$; ●●, $P < .005$. ANOVA: *, $P < .05$.

Maxillary incisor position and angulation changes

Changes in maxillary incisor position and angulation with treatment are presented in Table 7. A mean reduction in maxillary incisor protrusion and proclination was noted in all maxillary premolar extraction groups. Statistically significant differences for all 5 variables were found among the different extraction groups. There was a significantly larger mean retraction of the maxillary incisors in relation to the APog line in both the maxillary first premolar extraction subgroups than in the second premolar group. The 4/4 and 4/5 subgroups had mean incisor retractions of 4.2 mm and 3.7 mm, respectively, whereas the 5/5 group had a mean retraction of 2.3 mm. Similar results were noted for the changes in maxillary incisor angulation to the APog line, with the overall maxillary first premolar extraction group showing a significantly larger mean reduction in angulation (8.2°) than the second premolar group (3.3°). The mean incisor angulation changes in relation to the palatal plane also were significantly different among the groups, with mean reductions of 5.0° and 1.6°, respectively, in the maxillary first premolar and maxillary second premolar extraction groups. As with all variables, however, there were large ranges of individual variation. Interincisal angulation increased on average as a result of changes in the angulations of both maxillary and mandibular incisors. Large standard deviations were also noted for this measurement.

Maxillary cephalometric superimposition

Anteroposterior changes recorded at the maxillary incisor tip when pre- and posttreatment tracings were superimposed on the palatal plane at ANS are shown in Table 7 and are illustrated in Figure 6. There was a statistically significant difference in the mean incisor retraction in the maxillary first premolar group (2.5 mm) compared with the maxillary second premolar group (1.6 mm). Incisors were retracted from their pretreatment positions in all subjects in the 4/4 and 4/5 groups, whereas only 85% of the subjects within the 5/5 group showed any incisor retraction. A wide range of individual changes was evident within each group.

Molar versus incisor changes

The anteroposterior change in maxillary first molar position was estimated by calculating the difference between the arch-depth change (mm) and incisor position change (mm) measured from superimposition on the palatal plane at ANS. This was made possible by the multiplication of the linear cephalometric measurements by the 0.92 factor. Anteroposterior changes in the maxillary first molar position are shown in Table 8 and are illustrated in Figure 7. Mean changes in the estimated molar movement were not found to be significantly different among the groups. Calculated in this way, mean forward movements of the molars for the groups ranged from 3.7 mm to 4.7 mm. When comparing relative amounts of movement, the incisors had un-

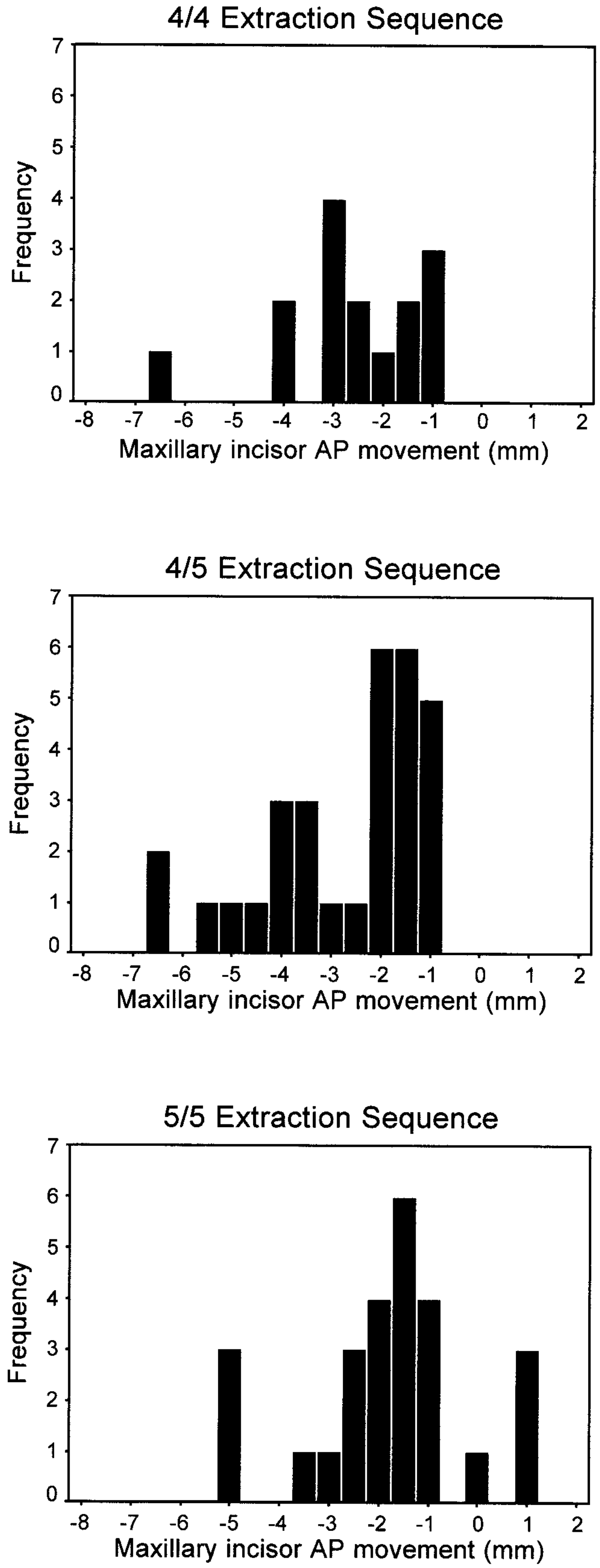


FIGURE 6. Frequency of maxillary incisor anteroposterior movement following different premolar extraction sequences.

TABLE 8. Estimated Molar Movement[a]

Group	n	Forward Molar Movement (mm) Mean	SD
Total	71	4.4	2.0
Males	34	4.1	2.3
Females	37	4.7	1.8
Exo 4s	45	4.3	2.3
4/4	15	3.7	2.3
4/5	30	4.7	2.3
Exo 5s, 5/5	26	4.5	1.5

[a] No significant differences among groups.

dergone greater movement than the first molars in 20% of the cases in each of the maxillary first premolar extraction subgroups and in 19% of cases in the maxillary second premolar extraction group. Little, if any, incisor retraction was found in 13% of the subjects in both the 4/4 and 4/5 groups, while the same was true in 19% of subjects in the 5/5 group.

Individual variation

Because of the wide ranges of individual variation within each of the groups, it was decided to look for any similarities that might exist between the individuals who had shown extremes of incisor movement within each group. Two individuals were chosen from each extraction subgroup, one in whom there was the greatest incisor retraction and another in whom there was only minimal incisor change. A third individual, in whom there was actual protrusion of the incisors, was chosen in the 5/5 group (Table 9, Figures 8–10). When viewing these cases, there appeared to be a tendency toward greater retraction of the incisors in cases with less crowding or greater amounts of residual space. It was also interesting to note that changes in the position of the maxillary incisors on the underlying bone were not necessarily consistent with maxillary incisor changes in relation to the APog line. For example, in individual B (Table 9), a reduction in the prominence of the incisors in relation to the APog line was accompanied by little, if any, change on the underlying bone. It seems therefore that changes in the anteroposterior and vertical positions of point A and pogonion were occurring at the same time.

Further correlations

When Pearson's coefficients were calculated, changes in interincisal angulation and the initial incisor position in relation to the APog line were both found to be significantly correlated with maxillary incisor movement (Table 10). These findings would not be unexpected since these measurements are all somewhat dependent on each other. No other significant correlations were found.

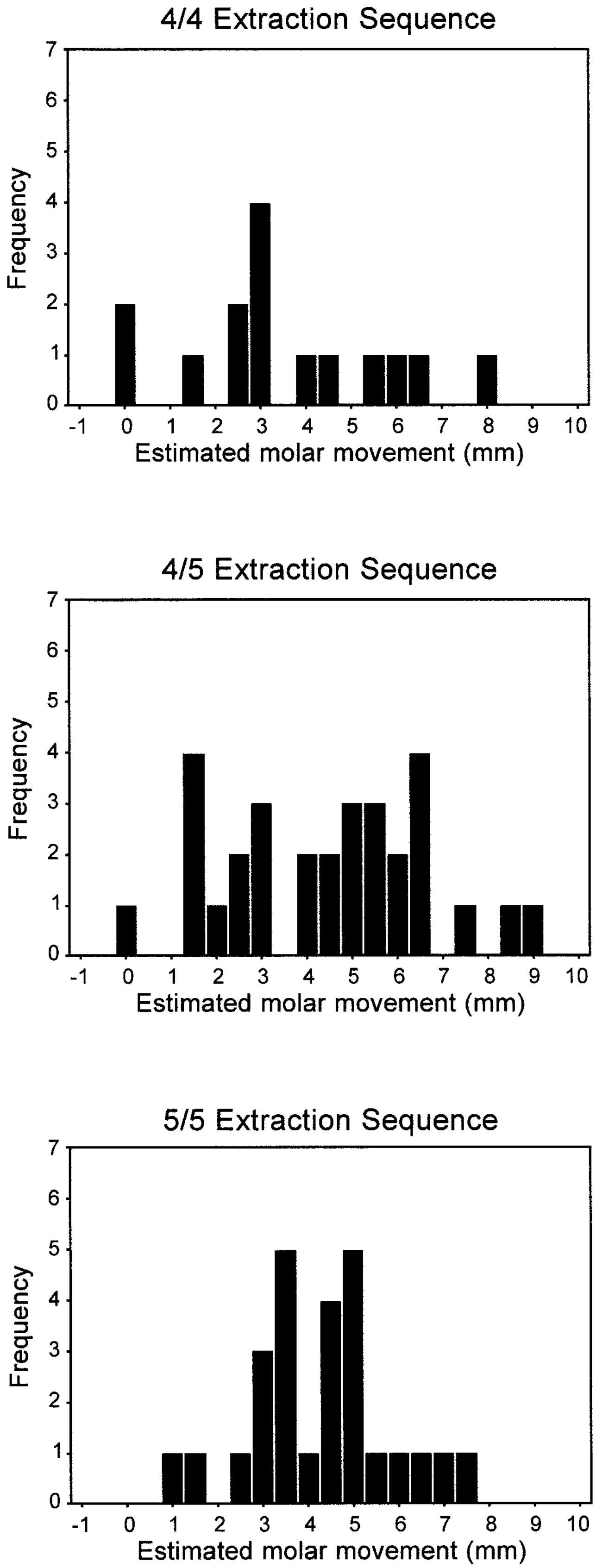


FIGURE 7. Frequency of estimated molar movement following different premolar extraction sequences.

DISCUSSION

The presence of significant differences in mean pretreatment overjet, Class II molar relationship, and incisor protrusion among the different extraction subgroups suggests that these factors had somehow influenced the extraction sequence decision. Crowding has consistently been considered the major factor to be taken into account when deciding whether to extract teeth as part of orthodontic treatment,[19,59–61] and the choice of particular extraction sequences seems to have been based largely on anecdotal clinical opinions.[15,16,26] Recently, Saelens and De Smit[25] evaluated pretreatment variables involved in extraction decisions and reported that the amount of crowding had a significant influence on the decision to extract 4 first premolars. In cases with mild crowding and mild dental protrusion, however, the decision was often made to extract 4 second premolars instead. It is interesting to note that, in an earlier study on mandibular premolar extraction effects, it was found that the underlying vertical facial pattern also seemed to significantly influence the mandibular extraction-sequence decision.[62] This was not found to be the case in this present maxillary arch study. That may be due to the fact that the final positions of the mandibular incisors are more likely to be chosen on the basis of the vertical facial pattern and the consequential lateral profile effects. It is also interesting to note that, in this randomly selected premolar extraction sample, the 4/4 group accounted for only 21% of the cases, while the 4/5 and 5/5 groups accounted for 37 and 42% of the cases, respectively. This is in contrast with the findings of previous studies[8–10] that have reported that 4 first premolars are the most likely teeth to be extracted as part of orthodontic treatment. One limitation of the present study has been this smaller sample size for the 4/4 group. One should realize, however, that the main focus of this study has been on the different maxillary premolar extraction choice.

In the present study, maxillary arch dimensional changes in each group involved, in general, some contraction of the anteroposterior dimension. The fact that the mean reductions in both arch depth and chordal arch length were similar in all groups might have been expected anyway since there were similar mean amounts of crowding in each group, resulting in similar amounts of overall residual space. The mean overall chordal arch-length reduction of 11.3 mm is consistent with those reductions reported by Paquette et al[17] and De La Cruz et al[20] but is somewhat greater than that reported by Luppanapornlarp and Johnston.[18] These latter authors reported a mean chordal arch-length reduction of 8.3 mm during treatment in first premolar extraction cases. The difference is likely to be due to the greater mean crowding found in the Luppanapornlarp and Johnston sample (5.8 mm) compared with the present sample (3.5 mm).

Because a significant number of the cases included in

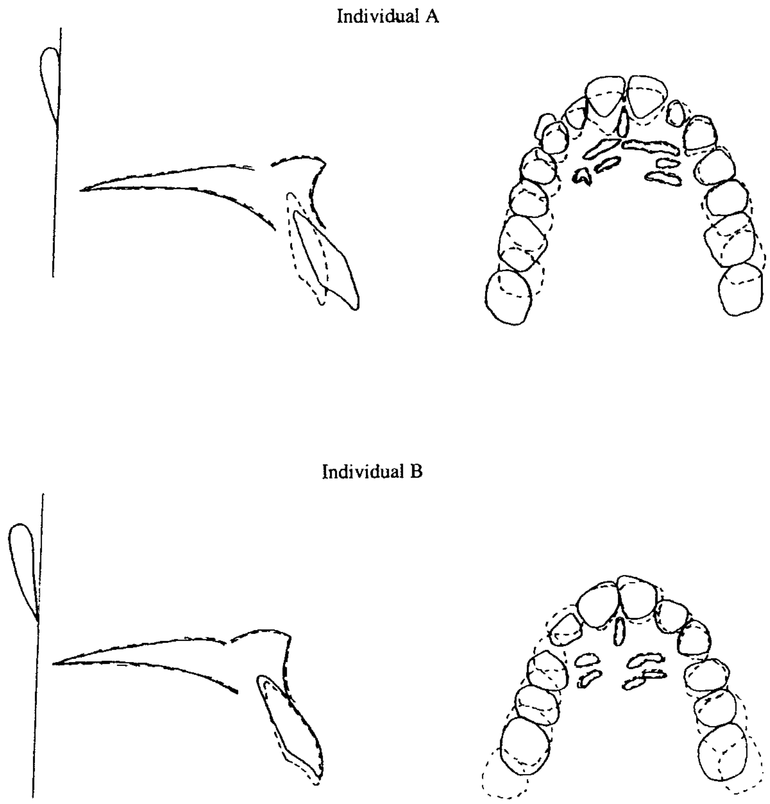


FIGURE 8. Individual maxillary cephalometric and occlusal superimpositions (4/4 extraction sequence).

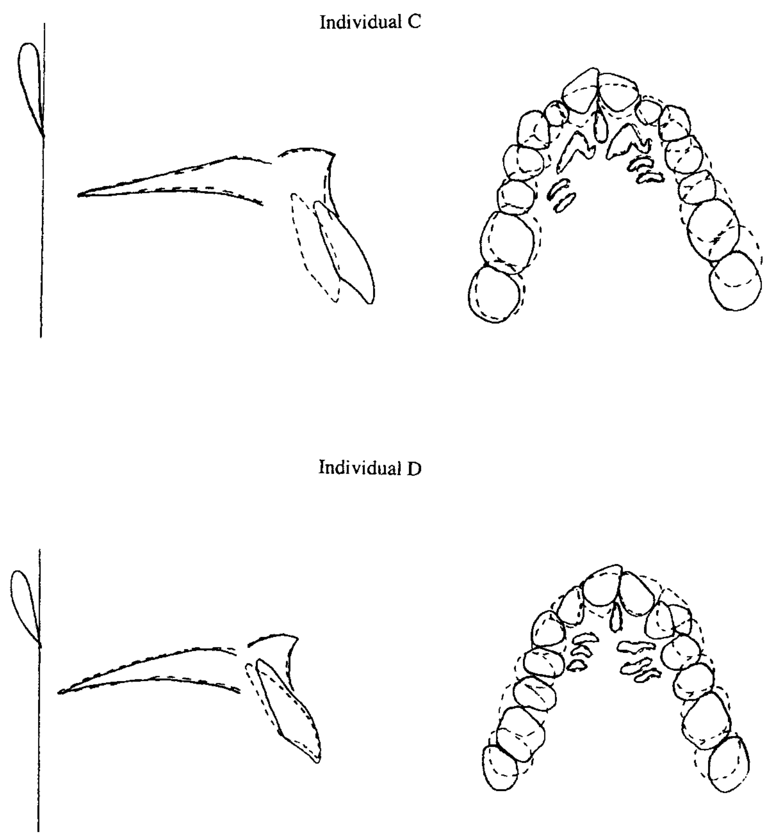


FIGURE 9. Individual maxillary cephalometric and occlusal superimpositions (4/5 extraction sequence).

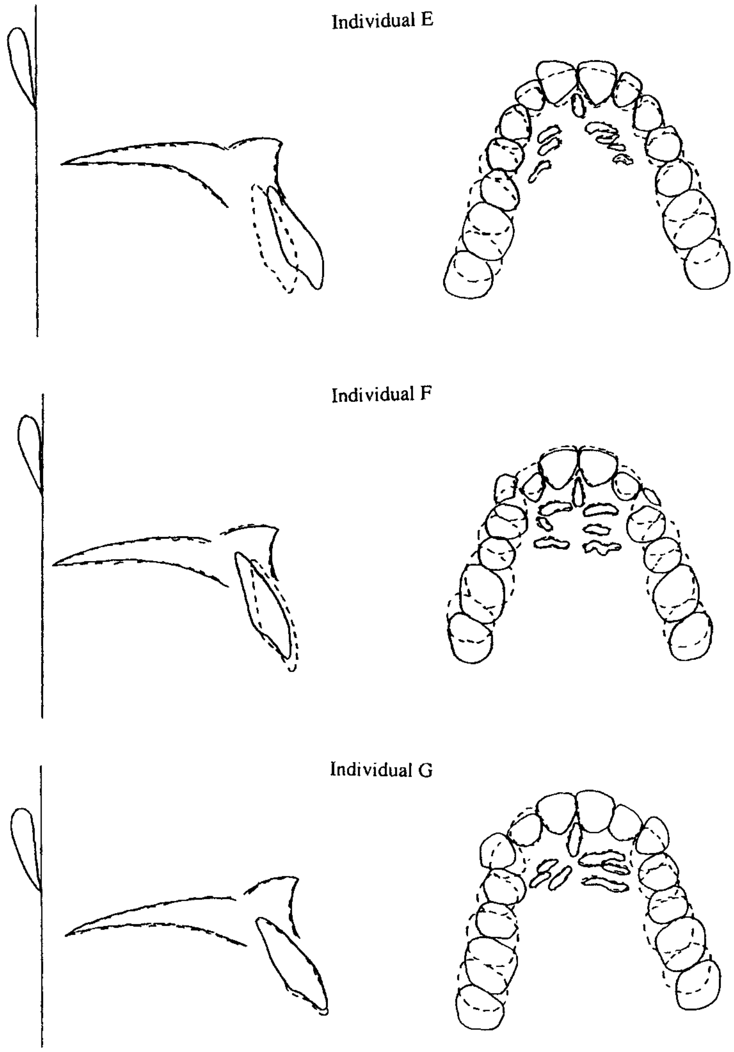


FIGURE 10. Individual maxillary cephalometric and occlusal superimpositions (5/5 extraction sequence).

this experimental sample involved unerupted, impacted, or buccally displaced maxillary canines, the width across the anterior segment of the arch was measured across the most anterior premolars on both pre- and posttreatment casts. A mean increase in arch width in this region was noted in all groups. This means that the arch form was, on average, rounded out somewhat across the premolars regardless of the extraction sequence. In contrast with this increase in arch width across the premolars, there was a significantly greater mean reduction in intermolar width in the 5/5 group. This would suggest that, in clinical practice, it might be easier to maintain the initial intermolar width if the second premolars have not been extracted.

The mean changes in anteroposterior position of the maxillary incisors found in this study are consistent with those reported in previous studies.[18,25] In the present sample, there was a mean maxillary incisor retraction of 2.5 mm ($\pm$1.9) and 1.6 mm ($\pm$1.6) in the maxillary first premolar and maxillary second premolar extraction groups, respectively. Saelens and De Smit[25] reported an average 2.1 mm ($\pm$2.5) and 1.9 mm ($\pm$2.4) retraction in their 4 first premolar and 4 second premolar extraction groups, respectively. Luppanapornlarp and Johnston[18] found an overall mean 2 mm to 3 mm retrusive effect with first premolar extractions. It should be noted that there were wide ranges of individual variation in maxillary incisor changes in both the present study and the study of Saelens and De Smit.[25] It would, therefore, seem to be unreasonable to estimate likely incisal position changes in an individual patient by simply using mean values, as has been suggested by some authors.[15,18] The mean changes in maxillary incisor position in relation to the APog line are consistent with the incisor changes on the underlying bone in that they do seem to vary according to the chosen extraction sequence. It is important to realize, however, that, as was seen in individual B (Table 9), the changes in the 2 measurements in individual patients may not always be consistent.

It has been generally accepted that greater forward move-

TABLE 9. Individual Variation in Incisal Behavior

Extraction Sequence	Incisal Tip Change (Superimposition) (mm)	Crowding (mm)	Residual Space (mm)	Initial Molar Relationship	Initial 11,21-APog (mm)	Final 11,21-APog (mm)
4/4						
Individual A	−6.5	0.5	13.6	II	12.2	5.5
Individual B	−0.5	6.4	9.0	II	11.3	7.1
4/5						
Individual C	−6.5	5.6	9.5	II	9.1	2.8
Individual D	−0.7	9.8	3.5	II	5.6	4.3
5/5						
Individual E	−5.0	−1.2	14.9	I	9.1	4.2
Individual F	+1.4	9.4	2.9	II	2.7	3.2
Individual G	0.0	4.8	8.1	I	5.3	5.1

TABLE 10. Correlations With Maxillary Incisor Movement (superimposition)[a]

Variable	Pearson's Correlation (*r*)
Age (months)	−0.228
Initial 11,21-APog (mm)	−0.514*
Initial 11,21-APog (°)	−0.323
Initial molar relationship (mm)	−0.067
Crowding (mm)	0.396
Residual space (mm)	−0.444
ML change (mm)	−0.071
SNMP change (°)	0.095
IIA change (°)	0.561*
11,21-ANS, PNS change (°)	−0.445
Overjet change (mm)	−0.269
Overbite change (mm)	0.315
Molar relationship change (mm)	0.038
Estimated molar movement (mm)	0.154
Interpremolar width change (mm)	−0.068
Intermolar width change (mm)	−0.032

[a] *, Significant correlation. See Tables 3 and 4 for definitions.

ment of the molars should be expected following the extractions of maxillary second premolars than first premolars.[16,23,26,63] This was, however, not necessarily found to be the case in the patients within this experimental sample. When relative maxillary incisor and molar movements were compared, greater molar movements occurred in 73%, 80%, and 81% of cases in the 4/4, 4/5 and 5/5 groups, respectively. If this were true for any maxillary premolar extraction sample, it might suggest that differential extraction alone may not provide sufficient maxillary anchorage control in all cases. Other methods of anchorage control would need to be considered.

Individual variation was also evident when extremes of incisor movement were evaluated (Table 9). It does seem possible for a variety of maxillary incisor changes to accompany each of these premolar extraction sequences, although there do appear to be some definite trends in incisal behavior. For instance, those patients in each of the groups in whom maximum incisor retraction had occurred appeared to have consistently less crowding and, in turn, greater residual space than other individuals in the same groups. A similar tendency has previously been documented for the mandibular arch.[62] In both maxillary and mandibular arches, therefore, it seems that both crowding and the residual space following leveling and relief of crowding play significant roles in determining the final incisal positions. Because such wide individual variation has been found in response to orthodontic treatment with any of the investigated premolar extraction sequences, it is important to assess each case on an individual basis when making a detailed treatment plan rather than simply choosing a particular extraction sequence based on published mean incisal changes for different extraction sequences.

CONCLUSIONS

From the study results, the conclusions are as follows:

1. Pretreatment characteristics, which may influence the maxillary premolar extraction-sequence decision, include the amount of incisal overjet, the first permanent molar relationship, and the initial amount of incisor protrusion.
2. There are likely to be similar ranges of decreases in maxillary anteroposterior arch dimension regardless of the chosen premolar extraction sequence. Greater reduction in intermolar width is likely to occur following the extractions of maxillary second premolars than first premolars.
3. Although there is some evidence that greater incisor retraction accompanies maxillary first premolar extractions, considerable individual variation in incisor and molar movements is likely to be seen with any premolar extraction sequence. A specific extraction sequence does not necessarily seem to guarantee that certain amounts of incisor retraction or molar protraction will occur.
4. Individual variation in response to growth and treatment is likely to be a result of different treatment mechanics and facial and occlusal objectives and is likely to depend as much on pretreatment characteristics as on the extraction sequence itself.

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REFERENCES

1. Angle EH. *Treatment of Malocclusion of the Teeth.* 7th ed. Philadelphia, Pa: S.S. White Dental Manufacturing Co; 1907.
2. Hahn GW. Orthodontics: its objectives, past and present. *Am J Orthod Oral Surg.* 1944;30:401–404.
3. Case CS. The question of extraction in orthodontia. *Am J Orthod.* 1964;50:658–691.
4. Bernstein L. Edward H. Angle versus Calvin S. Case: extraction versus nonextraction. Part I. Historical revisionism. *Am J Orthod Dentofac Orthop.* 1992;102:464–470.
5. Bernstein L. Edward H. Angle versus Calvin S. Case: Extraction versus nonextraction. Historical revisionism. Part II. *Am J Orthod Dentofac Orthop.* 1992;102:546–551.
6. Baumrind S, Korn EL, Boyd RL, Maxwell R. The decision to extract: part 1—interclinician agreement. *Am J Orthod Dentofac Orthop.* 1996;109:297–309.
7. Weintraub JA, Vig PS, Brown C, Kowalski CJ. The prevalence of orthodontic extractions. *Am J Orthod Dentofac Orthop.* 1989;96:462–466.
8. Gottlieb EL, Nelson AH, Vogels DS. JCO study of orthodontic diagnosis and treatment procedures. Part 1—overall results. *J Clin Orthod.* 1986;20:612–625.
9. Gottlieb EL, Nelson AH, Vogels DS. JCO study of orthodontic diagnosis and treatment procedures. Part 1–results and trends. *J Clin Orthod.* 1996;30:615–629.
10. Proffit WR. Forty-year review of extraction frequencies at a university orthodontic clinic. *Angle Orthod.* 1994;64:407–414.
11. Crossman IG, Reed RT. Long term results of premolar extractions in orthodontic treatment. *Br J Orthod.* 1978;5:61–66.
12. Brandt S, Safirstein GR. Different extractions for different malocclusions. *Am J Orthod.* 1975;68:15–41.
13. de Castro N. Second-premolar extraction in clinical practice. *Am J Orthod.* 1974;65:115–137.
14. Saatci P, Yukay F. The effect of premolar extractions on tooth-size discrepancy. *Am J Orthod Dentofac Orthop.* 1997;111:428–434.
15. Steyn CL, du Preez RJ, Harris AMP. Differential premolar extractions. *Am J Orthod Dentofac Orthop.* 1997;112:480–486.
16. Creekmore TD. Where teeth should be positioned in the face and jaws and how to get them there. *J Clin Orthod.* 1997;31:586–608.
17. Paquette DE, Beattie JR, Johnston LE. A long-term comparison of nonextraction and premolar extraction edgewise therapy in ''borderline'' Class II patients. *Am J Orthod Dentofac Orthop.* 1992;102:1–14.
18. Luppanapornlarp S, Johnston LE. The effects of premolar-extraction: a long-term comparison of outcomes in ''clear-cut'' extraction and nonextraction Class II patients. *Angle Orthod.* 1993;63:257–272.
19. Bishara SE, Bayati P, Zaher AR, Jakobsen JR. Comparisons of the dental arch changes in patients with Class II, division 1 malocclusions: extraction vs nonextraction treatments. *Angle Orthod.* 1994;64:351–358.
20. De La Cruz AR, Sampson P, Little RM, Artun J, Shapiro PA. Long-term changes in arch form after orthodontic treatment and retention. *Am J Orthod Dentofac Orthop.* 1995;107:518–530.
21. Kahl-Nieke B, Fischbach H, Schwarze CW. Treatment and postretention changes in dental arch width dimensions—a long term evaluation of influencing cofactors. *Am J Orthod Dentofac Orthop.* 1996;109:368–378.
22. Lee RT. Arch width and form: a review. *Am J Orthod Dentofac Orthop.* 1999;115:305–313.
23. Schoppe RJ. An analysis of second premolar extraction procedures. *Angle Orthod.* 1964;34:292–302.
24. Williams R, Hosila FJ. The effect of different extraction sites upon incisor retraction. *Am J Orthod.* 1976;69:388–410.
25. Saelens NA, De Smit AA. Therapeutic changes in extraction versus non-extraction orthodontic treatment. *Eur J Orthod.* 1998;20:225–236.
26. Proffit WR, Fields HWJ. *Contemporary Orthodontics.* 2nd ed. St Louis, Mo: Mosby Year Book; 1993:306–309.
27. Riedel RA. An analysis of dentofacial relationships. *Am J Orthod.* 1957;43:103–119.
28. Bloom LA. Perioral profile changes in orthodontic treatment. *Am J Orthod.* 1961;47:371–379.
29. Rudee DA. Proportional profile changes concurrent with orthodontic therapy. *Am J Orthod.* 1964;50:421–434.
30. Lew KK. Profile changes following orthodontic treatment of bimaxillary protrusion in adults with the Begg appliance. *Eur J Orthod.* 1989;11:375–381.
31. Diels RM, Kalra V, DeLoach N, Powers M, Nelson SS. Changes in soft tissue profile of African-Americans following extraction treatment. *Angle Orthod.* 1995;65:285–292.
32. Koch R, Gonzales A, Witt E. Profile and soft tissue changes during and after orthodontic treatment. *Eur J Orthod.* 1979;1:193–199.
33. Rains MD, Nanda R. Soft-tissue changes associated with maxillary incisor retraction. *Am J Orthod.* 1982;81:481–488.
34. Talass MF, Talass L, Baker RC. Soft-tissue profile changes resulting from retraction of maxillary incisors. *Am J Orthod Dentofac Orthop.* 1987;91:385–394.
35. Finnöy JP, Wisth PJ, Böe OE. Changes in soft tissue profile during and after orthodontic treatment. *Eur J Orthod.* 1987;9:68–78.
36. Valentim ZL, Capelli J, Almeida MA. Incisor retraction and profile changes in adult patients. *Int J Adult Orthod Orthognath Surg.* 1994;9:31–36.
37. Caplan MJ, Shivapuja PK. The effect of premolar extractions on the soft-tissue profile in adult African American females. *Angle Orthod.* 1997;67:129–136.
38. Drobocky OB, Smith RJ. Changes in facial profile during orthodontic treatment with extraction of four first premolars. *Am J Orthod Dentofac Orthop.* 1989;95:220–230.
39. Young TM, Smith RJ. Effects of orthodontics on the facial profile: a comparison of changes during nonextraction and four premolar extraction treatment. *Am J Orthod Dentofac Orthop.* 1993;103:452–458.
40. Bravo LA. Soft tissue facial profile changes after orthodontic treatment with four premolars extracted. *Angle Orthod.* 1994;64:31–42.
41. Bishara SE, Cummins DM, Jakobsen JR, Zaher AR. Dentofacial and soft tissue changes in Class II, division 1 cases treated with and without extractions. *Am J Orthod Dentofac Orthop.* 1995;107:28–37.
42. Bravo LA, Canut JA, Pascual A, Bravo B. Comparison of the changes in facial profile after orthodontic treatment, with and without extractions. *Br J Orthod.* 1997;24:25–34.
43. James RD. A comparative study of facial profiles in extraction and nonextraction treatment. *Am J Orthod Dentofac Orthop.* 1998;114:265–276.

44. Little RM. Stability and relapse of dental arch alignment. *Br J Orthod.* 1990;17:235–241.
45. Kahl-Nieke B. Retention and stability considerations for adult patients. *Dent Clin North Am.* 1996;40:961–994.
46. Vaden JL, Harris EF, Gardner RLZ. Relapse revisited. *Am J Orthod Dentofac Orthop.* 1997;111:543–553.
47. Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment—first premolar extraction cases treated by traditional edgewise orthodontics. *Am J Orthod.* 1981;80:349–365.
48. Shields TE, Little RM, Chapko MK. Stability and relapse of mandibular anterior alignment: a cephalometric appraisal of first premolar extraction cases treated by traditional edgewise orthodontics. *Am J Orthod.* 1985;87:27–38.
49. Little RM, Riedel RA, Artun J. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. *Am J Orthod Dentofac Orthop.* 1988;93:423–428.
50. McReynolds DC, Little RM. Mandibular second premolar extraction—postretention evaluation of stability and relapse. *Angle Orthod.* 1991;61:133–144.
51. Uhde MD, Sadowsky C, BeGole EA. Long-term stability of dental relationships after orthodontic treatment. *Angle Orthod.* 1983;53:240–252.
52. Glenn G, Sinclair PM, Alexander RG. Nonextraction orthodontic therapy: posttreatment dental and skeletal stability. *Am J Orthod Dentofac Orthop.* 1987;92:321–328.
53. Rossouw PE, Preston CB, Lombard C. A longitudinal evaluation of extraction versus nonextraction treatment with special reference to the posttreatment irregularity of the lower incisors. *Semin Orthod.* 1999;5:160–170.
54. Ricketts RM. A foundation for cephalometric communication. *Am J Orthod.* 1960;46:330–357.
55. Sherman SL, Woods MG, Nanda RS. The longitudinal effects of growth on the Wits appraisal. *Am J Orthod Dentofac Orthop.* 1988;93:429–436.
56. Ricketts RM. A four step analysis to distinguish orthodontic changes from natural growth. *J Clin Orthod.* 1975;4:208–228.
57. Cook AH, Sellke TA, BeGole EA. The variability and reliability of two maxillary and mandibular superimposition techniques. *Am J Orthod Dentofac Orthop.* 1994;106:463–471.
58. Proffit WR, Fields HWJ. *Contemporary orthodontics.* 2nd ed. St Louis, Mo: Mosby Year Book; 1993:155–156.
59. Bishara SE, Cummins DM, Jakobsen JR. The morphologic basis for the extraction decision in Class II, division 1 malocclusions: a comparative study. *Am J Orthod Dentofac Orthop.* 1995;107:129–135.
60. Baumrind S, Korn EL, Boyd RL, Maxwell R. The decision to extract: part II. Analysis of clinicians' stated reasons for extraction. *Am J Orthod Dentofac Orthop.* 1996;109:393–402.
61. Bishara SE, Cummins DM, Zaher AR. Treatment and posttreatment changes in patients with Class II, Division 1 malocclusion after extraction and nonextraction treatment. *Am J Orthod Dentofac Orthop.* 1997;111:18–27.
62. Shearn BN, Woods MG. An occlusal and cephalometric analysis of lower first and second premolar extraction effects. *Am J Orthod Dentofac Orthop.* 2000;117:351–361.
63. Schwab DT. The borderline patient and tooth removal. *Am J Orthod.* 1971;59:126–145.