The extraction of permanent second molars and its effect on the dentofacial complex of patients treated with the Tip-Edge appliance

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SUMMARY The aim of this investigation was to assess the dentofacial changes in a group of patients consecutively treated with Tip-Edge™ appliances and the extraction of four permanent second molars by one specialist orthodontic practitioner. Before and after treatment lateral cephalograms and study cast measurements of 45 individuals, 26 females (mean age 13.8 years) and 19 males (mean age 13.9 years), were collated and statistically analysed. Cephalometric variables that exhibited, before treatment, significant sex differences, included SNA, SNB (both smaller in males, $P < 0.05$) and U1–NA degrees ($P < 0.05$), nasolabial angle ($P < 0.05$), and upper lip length $P < 0.01$ (all larger in males). After treatment, sex differences were demonstrated for SNA (smaller in males, $P < 0.05$), mandibular length ($P < 0.01$), upper face height ($P < 0.05$), lower face height ($P < 0.01$), anterior face height ($P < 0.001$), posterior face height ($P < 0.01$), nasolabial angle ($P < 0.05$), and upper lip length and thickness ($P < 0.001$; all larger in males). For the cast analysis, before treatment differences indicated larger values for males than females for lower arch inter-canine, premolar, and molar widths, arch depth (all $P < 0.05$), tooth size, and arch length ($P < 0.01$). Similar findings were noted in the upper arch except for inter-canine and premolar arch width. Despite most arch variables displaying sex differences, no gender effect was found for irregularity or crowding parameters. The same variables exhibited significant sex differences and changes after treatment (except tooth size, lower arch depth, and upper arch inter-canine width). Overall, the pattern of correction exhibited by the subjects included dental, skeletal, and soft tissue changes. Males tended to have greater mean increases in mandibular skeletal and soft tissue variables compared with females. Both males and females had increases in most dental arch variables measured from the study casts. Both sexes demonstrated a small uprighting, but statistically non-significant distalizing of the buccal segments. The lower incisors in the sagittal plane revealed a mean tendency to remain in their pre-treatment positions, with some individual variation. Overall, the treatment results were considered favourable, but case selection appeared to bias towards Angle Class I skeletal patterns of average to slightly reduced facial height, overbite and overjet ≤ 4 mm, lip competence, no incisor protrusion, and moderate tooth size to arch length discrepancy (3–3.5 mm lower arch, 1 mm upper arch). Further evaluation of third molar eruption responses may provide insight into appropriate timing of second molar extractions.

Introduction

The extraction of teeth as an adjunct to orthodontic treatment is a well-documented procedure. There is current debate as to which teeth should be removed to provide the best outcome to achieve both dental arch space gain and dentofacial harmony. Historically, the most common extraction pattern is that of four permanent first or second premolars. While this

usually achieves the required dental arch space gain, several investigators have questioned the post-treatment consequences of extracting anteriorly and the possible detrimental effects on the dentofacial profile (Liddle, 1977; Drobocky and Smith, 1989).

Literature review

The extraction of one or more second permanent molars has been advocated as a possible alternative to the traditional premolar extraction pattern particularly in cases with mild or anticipated crowding (Richardson, 1996). A good deal of comment and controversy has arisen with much discussion based on anecdotal evidence (Haas, 1986). A paucity of data, most of which is based on minimal research and small sample sizes, has added to the disquiet within the orthodontic profession as to the efficacy of such an extraction regime (Bishara and Burkey, 1986).

Several dentofacial consequences of second permanent molar extraction therapy have been analysed previously. The effects on lower incisor crowding have been investigated by Tulley (1959), who found a minimization in the deterioration of lower incisor alignment. Wilson (1966) reported a spontaneous alignment of the lower labial segment following second molar extractions. Cryer (1967), in a study on 66 post-treatment records, concluded that the extraction of lower second molars helped prevent an increase in lower incisor crowding. Richardson (1996) reported on the 10-year longitudinal post-treatment findings of a group of second molar extraction cases, and found a slight decrease in crowding and distal molar movement, indicating stability of lower arch alignment in the medium term.

Liddle (1977) theorized that the lower first molars distalized as a response to pressure from the mesial dentition. Brenchley and Ardouin (1968) believed that distal drifting of the lower first molars was possibly influenced by a concomitant distalization of the maxillary dentition. Huggins and McBride (1978) reported that the extraction of second molars assisted the eruption of impacted second premolars.

Numerous authors have assessed the possible effects on the lower third molars following second molar extractions. Cryer (1967) found that if extraction of the second molar occurred when full crown formation of the lower third molars had been reached, 70 per cent of lower third molars subsequently achieved 'good' positions. Dacre (1987) also revealed that full crown development of the third molar yielded the highest proportion of well-placed third molars at 5 years follow-up. Richardson (1974) and Quinn (1985) reported early eruption of third molars where second molar extractions had been performed. Lawlor (1978), in a 5-year follow-up of 60 second molar extraction cases, found 14 lower third molars were in an 'unsatisfactory' position (not in occlusion and in poor contact with the lower first molar). Of these, 13 had no initial root formation at the time of extraction. Gaumond (1985) advocated second molar enucleation with radiographic evidence of a third molar tooth germ.

Conversely, Brown (1974) reported on the progressive impaction of a lower third molar following lower second molar extraction, and Haas (1986) believed the extraction of permanent second molars was 'akin to disposing of a new Mercedes to make room for a Mini'. Gooris et al. (1990) analysed the consecutive panoramic radiographs of 95 subjects, and found that lower third molars invariably tipped mesially, and rarely achieved correct angulations or tooth contacts following lower second molar extractions.

For the soft tissue profile, Liddle (1977) and Quinn (1985) justified the extraction of second molars in order to achieve a slightly protrusive profile, rather than a concave 'dished-in' face said to occur where premolars have been extracted. Marceau and Trottier (1983) believed second molar extractions maintained good facial aesthetics, whereas Staggers (1990) found an insignificant difference in facial convexity changes compared with a first premolar extraction group.

Several authors have investigated the possible benefits of second molar extractions on the duration and complexity of orthodontic treatment. Thurow (1985) cautioned that 'recommending a procedure with objectives that will not be

realized for 5 or 10 years means a commitment on the part of the doctor and patient to follow through'. McBride and Huggins (1970) reported that where second molar extractions had been performed, appliances were not required for relief of minor crowding. Wilson (1971, 1974) also found that fixed appliances were unnecessary, allowing shorter treatment times with the use of extra-oral traction and removable appliances only. Lehman (1979) believed that with the use of extra-oral traction alone, treatment times were seldom greater than 1 year.

However, Dacre (1987) concluded that one in every five lower third molars would require uprighting, and Quinn (1985) believed some third molar alignment would be necessary following initial treatment. Magness (1986) stated that treatment could not be concluded until the lower third molars were occluding and aligned, which would inevitably lead to longer treatment times. Staggers (1990) reported that treatment time was dependent on orthodontic treatment mechanics, patient co-operation, and motivation. She found no significant treatment time difference between a first premolar and a second molar extraction group and believed that post-treatment monitoring and third molar alignment may extend 'true' treatment times.

The aims of the current study were:

1. to analyse the selection criteria and treatment responses in a group of orthodontic patients treated with the extraction of four permanent second molars;
2. to assess the dentofacial changes contributing to the correction of the malocclusion;
3. to prepare data for a long-term follow-up of future dentofacial changes, particularly the eruption pathways and final occlusion of the third molars.

Materials and methods

Sample

The sample for the present investigation was drawn from the orthodontic patient records of one of the authors (CT). The cephalometric and study model records of 45 consecutively treated patients (19 males and 26 females) were evaluated according to the following selection criteria:

1. A complete record of treatment by the operator who had determined the patients as 'borderline' for extraction and requiring minimal facial change.
2. Full fixed appliance therapy utilizing the Tip-Edge™ bracket (TP Orthodontics Pty Ltd, La Porte, Indiana, USA).
3. Each member of the sample had all four permanent second molars removed during the course of treatment, and all four permanent third molars were present radiographically and in a seemingly good position.
4. Standardized pre-treatment lateral cephalometric radiographs taken within 6 months of the start of fixed appliance treatment. The average time between the pre-treatment lateral cephalogram and full fixed appliance placement ('lead' time) was 123 days for females and 142 days for males.
5. Standardized end of treatment lateral cephalometric radiographs taken within 6 months of fixed appliance removal. The average time between the end of treatment lateral cephalogram and removal of full fixed appliances ('lag' time) was 38 days for females and 47 days for males.
6. Pre-treatment study models taken before the start of fixed appliance treatment.
7. End of treatment study models taken on the day of fixed appliance removal.

The average age of the female sample at the start of treatment was 13.8 years (range of 12.1–17.7 years) and for the male sample 13.9 years (range of 12.1–15.6 years). The average total treatment time from the placement to the removal of fixed appliances for females was 1.7 years (range of 1.0–2.4 years) and for males 1.7 years (range of 1.1–2.9 years).

Four second permanent molars were removed either just prior to fixed appliance treatment or when the third molars demonstrated at least initial root formation, mesial inclination, and apparent lack of space [especially overlapping of the third molar with the second molar roots

as viewed on the dental pantomograms (DPT) and lateral head radiographs].

Cephalometric analysis

All radiographs were traced by one observer (PG) under standardized conditions in a darkened room, using a viewing light box with opaque sliding screens to reduce peripheral light in the immediate area of interest. Each tracing was completed with the use of acetate sheets (3M™ Unitek, Monrovia, California, USA) and a 0.3-mm mechanical pencil.

The landmarks (Figure 1 and Appendix 1) for each cephalogram were placed in one sitting, and the hard and soft tissue variables are described in Appendix 2.

The method of superimposition for the pre- and post-treatment lateral cephalograms was based on the structural superimposition technique employed and described by Björk (1968), and Björk and Skieller (1983). This was applied to the cranial base and mandibular superimpositions.

Figure 1 Cephalometric landmarks in order of digitization with magnification scale. See Appendix 1 for landmark identification.
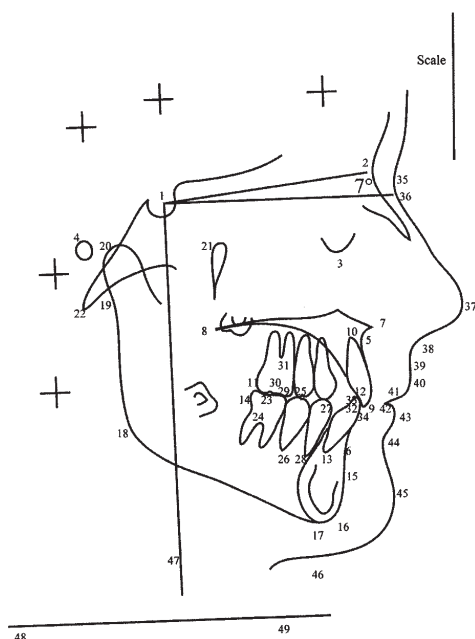
All tracings were digitized on a Hewlett Packard 9874A digitizer utilizing an Apple IIGS computer and a computerized cephalometric software programme developed by Professor T Brown, University of Adelaide. All computations were corrected for radiographic magnification by conversion from the image of a millimetre ruler captured on each film.

Study model analysis

Standardized photographs were taken of all the pre- and post-treatment study casts, which were securely placed in an adjustable stand and orientated, such that the occlusal plane was parallel to the film plane by use of a tripod and spirit level. The carefully orientated models were photographed at a pre-determined focal length, which allowed for standardized enlargement and minimal distortion. A millimetre scale placed between the upper and lower casts during the photographic process allowed the negatives to be enlarged to a 1:1 scale. This method has been validated against the corresponding cast measurements (Telfer, 1978; Fraser, 1993).

The photographs were then measured with electronic callipers (resolution to 0.01 mm; Fowler & NSK, Max-Cal., Japan).

The following measurements were determined for both upper and lower arches (Figure 2a,b):

1. *Inter-canine width (ICW)*: distances between the canines defined at the constructed centroids.
2. *Inter-premolar width (IPMW)*: distances between the second premolars defined at the constructed centroids.
3. *Inter-molar width (IMW)*: distances between the first permanent molars defined at the constructed centroids.
4. *Arch depth (AD)*: distances measured from the mid-points of the most labial points of the central incisors to a line joining the distal midpoints of the second premolars.
5. *Arch length (AL)*: distances measured from the mid-points of the most labial points of the central incisors to the distal midpoints of the second premolars.
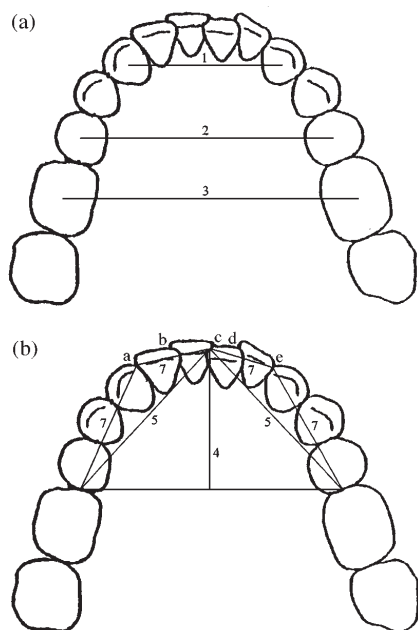
Figure 2 (a) Study model parameters for the determination of inter-canine width (1), inter-premolar width (2), and inter-molar width (3) measured to constructed centroids (Moyers *et al.*, 1976). (b) Study model parameters for the determination of arch depth (4), arch length (5), and tooth size–arch length discrepancy (7). Irregularity index (Little, 1975) = a + b + c + d + e.

6. *Irregularity index (Little, 1975)*: the sum total of the deviations of the contact points labio-lingually from the mesial contact point of the left canine to the mesial contact point of the right canine.
7. *Tooth size arch length discrepancies (Lundström, 1954)*: the sum of the mesio-distal tooth widths measured from the distal midpoints of the second premolars minus the total available arch length, utilizing the segmental arch technique.

The arch width measurements were taken from constructed centroids of the teeth as described by Moyers *et al.* (1976).

Statistical analysis

Basic descriptive statistics were applied to the data. Student's *t*-tests were used to assess the significance of the differences between values for both paired and unpaired data. Significance was set at $P < 0.05$.

Error of the method

Errors associated with the present investigation could arise from several sources, including cephalometric projection (Houston, 1983), landmark identification (Baumrind and Frantz, 1971a,b), tracing (Houston, 1983), digitization (Baumrind and Frantz, 1971a,b), automated measurement by the equipment, superimposition errors (Baumrind *et al.*, 1976), and model casting and measurement errors.

To determine the presence and extent of errors for the cephalometric investigation, 20 patients were randomly selected, and their radiographs were re-traced by the same observer and re-digitized not less than three months after the original tracings. The cranial base superimpositions were repeated for each set of radiographs.

To quantify the error in the model measurements, 20 sets of study models were selected at random and re-measured not less than three months after the original recordings.

Statistical analyses were then applied to compare the results with the original data and determinations made for random error using coefficients of reliability and Dahlberg's formula (1940). Paired *t*-tests were used to assess systematic error.

Coefficients of reliability varied from 91 to 99 per cent for the cephalometric error variables and 98 to 99 per cent for the study model measurements. Systematic error was found in eight linear cephalometric variables including L1–MP, LM–S vert, Ls–A, ST UFH, Li–E line, STPog–STN, Ss–S vert, Si–S vert ($P < 0.05$). These values reflected the difficulty in relocating L1A and LM points and the variable quality of the radiographic soft tissue images. Systematic error was determined in four of the study model variables, which included in the lower arch ICW, IPMW, and IMW ($P < 0.05$) and in the upper arch AL ($P < 0.001$). While these results must be considered in the final interpretation of the data, relatively small standard error of the mean

differences resulted in significant *t*-values for these parameters.

Controls

As this study involved consecutively treated cases, no untreated control sample was available. For comparative purposes, the pre- and post-treatment and treatment changes variables were matched by age and sex with two studies derived from similar populations (Riolo *et al*., 1974; Bhatia and Leighton, 1993).

Results

Subjects' ages and treatment time (Table 1)

Before and after treatment chronological ages were similar for both groups. Intervals between cephalometric radiographs served to provide the data for the calculations of 'effective' treatment times. This allowed direct comparison with the variable data derived from the radiographs. No significant differences were noted between males and females for 'actual treatment' times, 'effective' times, or age.

Table 1 Age (years) of the sample and treatment times.

Variable	Males (n = 19)		Females (n = 26)	
	Mean	SD	Mean	SD
Treatment start age	14.3	1.10	14.1	1.37
Before treatment ceph. age	13.9	1.10	13.8	1.38
Treatment complete age	16.0	1.16	15.8	1.20
After treatment ceph. age	15.9	1.12	15.7	1.38
Treatment time	1.7	0.42	1.7	0.33
Effective time	1.9	0.45	2.0	0.49

Cephalometric comparisons of males and females before treatment (Table 2)

For the before treatment variables, males revealed reduced SNA and SNB angles, but a greater proclination of the upper incisors (U1–NA angle). Generally, both groups exhibited a mean Class I skeletal pattern (ANB angle). Both hard and soft tissue vertical variables were greater in males in absolute terms, presumably as a result of gender dimorphism.

Cephalometric comparisons of males and females after treatment (Table 2)

For the after treatment variables, males exhibited mandibular 'catch-up' negating any pre-treatment difference for SNB angle. The upper incisors remained further proclined in males compared with females, although this was not significant. Large increases were noted in males for absolute sagittal linear variables, presumably as a result of normal growth and development.

Cephalometric comparisons of males and females for treatment changes (Table 2)

Of the inter-regional skeletal variables (SNA, SNB, ANB), only SNB approached significant mean change between the genders ($P < 0.05$). SNB showed a mean increase in males and a mean decrease in females. This may reflect forward growth changes in males and a downward and backward mandibular rotation in females. SNA decreased in both sexes to similar degrees, as did ANB (greater in males). The variable S–Go also expressed a significantly greater mean increase in the male group ($P < 0.001$).

The mandibular skeletal variables Co–Gn ($P < 0.001$) and Ar–Gn ($P < 0.001$) both revealed greater mean increases in males. B–S vert had a significantly larger mean decrease in females ($P < 0.05$), perhaps as a result of a mandibular downward rotational change at point B. FMA increased nearly 2 degrees in both sexes.

The skeletal facial height variables UFH, N–Me (both $P < 0.001$), and LFH ($P < 0.01$) all exhibited greater mean linear dimensional increases in males. This is not unexpected based on the probability of a growth differential between the genders.

The upper incisors were retroclined more in males than females for all mean upper incisor variables, but the treatment changes were not significantly different between the sexes. The

Table 2 Cephalometric values before and after treatment with treatment changes.

Variable	Before treatment					After treatment					Treatment change				
	Males		Females		t-value	Males		Females		t-value	Males		Females		t-value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
SN–FH	9.21	2.83	9.72	2.68	0.62	8.23	2.75	9.07	2.51	1.06	–0.98	0.87	–0.65	0.87	1.01
SNA	78.98	3.37	81.15	3.21	**2.19***	78.50	3.33	80.74	3.04	**2.35***	–0.48	1.08	–0.41	1.06	0.15
MaxPl–SN	5.63	3.09	6.78	1.90	1.42	5.88	3.25	6.79	1.56	1.12	0.25	1.23	0.02	1.35	0.51
Co–A	87.15	4.17	85.21	4.32	1.51	88.51	4.42	85.15	3.79	**2.74****	1.37	2.79	–0.06	2.85	1.79
U1–SN	101.98	7.27	99.36	7.89	1.13	99.63	5.38	99.09	6.24	0.31	–2.35	5.59	–0.28	8.19	0.88
U1–NA	23.00	6.89	18.22	7.06	**2.27***	21.13	5.26	18.34	6.10	1.60	–1.87	5.68	0.13	8.05	0.88
U1–NA	4.72	2.45	3.39	2.47	1.78	4.21	2.30	3.06	2.33	1.64	–0.51	2.09	–0.33	2.60	0.25
U1–Max	107.61	6.70	106.14	7.26	0.69	105.51	5.86	105.88	6.73	0.19	–2.10	5.93	–0.26	7.84	0.80
U1–L1	134.83	7.15	139.26	10.36	1.60	136.15	8.00	136.56	6.88	0.19	1.31	9.28	–2.70	10.80	1.38
OJ	4.45	2.42	3.51	1.62	1.56	2.22	1.06	2.09	0.97	0.44	–2.23	1.79	–1.43	1.78	1.34
OB	4.24	2.10	4.27	1.47	0.06	2.35	1.25	2.51	1.12	0.46	–1.89	1.44	–1.76	1.61	0.23
ANB	2.85	2.16	3.04	1.90	0.31	1.96	1.75	2.90	1.84	1.72	–0.89	1.21	–0.14	1.20	1.77
L1–NB	19.32	3.71	19.49	5.46	0.12	20.76	6.07	22.19	5.20	0.85	1.44	4.74	2.70	4.80	0.81
L1–NB	3.27	1.29	2.98	1.80	0.58	3.78	1.91	4.11	1.56	0.63	0.52	1.28	1.13	1.42	1.37
IMPA	87.59	4.37	86.45	6.63	0.65	87.62	7.64	88.22	7.68	0.26	0.02	5.02	1.77	4.91	1.13
L1–MP	18.34	3.03	17.41	2.17	1.20	20.14	4.00	18.53	2.39	1.55	1.81	1.46	1.12	1.30	1.40
SNB	76.13	2.13	78.11	2.83	**2.56***	76.54	2.71	77.84	2.75	1.58	0.41	0.69	–0.27	1.07	1.95
Co–Gn	110.36	5.49	108.69	4.61	1.10	115.82	6.53	110.73	4.23	**2.89****	5.46	3.20	2.04	3.29	**3.71*****
Ar–Gn	102.50	5.89	101.50	3.80	0.65	107.53	5.76	102.70	3.62	**3.11****	5.02	2.10	1.21	2.13	**5.51*****
Co–Go	51.18	3.66	49.97	3.86	1.06	53.68	4.27	51.54	3.51	1.84	2.50	2.31	1.57	3.26	1.03
Ar–Go	41.75	4.06	41.47	3.83	0.24	43.86	4.41	42.29	3.61	1.31	2.11	1.34	0.82	2.02	1.88
UFH	49.48	3.57	48.96	3.05	0.52	51.73	3.98	49.55	2.46	**2.08***	2.25	1.37	0.58	1.36	**3.41*****
LFH	64.59	5.59	61.80	3.46	1.89	68.98	6.26	64.61	4.16	**2.59****	4.39	1.62	2.81	1.73	**2.83****
UFH:LFH	77.15	8.39	79.50	7.15	1.01	75.57	8.79	77.00	6.53	0.63	–1.58	2.47	–2.50	2.62	1.10
N–Me	112.91	7.10	109.40	4.40	1.88	119.64	7.66	112.57	4.53	**3.44*****	6.73	2.32	3.17	2.33	**4.29*****
S–Go	71.07	5.08	68.75	4.79	1.56	75.06	5.00	70.26	4.47	**3.38****	3.99	1.68	1.51	1.95	**4.43*****
PFH:AFH	63.03	3.85	62.89	4.41	0.11	62.86	4.04	62.50	4.51	0.27	–0.17	1.21	–0.39	1.84	0.44
FMA	26.39	5.22	25.20	4.42	0.83	28.37	5.80	27.06	5.30	0.79	1.98	1.93	1.86	2.29	0.20
A–S vert	64.70	3.22	64.27	4.39	0.36	64.13	3.60	63.06	4.66	0.83	–0.57	1.53	–1.20	1.47	1.02
B–S vert	57.27	4.21	58.44	5.36	0.79	56.81	5.05	56.42	6.27	0.22	–0.46	2.52	–2.02	2.50	**2.10***
Pog–S vert	58.28	4.99	59.22	6.03	0.55	57.64	5.87	57.11	6.77	0.27	–0.65	2.74	–2.11	2.83	1.80
LM–S vert	28.54	3.08	29.92	4.52	1.15	28.16	3.82	28.59	4.89	0.31	–0.38	2.20	–1.34	2.23	1.35
UM–S vert	29.08	3.37	30.15	4.16	0.92	27.23	3.35	27.78	4.65	0.44	–1.86	1.91	–2.36	1.86	0.95
LM–MP	77.87	6.60	75.81	5.75	1.11	70.81	7.20	71.22	5.83	0.21	–7.06	5.94	–4.60	5.60	1.28
L5–MP	75.68	4.50	76.03	5.12	0.24	68.99	5.26	70.99	4.41	1.38	–6.69	4.26	–5.04	5.10	1.20
L4–MP	73.98	6.57	73.93	4.90	0.03	69.60	5.33	71.29	4.84	1.11	–4.38	4.60	–2.64	4.85	1.15
UM–PP	74.80	5.89	80.15	4.82	**3.34****	76.29	5.33	79.20	6.91	1.53	1.49	5.62	–0.95	5.18	1.41
SN–OP	15.57	5.24	16.35	4.43	0.54	18.38	3.88	18.28	5.12	0.07	2.81	4.03	1.93	5.43	0.54
MP–OP	20.03	4.30	18.57	5.09	1.01	18.23	5.65	17.85	4.20	0.26	–1.80	3.88	–0.72	4.29	0.77
F conv	127.42	4.02	129.08	4.46	1.28	125.34	3.85	129.35	3.96	**3.39****	–2.08	2.25	0.28	2.33	**3.29****
N–L angle	133.28	6.83	129.40	5.85	**2.05***	135.00	8.20	130.37	6.17	**2.16***	1.72	5.72	0.97	6.08	0.39
L–M angle	129.23	7.48	128.14	7.69	0.48	131.11	9.13	128.65	9.48	0.87	1.88	7.79	0.51	8.14	0.55
H angle	156.43	5.11	158.29	4.65	1.27	157.74	4.11	159.81	4.00	1.70	1.31	3.12	1.52	3.20	0.21
Ls–A	21.54	2.62	20.34	1.88	1.78	22.45	2.43	19.76	1.66	**4.40*****	0.91	1.03	–0.58	0.95	**3.11****
Li–B	23.26	2.56	21.38	2.61	**2.41***	24.61	2.97	22.90	3.01	1.90	1.35	2.39	1.52	2.16	0.23
ST TFH	116.81	7.56	114.65	4.80	1.08	124.24	7.89	118.35	4.83	**2.80****	7.43	3.32	3.70	3.53	**3.38****
ST UFH	50.00	3.87	50.22	4.11	0.19	53.42	3.67	51.53	3.85	1.66	3.43	2.98	1.31	3.09	**2.57****
ST LFH	71.85	5.79	69.27	3.45	1.71	76.25	6.27	71.51	4.15	**3.05****	4.40	1.87	2.24	2.09	**2.97****
ST LFH%	61.49	2.37	60.44	2.54	1.41	61.34	2.15	60.42	2.52	1.27	–0.16	1.62	–0.02	1.82	0.33
Ls–E line	–3.10	2.46	–3.79	1.98	1.03	–4.63	2.00	–4.58	1.92	0.09	–1.53	1.22	–0.79	1.16	1.73
Li–E line	–1.96	2.26	–2.68	2.37	1.03	–2.25	2.02	–2.01	1.97	0.40	–0.29	1.25	0.68	1.21	**2.40***

Table 2 Continued

Variable	Before treatment					After treatment					Treatment change				
	Males		Females		t-value	Males		Females		t-value	Males		Females		t-value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
ULL	22.72	2.12	21.05	1.91	**2.76****	23.52	2.05	20.93	2.09	**4.14*****	0.80	1.19	–0.12	1.17	**2.28***
LLL	48.40	4.41	48.08	3.04	0.29	52.24	4.77	50.39	3.13	1.57	3.84	1.82	2.31	1.94	1.90
STPog–STN	98.16	5.10	97.44	4.28	0.51	104.16	5.48	100.01	4.38	**2.83****	6.00	3.27	2.56	3.51	**2.98****
Sn–S vert	81.72	3.48	79.98	3.87	1.55	83.26	4.13	79.05	4.47	**3.22****	1.54	1.67	–0.93	1.66	**4.43*****
Ss–S vert	79.05	3.60	78.12	4.30	0.77	79.42	3.63	76.70	4.81	**2.07***	0.37	1.58	–1.42	1.53	**3.36****
Ls–S vert	80.93	4.28	80.36	4.39	0.43	81.23	3.79	78.76	4.97	1.81	0.30	1.95	–1.60	2.01	**2.93****
Li–S vert	76.91	3.77	76.81	5.00	0.07	77.71	4.42	76.22	5.58	0.96	0.80	2.45	–0.59	2.35	1.93
Si–S vert	68.45	4.05	69.14	5.16	0.48	68.54	5.18	67.63	5.97	0.53	0.08	2.15	–1.51	2.11	**2.36***
STPog–S vert	70.28	4.91	71.85	5.94	0.94	70.09	5.95	69.81	7.03	0.14	–0.19	2.70	–2.03	2.71	**2.21***

t-values significant at: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

lower incisors were minimally proclined in both groups.

Of the mean soft tissue variable changes, 14 expressed significant differences between the groups. F conv had a greater mean change (decrease) in males, reflecting increases in nasal dimension. ULL ($P < 0.05$) increased sagittally in males. For the soft tissue variables to S vert, all (except Si–S vert) were significantly different pre- and post-treatment. All of these dimensions had a mean decrease in females, whereas there was a trend for a mean increase in males. An overall growth differential, as well as a greater downward rotation in the female sample, may in some way explain these mean differences.

The vertical soft tissue variables reflected the underlying skeletal changes, with ST TFH, ST UFH, ST Pog–STN, and ST LFH (all $P < 0.01$) showing significantly greater mean increases in males.

The overall mean changes during treatment for both males and females are represented graphically in the composite tracings superimposed on anatomical cranial base structures (Figures 3 and 4).

Comparison with 'controls'

Pre-treatment. The study sample resembled the control groups in most parameters except the
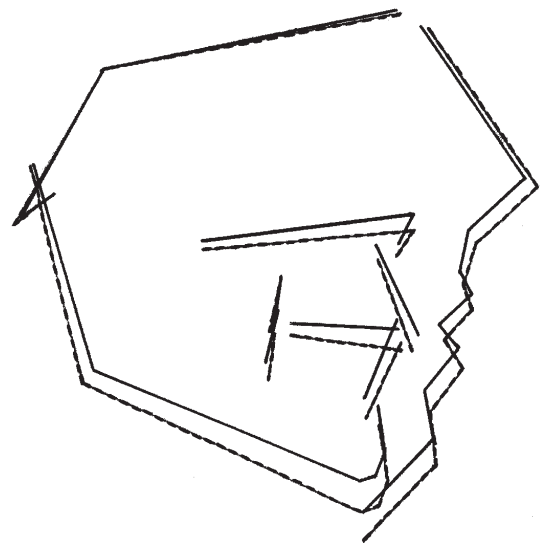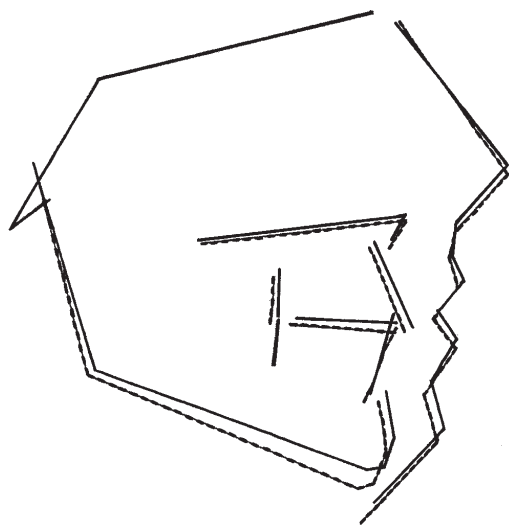

Figure 3 Composite tracings superimposed on anatomical cranial base structures—males. Solid line, before treatment; broken line, after treatment.

incisors, which were marginally more upright, overbite was deeper, ramal length was shorter, MP-OP was greater, and facial convexity was increased.

Post-treatment. The study sample differed from the control values in that the upper incisors were not proclined, the overbite and overjet were

Figure 4 Composite tracings superimposed on anatomical cranial base structures—females. Solid line, before treatment; broken line, after treatment.

reduced, the lower incisors were proclined slightly, ramal length remained shorter, face height increased, FMA increased, and facial convexity remained increased.

The study sample most closely followed the growth changes reported by Bhatia and Leighton (1993).

Mandibular regional superimpositions (Table 3)

No significant angular differences between the sexes were noted pre-treatment. LM (lower first molar) angle exhibited a tendency to be larger in the male group. There were no statistically significant differences for the post-treatment variables between the genders. L5 and L4 angles tended to be larger in females. For treatment changes (Table 3), no variables exhibited statistically significant differences between males and females. LM and L5 angles approached significance at $P < 0.05$. For the male sample, all the dental angular variables revealed a mean decrease after treatment. The same mean tendency was exhibited by the female group except for LI angle, which increased slightly. Overall, the lower buccal segment exhibited mean distal uprighting, whereas the lower labial segment remained relatively stable in the sagittal plane.

**Table 3** Treatment changes mean mandibular cephalometric variables.

Variable	Males		Females		t-value
	Mean	SD	Mean	SD	
LI angle	−0.14	5.36	1.68	5.13	0.61
LM angle	−8.31	6.82	−5.03	6.87	1.96*
L5 angle	−6.96	3.48	−4.73	4.71	1.96*
L4 angle	−4.71	4.65	−2.38	4.46	1.25

t-values significant at: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

The overall mean changes during treatment for both males and females are represented graphically in the composite tracings superimposed on stable mandibular anatomical structures (Figures 5 and 6).

Study model comparisons of males and females before treatment (Tables 4 and 5)

Analysis of the study model variables revealed larger arch perimeter and tooth size in males. Irregularity indices and tooth size–arch length discrepancy were similar in both upper and lower arches in both genders before treatment (Table 4). Statistically significant greater mean values for all variables in the male sample were revealed for both transverse and sagittal
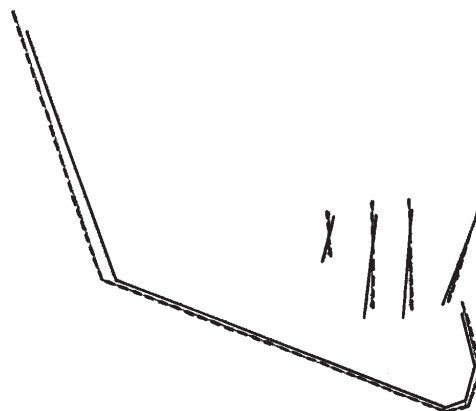
Figure 5 Composite tracings superimposed on anatomical mandibular structures—males. Solid line, before treatment; broken line, after treatment.
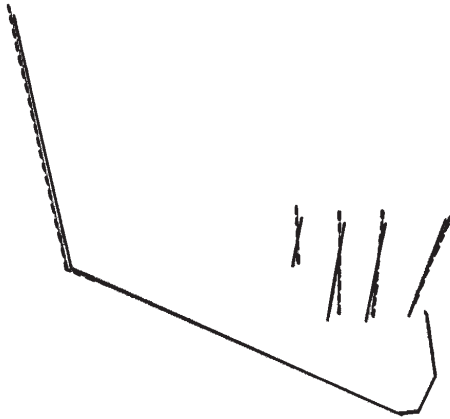
Figure 6 Composite tracings superimposed on anatomical mandibular structures—females. Solid line, before treatment; broken line, after treatment.

Table 4 Pre-treatment (T1) mean crowding and irregularity study model variables.

Variable (mm)	Males		Females		t-value
	Mean	SD	Mean	SD	
Lower arch—T1					
Irregularity index	5.00	1.81	4.33	1.73	1.26
Arch perimeter	64.48	3.26	62.99	3.14	1.55
Tooth size	67.95	2.61	65.89	2.18	2.87**
TSALD	–3.47	2.64	–2.90	2.41	0.75
Upper arch—T1					
Irregularity index	6.59	2.12	6.34	2.10	0.39
Arch perimeter	74.91	3.57	72.79	3.22	2.09*
Tooth size	75.82	3.66	73.74	2.26	2.15*
TSALD	–0.91	2.55	–0.95	2.53	0.05

t-values significant at: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

measurements (Table 5), except ICW and IPMW in the upper arch.

Study model comparisons of males and females after treatment (Table 6)

Both the irregularity index and tooth size–arch length discrepancies were considered to approximate zero at the completion of active treatment. However, a mean increase over the before treatment absolute values for both sexes in both arches was revealed (Table 6). The values

Table 5 Pre-treatment mean study model variables.

Variable (mm)	Males		Females		t-value
	Mean	SD	Mean	SD	
Lower arch—T1					
ICW	24.94	1.83	23.73	1.50	2.43*
IPMW	35.50	2.29	33.91	2.84	2.01*
IMW	41.24	2.92	39.00	3.27	2.38*
AD	23.61	1.32	22.60	1.35	2.51*
AL	61.11	2.57	58.32	2.90	3.33**
Upper arch—T1					
ICW	31.02	2.22	30.53	1.99	0.78
IPMW	39.66	2.42	38.40	2.46	1.70
IMW	45.90	2.55	44.24	2.58	2.14*
AD	28.98	1.96	27.03	1.74	3.52**
AL	71.32	3.55	67.54	3.07	3.80***

t-values significant at: $P < 0.05$*; $P < 0.01$**; $P < 0.001$***

Table 6 Post-treatment mean study model variables.

Variable (mm)	Males		Females		t-value
	Mean	SD	Mean	SD	
Lower arch—T2					
ICW	26.04	1.31	25.02	1.07	2.86**
IPMW	36.45	2.41	34.15	2.00	3.49**
IMW	41.32	2.55	39.33	2.53	2.60*
AD	24.64	1.33	23.91	1.14	2.00
AL	63.15	2.32	60.48	2.13	3.98***
Upper arch—T2					
ICW	32.35	1.79	31.74	1.40	1.27
IPMW	41.88	1.92	40.49	2.06	2.29*
IMW	46.59	2.29	45.03	2.30	2.25*
AD	28.67	1.42	27.65	1.33	2.48*
AL	71.77	3.09	69.24	2.57	2.99**

t-values significant at: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

were significantly larger in males for all variables except for ICW in the upper arch and AD in the lower arch.

Study model comparisons of males and females for treatment changes (Table 7)

For mean treatment changes in arch form, there were no significant differences between males and females except for AD, which revealed a

Table 7 Treatment changes mean study model variables.

Variable (mm)	Males		Females		t-value
	Mean	SD	Mean	SD	
Lower arch					
ICW	1.10	1.20	1.30	1.02	0.58
IPMW	0.95	1.40	0.24	1.43	1.67
IMW	0.08	2.11	0.33	1.59	0.45
AD	1.03	1.05	1.31	1.41	0.72
AL	2.04	2.14	2.16	2.75	0.15
Upper arch					
ICW	1.33	1.81	1.22	1.68	0.21
IPMW	2.22	1.67	2.09	1.89	0.24
IMW	0.69	2.03	0.79	1.40	0.19
AD	–0.31	1.17	0.61	1.56	2.16*
AL	0.45	2.29	1.70	2.58	1.68

t-values significant at: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

mean decrease in males and an increase in females. Generally, there was an increase in the values for the variables analysed.

Discussion

Sample size

The current study sample comprised the complete cephalometric and study model records of 45 patients, 19 males, and 26 females. The ratio of males to females (1:1.4) in the sample reflected the general attendance patterns of the population presenting for orthodontic treatment (Shaw *et al.*, 1991).

The current study sample size compares favourably with similar published research. Staggers (1990) and Cavanaugh (1985) examined the radiographic data of a total sample of 25 second molar extraction cases. Cryer (1967) examined the complete records of 66 cases, whereas Huggins and McBride (1978) investigated 27 cases. In a 5-year follow-up study, Lawlor (1978) recalled 60 patients for an assessment of both lateral oblique radiographs and study casts. Richardson (1996) examined the study models of a group of 30 patients (eight males) as part of a 10-year follow-up examination.

Sample age

The sample was of Caucasian origin and the ages bear similarities between genders. Chronologically, the average age of the pre-treatment females was 13.8 years compared with the male group of 13.9 years. Based on the limited available literature regarding 'ideal' timing of permanent second molar extractions and the uneventful and successful eruption of permanent third molars (Bishara and Burkey, 1986), it is intended to follow up these 'cases', and assess their occlusal status in the medium to long-term.

Treatment time

The average treatment time for both males and females was 1.7 years, although the range varied broadly with females 1.0–2.4 years and males 1.1–2.9 years. Several authors have advocated the extraction of permanent second molars in order to decrease treatment times compared with premolar or 'mid-arch' extraction cases. Unfortunately, these authors failed to report the actual amounts of decreased time intervals they had observed (Marceau and Trottier, 1983; Quinn, 1985). Staggers (1990) compared the treatment times of a group of premolar extraction cases with a sample of permanent second molar extraction cases and found no significant difference in treatment times between the groups. The second molar extraction group actually experienced slightly longer mean treatment times of 3.2 years compared with 3.1 years for the premolar group. These results indicated comparatively shortened treatment times for the current study group by a factor of two. The 'overall' treatment time should be calculated considering the possibility of 'follow-up' mechanics to align the third molars (Magness, 1986). Whitney and Sinclair (1987) reported on the changes in 30 individuals following permanent second molar extraction. 'Combination therapy' involving 12.5 months of sagittal appliances, 14.0 months of Bionator therapy, and 13.0 months of fixed appliances resulted in overall treatment times far greater than those for the current study group.

Careful case selection may have influenced the outcome, but the present sample were treated

with a single phase of Tip-Edge™ appliance therapy utilizing minimal Class II intermaxillary elastic wear.

Cephalometric comparisons between genders

The before treatment groups revealed an essentially Class I skeletal pattern with moderately increased overjet, vertical parameters, and upper incisor protrusion in the male group, and slightly retroclined lower incisors in both males and females. Remarkable similarities were exhibited for the cephalometric variables after treatment between the genders. Both groups were Class I or mild Class III (males) skeletal patterns with an increased vertical component in the male group. The dental parameters were broadly similar. The soft tissues reflected the skeletal proportions with males having larger upper lip lengths and depths. When assessing overall treatment changes, significant increases were noted for the skeletal variables SNB ($P < 0.05$), Co–Gn ($P < 0.001$), Ar–Gn ($P < 0.001$), and S–Go ($P < 0.001$) for males compared with females. This clearly demonstrated the mandibular developmental changes experienced by the male sample between the mean ages of 13.9 and 15.9 years and agrees with Björk (1951).

Sinclair and Little (1985) noted similar increases in vertical skeletal variables, namely UFH and LFH. Between 9 and 13 years of age, the male sample showed significantly greater increases than females for UFH and LFH in their untreated sample. The present study found similar face height changes where both growth and fixed appliance orthodontic treatment effects could be responsible.

The majority of the soft tissue variables analysed in the current study revealed significantly greater changes in males than females. Generally, the variables for lip prominence increased in the male sample, but decreased for the female sample. This could reflect the decrease in upper incisor proclination in males compared with females and a sexual dimorphism for overall soft tissue growth increases over the treatment period. Nanda *et al.* (1990) stated that lip position is affected by the position of the incisors and, in a longitudinal study, found that the average increase

in upper and lower lip length in males was more than twice that of females. Those authors also found that most of the soft tissue growth changes at the nose, lips, and chin were suggestive of sexual dimorphism, with males having a greater increase in these soft tissue parameters over a longer time period than females. Soft tissue face height differed significantly between the groups, with generally larger changes observed in the male group. This accurately reflected the skeletal change observed in the current study sample. Genecov *et al.* (1990) analysed the vertical soft tissue changes in an untreated group from the Bolton study and found that from the ages of 7 to 13 years, both sexes revealed 5–7 mm increases in upper face height, which reflected the underlying skeletal change. However, from 13 to 17 years, the male group in the present study continued to show soft tissue increases of 6 mm, while the female untreated group grew only 1 mm. Genecov *et al.* (1990) found similar increases for soft tissue lower face height with males greater than females from 13 to 17 years.

Cephalometric mandibular regional comparisons between genders

Mandibular regional superimpositions were completed in order to assess the dental movements observed in the lower arch. They were also used to test the null hypothesis that extraction of permanent second molars and fixed appliance therapy does not procline the lower incisors.

Long axes were constructed for the lower premolars and the lower first molars according to the method reported by Lindqvist and Thilander (1982) and Gardner *et al.* (1998).

Before treatment, there was no significant difference between the sexes for any of the variables analysed. There was a general trend for the long axes in the male group to be nearer the perpendicular than the female group. The reverse was true after treatment. Both groups revealed a distalizing of the lower buccal segments (despite minimal or no intermaxillary elastic traction), with the males exhibiting a greater change than the females. The lower incisors remained virtually unchanged. Sinclair and Little (1985), in an untreated sample,

revealed mesial tipping of the lower molars, and upward and forward movement of the mandibular incisors especially in males. These changes were thought to be 'dental compensation' in response to any skeletal changes in order to maintain occlusal integrity. The difference in the change for lower first molar angle and lower second premolar angle between the sexes approached significance at $P < 0.05$.

Staggers (1990) superimposed successive mandibular tracings to assess positional changes of the lower first molar and lower incisors in a group who had all second permanent molars extracted and fixed appliance therapy. This showed an anterior movement of the lower first molars (0.3 mm) and mandibular incisors (1.3 mm). Whitney and Sinclair (1987) reported distal tipping of the lower first molars (3.1 degrees) and lower incisors (insignificant) along the occlusal plane as part of the 'combination' therapy received by their sample.

The current study revealed changes in the lower buccal segment that were contributory toward the alignment of the lower incisors. The lower incisors remained virtually static. The null hypothesis that the lower incisors do not procline significantly during fixed appliance therapy following the extraction of four second permanent molars was satisfied for both sexes. The response is consistent with the Tip-Edge appliance, which is conducive to free tipping and uprighting movements of the teeth.

Study model comparisons between genders

For the lower arch, the variables inter-canine width, inter-premolar width, inter-molar width, arch depth, and arch length were all significantly larger in the male group before treatment. This equated with the findings of Sinclair and Little (1983).

The irregularity index was similar for both groups, tending to be more severe in males (5.0) than females (4.3). Conversely, Sinclair and Little (1983) found that untreated females had statistically greater lower incisor irregularity than their male sample. Whitney and Sinclair (1987) reported that their pooled sample required a pre-treatment score of 3.5 or greater to be

included in their study, but the exact scores are not provided. There was a significant sexual dimorphism for total mesio-distal tooth widths in the current study ($P < 0.01$), with males exhibiting larger values than females. Mandibular tooth size–arch length discrepancies were essentially similar between genders, being –3.5 mm for the current male sample and –2.9 mm for the current female group.

For the upper arch before treatment molar width, arch depth and arch length were all significantly greater in males. Moyers et al. (1976) found a similar gender dimorphism. There was a tendency for inter-canine and inter-premolar widths to also be larger in males. There was no significant difference for the irregularity index between sexes in the upper arch, and tooth size–arch length discrepancy was virtually identical between the groups, but less than for the lower arch. A paucity of published data for the maxillary incisor irregularity index (Bishara et al., 1989) precluded meaningful comparisons to be made with the current study group. Vaden et al. (1997), in a pooled treated sample, reported an average maxillary irregularity index of 7.9 mm pre-treatment compared with 6.6 mm for males and 6.3 mm for females in the current sample.

Remarkable, but not unexpected similarities were revealed for the lower arch after treatment. Inter-canine, inter-premolar, inter-molar widths, and arch length were all significantly larger for the male sample. Arch depth approached significance ($P < 0.05$), with the mean being greater in males.

The upper arch after treatment was a reflection of the before treatment upper arch, except for inter-premolar width ($P < 0.05$), which was significantly greater in males than females.

For the lower arch, no variables showed significant differences between the sexes from before to after treatment. All mean parameters increased in absolute terms with treatment. This change varied from a 0.1 mm increase in inter-molar width for males to a 2.2 mm increase in arch length in females.

For the upper arch, only arch depth exhibited a mean significant difference between genders for treatment changes ($P < 0.05$). In fact, arch depth in males decreased, the only parameter to

do so, and arch depth in females increased. However, the variables analysed tended to increase from before to after treatment, suggesting that mild arch expansion had occurred.

In comparison with a longitudinal control group (Moyers *et al.*, 1976), relatively larger increases were exhibited for inter-premolar width for both males and females in the upper arch for the treated group. Inter-molar width increased minimally in the lower arch in the male treated sample compared with a relatively larger increase in the control group. Arch depth, in the same sample, decreased minimally in the upper arch as for the controls.

The study model variable changes provided evidence for the method of resolution of crowding and irregularity. In the lower arch, an increase in arch length for both genders appeared to dominate the orthodontic correction. This was complemented, to a slightly lesser degree, by an increase in arch depth. The lower arch increases in both arch depth and length may be a reflection of the distalizing of the buccal segments revealed cephalometrically. Transversely, inter-canine width increased to a far greater degree than inter-premolar width and also inter-molar width, which remained virtually unchanged. For the upper arch, an increase in inter-premolar width, for both genders, appeared to provide the change required for the resolution of crowding. Inter-canine width also increased, but to a far lesser degree than that observed in the lower arch and inter-molar width again appeared stable. In contrast to the lower arch findings, upper arch depth and length showed little alteration except for arch length in the female sample, which increased by a mean of 1.7 mm.

Comparisons with 'untreated' second molar extraction samples

Richardson (1996) reported on the 10-year results of a group of eight males and 22 females who had four second permanent molars extracted. The average age at extraction was 13.9 years. All had Class I or mild Class II malocclusions with 'well-aligned, or slightly crowded lower arches'. There was no mechanical treatment in the lower arch, but the majority of the sample had

simple fixed appliances or removable appliance therapy in the upper arch. The 'space condition' was analysed with the use of a Vernier microscope and the degree of crowding assessed. The data were pooled as no significant differences were apparent between genders. Pre-treatment, the lower arch was crowded on average 1.3 mm. There was a significant average decrease in crowding after 5 years of 0.6 mm and an insignificant crowding increase of 0.1 mm at the 10-year interval. Males in the present study had a before treatment tooth size–arch length discrepancy of 3.5 mm and females 2.9 mm. From these findings, it would appear that crowding in the lower arch in the current group was greater than for Richardson's (1996) untreated sample. That author believed that the extraction of second molars in the teenage years is effective in preventing 'late' lower arch crowding and that the alignment may be maintained into the third decade. Whether this would apply to the current sample is yet to be analysed. Any effect of upper arch therapy on the lower arch has not been elucidated.

Battagel and Ryan (1998) assessed the lower arch changes on study casts in a sample of five males and 13 females following lower second molar extractions. Buccal segment retraction was completed in the upper arch only. The age at the start of treatment for the comparison group was 13.8 years and post-treatment 16.0 years, similar to the current study sample. Favourable 'spontaneous' alterations were noted for the above parameters in their group. The authors believed that this may be due to sympathetic movement of the lower arch following upper arch expansion and 'distalizing', and the facilitation of buccal and distal drift allowing expansion of the lower arch. Similar changes were revealed for increases in arch length and perimeter.

Comparing the two samples, inter-canine width appeared to be greater in the Battagel and Ryan (1998) sample pre-treatment. This may be evidence of a selection bias by the authors for cases that they deemed would be most likely to benefit from lower second molar extractions without orthodontic therapy. A similar scenario was exhibited for inter-molar widths. The long-term effects of these changes are yet to be fully

analysed in both samples, particularly with respect to lower incisor crowding in early adulthood.

It is possible that the extraction of permanent second molars in the current sample elicited a number of effects, including distal traction from healing extraction sites. Moreover, the present group had anchorage bends and minimal inter-maxillary traction as part of their mechano-therapy, such that any distalizing effects would be expressed.

Conclusions

1. Cephalometric variables before treatment showed that both sexes exhibited a Class I skeletal pattern and upright lower incisors. Males showed increased overjet, overbite, and face height. After treatment, general similar-ities existed between the sexes with sexual dimorphism for overall linear variables, indicating that males were usually larger. The male sample exhibited mandibular 'catch-up' growth over the observation period, whereas females indicated a more vertical treatment response. For the soft tissue changes, males revealed an overall 'straightening' of the soft tissue profile (F conv), reflecting mandibular growth, longer and thicker upper lip profiles and soft tissue vertical parameters compared with females.
2. Study model changes demonstrated that the irregularity and tooth size–arch length dis-crepancies were similar between the groups before treatment. Most dental variables remained significantly larger in males after treatment.
3. Regional mandibular superimpositions revealed no significant difference between genders for any of the parameters analysed. After treatment, both sexes exhibited slight distal uprighting of the buccal segments, which was greater in males than females. The lower incisors remained similar to their pre-treatment positions.
4. The resolution of crowding and incisor irregularity was achieved in the lower arch by an increase in arch length for both genders, and a smaller mean increase in arch depth. Transversely, an increase in inter-canine widths

and a lesser increase in inter-premolar widths occurred in both sexes in the lower arch. For the upper arch, inter-premolar width increases appeared to dominate the orthodontic correction in both males and females. Inter-canine width increases were also observed to a similar degree to those for the mandibular arch. Changes in upper arch length were less than the lower arch changes, while arch depth reduced slightly in males and marginally increased in females.
5. In carefully selected cases, the extraction of second permanent molars in conjunction with the Tip-Edge appliance represents a viable treatment option.

Future research

This current sample will be re-examined in the medium- and long-term in order to assess the pre- and post-eruption patterns of the third molars in both upper and lower arches, and to monitor the dental arch stability.

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Appendix I: the cephalometric landmarks (in order of digitization)

1. Sella turcica (S): the centre of the pituitary fossa of the sphenoid bone.
2. Nasion (N): the junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose.
3. Orbitale (Or): the lowest point on the average of the right and left borders of the bony orbit.
4. Porion (Po): the upper border of the external auditory meatus (anatomic).
5. Point A (A): the most posterior point on the curve of the maxilla between the anterior nasal spine and supradentale.
6. Point B (B): the point most posterior to a line from infradentale to pogonion on the anterior surface of the symphyseal outline of the mandible; it should lie within the apical third of the incisor roots.
7. Anterior nasal spine (ANS): the tip of the median, sharp bony process of the maxilla at the lower margin of the anterior nasal opening.
8. Posterior nasal spine (PNS): the most posterior point at the sagittal plane on the bony hard palate.
9. Upper incisal edge (U1E): the incisal tip of the maxillary central incisor.
10. Upper incisal apex (U1A): the root tip of the maxillary central incisor.
11. Upper molar distal cusp reference point (UM): the most postero-inferior point on the distal border of the crown of the upper first permanent molar.
12. Lower incisal edge (L1E): the incisal tip of the mandibular central incisor.
13. Lower incisal apex (L1A): the root tip of the mandibular central incisor.
14. Lower molar distal cusp reference point (LM): the most postero-superior point on the distal border of the crown of the lower first permanent molar.
15. Pogonion (Pog): the most anterior point on the contour of the bony chin, determined by a tangent through N.
16. Gnathion (Gn): the most anterior-inferior point on the contour of the bony chin symphysis, determined by bisecting the angle formed by the mandibular plane, and a line through Pog and N.
17. Menton (Me): the most inferior point on the symphyseal outline.
18. Gonion (Go): the mid-point of the angle of the mandible, found by bisecting the angle formed by the mandibular plane and a plane through articulare posterior, and along the portion of the mandibular ramus inferior to it.
19. Articulare (Ar): the point of intersection of the inferior cranial base surface and the averaged posterior surfaces of the mandibular condyles.
20. Condylion (Co): the most posterior-superior point on the curvature of the average of the right and left outlines of the condylar head, determined as the point of tangency to a perpendicular construction line to the anterior and posterior borders of the condylar head.
21. Pterygo-maxillary fissure (PTM): the most postero-superior point on the border of the PTH, where the overlap between the cranial base (f. rotundum) and PTH was visible, the midpoint of the intersecting outlines was taken as the correct landmark.
22. Basion (Ba): the most inferior-posterior point on the anterior margin of foramen magnum.
23. Lower molar centre (LMC): the measured midpoint of the mandibular first molar crown.
24. Lower molar furcation (LMF): the most occlusal point in the bifurcation of the roots of the mandibular first molar.
25. Lower second premolar cusp tip (L5E): the cusp tip of the mandibular second premolar.
26. Lower second premolar apex (L5A): the root tip of the mandibular second premolar.
27. Lower first premolar cusp tip (L4E): the cusp tip of the mandibular first premolar.
28. Lower first premolar apex (L4A): the root tip of the mandibular first premolar.
29. Posterior Downs point (PDP): the midpoint of a line connecting the mesial cusp tip of the mandibular first molar and the mesial cusp tip of the maxillary first molar. This represents the posterior point through which Downs occlusal plane passes.
30. Upper molar centre (UMC): the measured midpoint of the maxillary first molar crown.
31. Upper molar furcation (UMF): the most occlusal point in the trifurcation of the roots of the maxillary first molar.
32. Labial lower incisor (L1L): the most labial point on the labial surface of the most proclined lower incisor.
33. Anterior Downs point (ADP): the midpoint of a line connecting landmarks 9 and 12 (U1E and L1E). This represents the anterior point through which Downs occlusal plane passes.
34. Lower incisor centre (L1C): a constructed point representing the intersection of a line perpendicular to SN–7 degrees passing through landmark 12 (L1E) and a line parallel to SN–7 degrees passing through landmark 9 (U1E).
35. Soft tissue nasion (ST N): the point of greatest concavity in the midline between forehead and nose
36. Soft tissue 7 (ST 7): the point representing the intersection of the cephalometric plane SN–7 degrees with the soft tissue profile.
37. Nasal tip (N tip): or pronasale, the most prominent point on the contour of the nose.
38. Subnasale (Sn): the point at which the nasal septum merges with the upper cutaneous lip in the mid-sagittal plane.
39. Sulcus superius (Ss): the point of greatest concavity in the midline of the upper lip between subnasale and labrale superius.
40. Labrale superius (Ls): a point indicating the mucocutaneous border of the upper lip.
41. Upper lip lowest point (ULL): or stomion superius, the lowermost point of the vermilion border of the upper lip.
42. Lower lip highest point (LLH): or stomion inferius, the uppermost point of the vermilion border of the lower lip.
43. Labrale inferius (Li): a point indicating the mucocutaneous border of the lower lip.

44. Sulcus inferius (Si): the point of greatest concavity in the midline between the lower lip and chin.
45. Soft tissue pogonion (ST Pog): the most anterior point on the soft tissue chin.
46. Soft tissue menton (ST Me): the lowest point on the contour of the soft tissue chin; found by dropping a perpendicular from the horizontal reference plane through menton.

The following describes the points used to define the X and Y cartesian axes:

47. Y: a point on the line perpendicular to SN–7 degrees passing through landmark 1 (S).
48. X1: the origin point on the X axis, which is parallel to SN–7 degrees.
49. X2: the terminal point on the X axis, which is parallel to SN–7 degrees.

Appendix II: definitions of the angular and linear variables

1. Sella–nasion to Frankfort horizontal (SN–FH, in degrees): the angle formed between S–N and porion-orbitale.
2. SNA (degrees): the angle formed between the S–N line and a line drawn through N and Downs point A.
3. Maxillary plane to S–N (MaxPl–SN, in degrees): the angle formed between the S–N line and the line joining ANS and PNS.
4. Maxillary length (Co–A point, mm): the linear distance from Co to point A.
5. Upper incisor to S–N (U1–SN, in degrees): the angle formed between a line drawn through S–N and a line drawn through the long axis of the most prominent upper central incisor.
6. Upper incisor to NA (U1–NA, in degrees): the angle formed between a line drawn through the long axis of the most prominent upper central incisor and a line drawn through nasion and Downs point A.
7. Upper incisor to NA (U1–NA, mm): the linear distance measured parallel to SN–7 degrees from the most prominent upper central incisor crown tip to a line drawn through N and Downs point A.
8. Upper incisor to maxillary plane (U1–MaxPl, in degrees): the angle formed between the long axis of the most prominent upper central incisor and a line formed by joining ANS and PNS.
9. Inter-incisal angle (U1–L1, in degrees): the angle formed between the lines drawn through the long axes of the most prominent upper and lower central incisors.
10. Overjet (OJ, mm): the linear distance measured parallel to SN–7 degrees between the cusp tip of the most prominent upper central incisor and the labial surface of the most prominent lower central incisor.
11. Overbite (OB, mm): the linear measure of vertical overlap between the cusp tip of the most prominent upper central incisor and the cusp tip of the most prominent lower central incisor.
12. ANB (degrees): the angular difference between the angles S–N, and Downs point A and S–N point B.
13. Lower incisor to NB (L1–NB, degrees): the angle formed between a line drawn through the long axis of the most prominent lower central incisor, and a line drawn through N and point B.
14. Lower incisor to NB (L1–NB, mm): the linear distance measured parallel to SN–7 degrees from the most prominent lower central incisor, and a line drawn through N and point B.
15. Lower incisor to mandibular plane (IMPA, degrees): the angle formed between a line drawn through Go and Gn and a line drawn through the long axis of the most prominent lower central incisor.
16. Lower incisor to mandibular plane (L1–MP, mm): the linear distance between a line drawn through Go and Gn, and the apex of the most prominent lower central incisor.
17. SNB (degrees): the angle formed between a line drawn through S–N and N point B.
18. True mandibular length (Co–Gn, mm): the linear distance of the line joining Co and Gn.
19. Mandibular length (Ar–Gn, mm): the linear distance of the line joining Ar and Gn.
20. True ramus height (Co–Go, mm): the linear distance of the line joining Co and Go.
21. Ramus height (Ar–Go, mm): the linear distance of the line joining Ar and Go.
22. Upper anterior face height (UFH, mm): the linear distance of the line joining N and ANS measured perpendicular to SN–7 degrees.
23. Lower anterior face height (LFH, mm): the linear distance of the line joining ANS and Me measured perpendicular to SN–7 degrees.

24. Anterior face height ratio (UFH:LFH): the proportion of the upper anterior face height to the LFH height expressed as a ratio.
25. Total anterior face height (Na–Me, mm): the linear distance of the line joining N and Me measured perpendicular to SN–7 degrees.
26. Posterior face height (S–Go, mm): the linear distance of the line joining S and Go.
27. Posterior to anterior face height ratio (PFH:AFH): the proportion of the posterior face height to the anterior face height expressed as a ratio.
28. Frankfort horizontal to mandibular plane (FMA, degrees): the angle formed between the lines joining Or and Po and Go–Gn.
29. A–S vert (mm): the linear perpendicular distance from point A to a vertical Y axis through S.
30. B–S vert (mm): the linear perpendicular distance from point B to a vertical Y axis through S.
31. Pog–S vert (mm): the linear perpendicular distance from Pog to a vertical Y axis through S.
32. Lower molar to sella vertical (LM–S vert, mm): the linear perpendicular distance from the LM to a vertical Y axis through S.
33. Upper molar to S vertical (UM–S vert, mm): the linear perpendicular distance from the UM to a vertical Y axis through S.
34. Lower molar angle (LM angle, degrees): the posterior angle between the lines formed by the centre of the crown and the bifurcation of the mandibular first molar and Go–Gn.
35. Lower second premolar angle (L5 angle, degrees): the posterior angle between the lines formed by the apex and cusp tip of the mandibular second premolar and Go–Gn.
36. Lower first premolar angle (L4 angle, degrees): the posterior angle between the lines formed by the apex and cusp tip of the mandibular first premolar and Go–Gn.
37. Upper molar to palatal plane (UM–PP, degrees): the posterior angle between the lines formed by the centre of the crown and trifurcation of the maxillary first molar and ANS–PNS.
38. Sella–nasion to Downs occlusal plane (SN–OP, degrees): the angle between the lines formed by S–N and ADP–PDP.
39. Mandibular plane to Downs occlusal plane (MP–OP, degrees): the angle between the lines formed by Go–Gn and ADP–PDP.
40. Facial convexity (F conv, degrees): the angle formed between the points ST N, nasal tip, and STPog.
41. Nasolabial angle (N–L angle, degrees): the angle formed between the points nasal tip, Sn, and Ls.
42. Labiomental fold (L–M fold, degrees): the angle formed between the points Li, Si, and STPog.
43. Holdaway's harmony angle ('H' angle, degrees): the angle formed between the STN, Ls, and STPog.
44. Upper lip thickness (Ls–A, mm): the linear distance between point A and Ls.
45. Lower lip thickness (Li–B, mm): the linear distance between point B and Li.
46. Soft tissue total face height (ST TFH, mm): the linear distance between ST N and ST Me measured perpendicular to SN–7 degrees.
47. Soft tissue upper face height (ST UFH, mm): the linear distance between ST N and Sn measured perpendicular to SN–7 degrees.
48. Soft tissue lower face height (ST LFH, mm): the linear distance between Sn and ST Me measured perpendicular to SN–7 degrees.
49. Soft tissue lower face percentage (ST LFH, per cent): the ratio between the linear distance between Sn and ST Me, and ST N and ST Me expressed as a percentage;
50. Upper lip to E line (Ls–E line, mm): the linear distance between a line drawn through nasal tip and STPog, and LS.
51. Lower lip to E line (Li–E line, mm): the linear distance between a line drawn through nasal tip and STPog and Li.
52. Upper lip length (ULL, mm): the linear distance from Sn to the most inferior point of the upper lip.
53. Lower lip length (LLL, mm): the linear distance from the most superior point of the lower lip to ST Me.
54. Soft tissue total face height (STPog–STN, mm).
55. Sn–S vert (mm): the linear perpendicular distance from subnasale to a vertical Y axis through S.
56. Ss–S vert (mm): the linear perpendicular distance from SS to a vertical Y axis through S. A measure of upper lip position.
57. Ls–S vert (mm): the linear perpendicular distance from LS to a vertical Y axis through S. A measure of upper lip position.
58. Li–S vert (mm): the linear perpendicular distance from Li to a vertical Y axis through S. A measure of lower lip position.
59. Si–S vert (mm): the linear perpendicular distance from Si to a vertical Y axis through S. A measure of lower lip position.
60. STPog–S vert (mm): the linear perpendicular distance from STPog to a vertical Y axis through S. A measure of soft tissue chin position.