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Agenesis of mandibular second premolars. Spontaneous space closure after extraction therapy: a 4-year follow-up

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SUMMARY The aim of this study was to investigate the space closure and occlusal changes in 11 subjects (mean age 11.8 years) with normal occlusion and agenesis of the mandibular second premolar, after extraction of the mandibular second primary molar and the maxillary second premolar on the side of the agenesis. The treatment started when the first premolars came into occlusion and the subjects were followed for 4 years. Dental casts were taken at the start of treatment and after 1, 2 and 4 years, and lateral cephalograms were taken at the start of treatment and after 2 and 4 years. Space closure, sagittal movements, rotational movements, and tipping of the first molars and first premolars and dental midline shift were measured on photographs of dental casts. Sagittal movement of the incisors was measured on lateral cephalograms.

The results showed that most of the extraction space closed during the first year (55 per cent in the maxilla, 46 per cent in the mandible) and at the end of the follow-up period 89 per cent of the extraction space closed in the maxilla and 80 per cent in the mandible, leaving a mean residual extraction space of 0.9 and 2 mm respectively. In the maxilla, 70 per cent of the extraction space closed by mesial and rotational movements of the first molars. Maxillary premolars moved distally, rotated and tipped only during the first year of observation. In the mandible, the space closure occurred by mesial/rotational movements and tipping of first molars and distal movement and tipping of the first premolars. Unilateral extraction had no influence on the maxillary midline while it caused a statistically significant mandibular dental shift to the extraction side. Extraction therapy had no impact on the overjet, overbite or incisor inclination.

Introduction

The prevalence of agenesis in the permanent dentition (third molars excluded) is reported to be 6.1–8.2 per cent in Scandinavian countries, and the most common missing tooth is the mandibular second premolar, which is absent in 2.4–4.3 per cent of the population (Grahnén, 1956; Ravn and Nielsen, 1973; Thilander and Myrberg, 1973; Wisth *et al.*, 1974; Bergström, 1977; Magnusson, 1977; Locht, 1980; Rölling, 1980). In 50 per cent of the cases of agenesis one tooth is missing and in 85 per cent two teeth are missing (Grahnén, 1956; Bergström, 1977; Locht, 1980).

In subjects with agenesis of the mandibular second premolar, extraction of the second primary molar before the eruption of the permanent first molars is believed to create favourable conditions for spontaneous space closure and to cause minimum tipping of the molars (Svedmyr, 1983). However, diagnosis of agenesis at this age is not reliable. Although odontogenesis of the second mandibular premolar begins in the majority of the cases at the age of 2–2.5 years (Haavikko, 1970), the range can vary widely (Garn *et al.*, 1958; Ravn and Nielsen, 1977). According to Wisth *et al.* (1974), reliable diagnosis is not possible before 9 years of age.

Lindqvist (1980) reported that extraction of the second primary molar at the age of 8–9 years in children with missing mandibular second premolars was followed by space closure, provided that the extraction was carried out before the root development of the mandibular first premolar was complete, and before the emergence of the second permanent molar. Neither description of the patient's malocclusion was given nor how the space closure occurred. In addition, how the tooth migration influenced the facial morphology was not analysed.

Consequently, there is a lack of knowledge regarding space closure after extraction of the second primary molars and the maxillary second premolar in cases without malocclusion but with missing mandibular second premolars.

The aim of this study was to investigate the amount and mechanism of space closure, and occlusal changes in the subjects with normal occlusion and agenesis of mandibular second premolars, after extraction of the mandibular second primary molar and the maxillary second premolar on the side of the agenesis.

Subjects and methods

The sample consisted of 11 patients (seven girls and four boys) with normal occlusion and unilateral (nine subjects) or bilateral (two subjects) agenesis of mandibular second premolar, all being patients at the Centre for Oral Health Sciences, Malmö, Sweden. The mean age of the patients at the start of treatment was 11 years 8 months (10 years 3 months–13 years), and they were followed for a period of 4 years (4 years 0 month–4 years 4 months). The following additional clinical criteria were used: (i) a normal molar relationship up to half a cusp width distally (flat terminal plane) on the side of the agenesis; (ii) overjet and overbite within the normal ranges; and (iii) no space deficiency.

Treatment was commenced when the occlusion of the first premolars was secured, i.e. at a defined stage of dental occlusal development. Treatment included the following steps: (i) the persistent mandibular second primary molar was extracted; (ii) in subjects with normal molar relationship, the maxillary second primary molar was extracted at the same time. In subjects with a cusp-to-cusp relationship between the first permanent molars, the maxillary second primary molar was not extracted until the mandibular molar had drifted into normal molar relationship; and (iii) the maxillary second premolar was extracted as soon as it had emerged in order to allow the first permanent molars to migrate mesially. No other treatment was performed.

The assessment of the skeletal maturity was based on body height. Measurements were performed with an interval of 1–3 years and with a precision of 5 mm at the child welfare clinics and school health clinics in all subjects except one. During the period of the study, the body height measurements were made every year with a precision of 1 mm. The measurements from each subject were plotted on a special chart and the age at pubertal maximum height was assessed using the method of Karlberg *et al.* (1992). The period between the pubertal maximum of height and the start of treatment was calculated for each subject.

Dental casts were taken at the start of treatment and at follow-ups 1, 2 and 4 years after treatment started. A wax bite index was taken in centric occlusion. Overjet and overbite were measured directly on dental casts (Lundström, 1948) with a steel ruler with an accuracy of 0.5 mm. Sagittal molar relationship was measured on the dental casts obtained at the start of treatment and at the 4-year follow-up. A deviation of more than half of a cusp width from a normal relationship was defined as mesial or distal molar relationship. Sagittal and rotational movements of teeth and dental midline shift (Fig. 1) were measured on enlarged ($\times 1.7$) standardized photographs of all dental casts perpendicular to the occlusal plane. One maxillary side in a subject with bilateral agenesis was excluded because the first premolar was not erupted on the initial dental cast. Space closure on the extraction side was measured as the shortest distance between the first molar and first premolar with an accuracy of 0.5 mm. Regarding sagittal and rotational movements and dental midline shift, the analysis was focused on differences between extraction and non-extraction sides, (nine subjects with unilateral agenesis). Maxillary canines were excluded because they had not erupted in most of the subjects at the start of treatment.

The measurements of sagittal and rotational movements of the first permanent molars, first premolars and mandibular canines and the dental midline shift were made by means of a reference grid which consisted of two lines (Fig. 1) and was constructed on the casts from year 0 as follows: Maxillary midline, a line between the distal aspect of the incisive papilla and the posterior border of the palatal raphe near the *fovea centralis* (Alavi *et al.*, 1988).

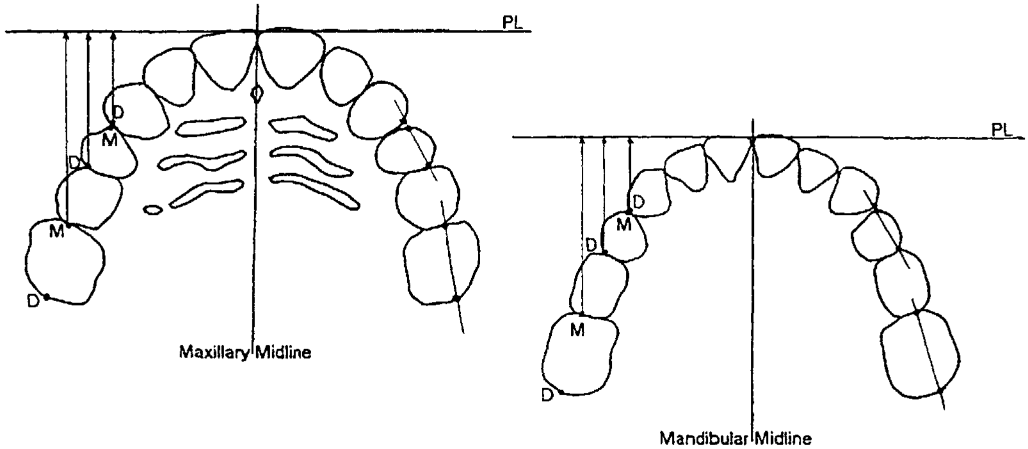

Figure 1 Diagram demonstrating the reference grid (maxillary and mandibular midlines and perpendicular line or PL) and the reference points, distance and lines used in the analysis of dental casts measured on occlusal photographs.
Maxillary molars
Mesial point: On the mesial marginal ridge, the mid-distance between the marginal groove and the mesio-buccal cusp.
Distal point: On the distal marginal ridge, at one-third of the distance between the marginal groove and the disto-buccal cusp.
Mandibular molars
Mesial point: On the mesial marginal ridge, at two-thirds of the distance between the marginal groove and the mesio-buccal cusp.
Distal point: The projection of the distal cusp on the distal marginal ridge.
Premolars
Mesial point: The mesio-bucco-occlusal point angle (point A angle is the point where three surfaces meet).
Distal point: The disto-bucco-occlusal point angle.
Canines
Distal point: The disto-bucco-occlusal point angle.
Incisors
Mesial point: The mesio-labio-incisal point angle.

With the aid of a specially-designed survey the maxillary midline was drawn and then transferred to the mandibular cast, making the mandibular midline. When the maxillary and mandibular midlines were drawn on the casts, the occlusal photographs were taken. The initial maxillary midline was transferred to the subsequent occlusal photograph by superimposition on the anatomical structures of the palate and teeth on the non-extraction side. The initial mandibular midline was transferred to the subsequent occlusal photographs as follows: an anterior point of the mandibular midline was transferred by using the maxillary midline. The deviation of the maxillary midline from the maxillary incisor on the agenesis side (mesial point) was measured on the photographs. By using the occluded dental casts, the deviation between the maxillary and mandibular incisors (mesial points) on the agenesis side was also measured. The anterior point of the mandibular midline could be constructed by adding the above mentioned deviations. After the anterior point was located, the mandibular midline was transferred by superimposing the templates on the anterior point and on the best fit of the teeth on the non-extraction side. The other reference line, the Perpendicular Line (PL, Fig. 1) was constructed perpendicular to the maxillary and mandibular midlines through the mid-distance of the mesial points of the central incisors, on all occlusal photographs. The measurement points were marked with a sharp soft pencil on all dental casts before photographs were taken.

The sagittal movements were measured in the following way: (i) molars, mesial point to PL; (ii) premolars, distal point to PL; and (iii) canines, distal point to PL (Fig. 1). For rotational movements, the rotation of the first molars and first premolars was measured by the angle formed between the line which connected the mesial and distal points of first molars and first premolars, and maxillary and mandibular midlines, respectively (Fig. 1). The initial recordings (year 0) were compared with the subsequent recordings (years 1, 2 and 4) and the differences expressed the amount of sagittal and rotational movement in relation to the reference grid. The non-extraction side served as control.

The distance from the mesial point of the central incisor on the extraction side to the midline was measured in the maxilla and mandible respectively on the initial (year 0) and final (year 4) dental casts in relation to respective midline. A difference in these distances was considered to be an effect on the midline in the respective dental arch.

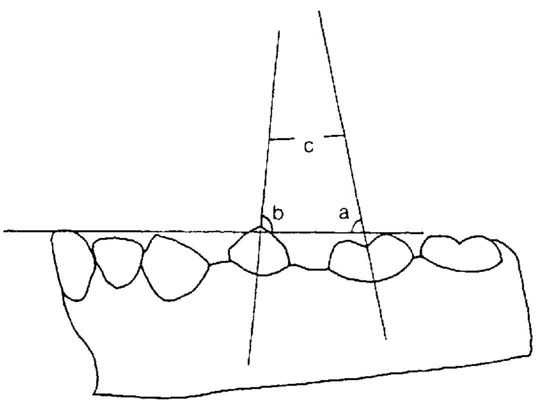

Figure 2 Diagram demonstrating the method used in constructing the dental angles, here exemplified with the measurement of the angulation of the maxillary first permanent molars (**a**) and maxillary first premolar (**b**) to the occlusal plane, and the angle between the first premolar and the first permanent molar (**c**).

Tipping of first permanent molars and first premolars was measured on standardized profile photographs, according to Pancherz (1976), as the angle between the long axis of these teeth as well as the angle between the long axis of each tooth and the occlusal line (Fig. 2), a line passing from the disto–buccal cusp of the first molar and the incisal edge of the central incisor. The long axis of each tooth was transferred from the initial photographs to the subsequent ones by using a template of each tooth and its long axis on the initial photographs which was superimposed on the subsequent photographs according to the best fit of the anatomy of that tooth. The initial recordings (year 0) were compared with the subsequent recordings (years 1, 2 and 4), and the differences expressed the amount of tipping of teeth. The recordings of the teeth on the non-extraction side of the nine subjects with unilateral agenesis (differences between years 0 and 4) served as controls.

Lateral cephalometric radiographs were taken at the start of treatment, and at follow-ups after 2 and 4 years. In the present study, radiographs taken at the start of treatment and year 4 were analysed. The angles and planes used in the standard cephalometric analysis are given in Table 1. Sagittal changes occurring parallel to the occlusal plane were analysed according to the cephalometric system of Pancherz (1982) (Fig. 3). The occlusal line (OL) and the occlusal line perpendicular (OLp)

Table 1. Dentofacial morphology at start and changes from the start of treatment to the end of the follow-up period in nine subjects. At year 4 two lateral cephalograms were missing.

	Year 0			Years 0–4		
Variable	Mean	SD	11 years[a]	Mean	SD	11–15 years[a]
SNA	83.4	2.1	81.1	0.4	1.7	0.3
SNB	80.5	2.5	76.9	1.3*	1.6	1.4
ANB	2.9	1.5	4.2	−0.9*	1.1	−1.0
SNPg	81.3	3.2	77.5	1.8**	1.3	1.7
NSL/ML	29.3	5.0	34.8	−2.9***	1.3	−2.0
NSL/NL	4.7	5.0	7.1	−0.5	2.3	−0.3
NL/ML	24.6	5.9	27.6	−2.4**	1.8	−2.2
Ils/NL	110.2	5.0	112.0	−3.5**	2.9	−1.3
Ili/ML	98.3	5.3	95.6	−3.0*	3.0	−1.2
Is/Li	127.2	8.4	125.9	8.9***	4.5	4.7
Ii-APg (mm)	2.1	1.8	1.9	−0.9*	0.8	−0.4

[a]Reference values (Riolo *et al.*, 1974).
$*P<0.05$; $**P<0.01$; $***P<0.001$

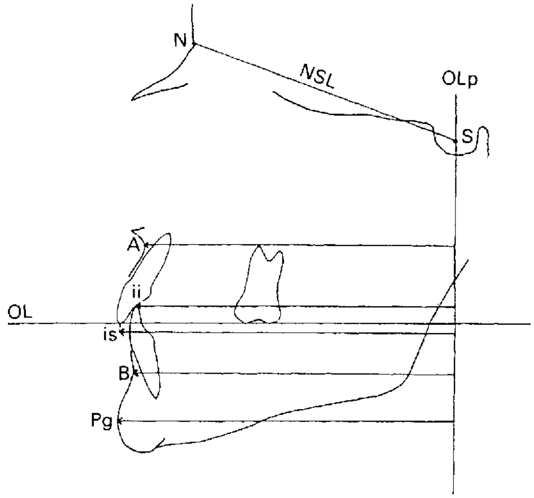

Figure 3 The landmarks and distances used in the cephalometric system of Pancherz (1982). The registration line (NSL) and reference grid (OL and OLp) are shown.
is/OLp minus A/OLp: change in position of the maxillary central incisor within the maxilla.
ii/OLp minus Pg/OLp: change in position of the mandibular central incisor within the mandible.
ii/OLp minus B/OLp: change in position of the mandibular central incisor within the mandible.
is/OLp minus ii/OLp: overjet.
A/OLp minus Pg/OLp: maxillary growth in relation to mandibular growth.

through Sella from the first radiograph were used as a reference grid. The grid was transferred from the first tracing to the following cephalograms by superimposition on Sella and on stable anatomical structures of the anterior cranial base by the structural method (Björk and Skieller, 1983). The cephalometric points were marked directly on the cephalometric radiographs.

The photographs and the lateral cephalograms were digitized with a Scriptel RDT Digitizer (Scriptel Corporation, Columbus, OH, USA) and the distances and angles were calculated by computer (PC 386 SXM/16, Copam, Taiwan). Correction for the magnification was made in the computer program.

Statistical methods

The arithmetic mean and standard deviation (SD) were calculated for each variable. To assess the statistical significance of the changes in the dental casts, *t*-tests for paired samples were used for the nine cases of unilateral agenesis for sagittal and rotational movements, dental midline shift and tipping of teeth. To assess the statistical significance of the observed changes in the cephalometric variables, *t*-tests for paired samples were used. The size of the combined method error (ME) (locating, superimposing and measuring the changes in different dental and cephalometric landmarks) was calculated with the formula: $ME = \sqrt{\Sigma d^2/2n}$ where d is the difference between two registrations of a pair, and n is the number of duplicate registrations (Dahlberg, 1940). The method errors for the analysis of the dental casts were found to be between 0.1–0.9 mm and 0.9–2.8 degrees. For the cephalometric analysis the method errors were 0.5–2.2 degrees (standard cephalometric analysis) and 0.2–0.9 mm (Pancherz's method).

Results

The skeletal maturity at the start of treatment ranged from 2 years 5 months before to 1 month after the pubertal maximum of height, except in one female subject who was close to the end of growth.

On average, the overjet decreased from 3 mm (SD = 0.8 mm) to 2.6 mm (SD = 0.8 mm), and the overbite increased from 3.8 mm (SD = 1.2 mm) to 4.1 mm (SD = 0.8 mm) during the 4-year follow-up. During the 4-year follow-up, the sagittal molar relationship remained unchanged on the extraction side in seven subjects, improved in four and deteriorated in two subjects, while on the non-extraction side it remained unchanged in seven subjects and improved in two subjects. During the first year, 55 per cent (4.6 mm) of the extraction space closed in the maxilla, and 46 per cent (4.3 mm) in the mandible (Table 2). During the 4-year follow-up, 89 per cent of the extraction space

Table 2 Residual extraction space (mm).

	Maxilla ($n = 12$)			Mandible ($n = 13$)		
Years	Mean	SD	Range	Mean	SD	Range
0	8.3	0.8	7.1–9.4	9.3	1.1	7.1–11.2
1	3.8	1.3	1.8–5.9	5.0	1.6	2.4–7.6
2	2.1	1.1	1.2–4.1	3.3	1.4	0.9–5.6
4	0.9	0.7	0.0–2.4	2.0	1.4	0.0–4.1

n = no. extractions in 11 subjects. In one subject, who had bilateral agenesis, the maxillary right side was excluded because the first premolar was not erupted on the initial dental cast.

Table 3 Sagittal movement (mm) of first permanent molars and premolars. Comparison between extraction and non-extraction sides of nine subjects with unilateral agenesis.

	Year	Extraction side Mean	SD	Non-extraction side Mean	SD	Differences (mm) between means
Maxilla						
M_1	0–1	2.4	0.5	0.7	0.5	1.7***
	0–2	4.0	0.7	1.5	0.1	3.5***
	0–4	5.1	0.9	2.3	0.6	2.8***
P_1	0–1	−2.0	0.8	0.2	0.8	2.2***
	0–2	−1.8	1.1	0.3	1.0	2.1***
	0–4	−1.8	1.2	0.7	1.2	2.5***
Mandible						
M_1	0–1	2.5	1.2	1.3	0.7	1.2**
	0–2	3.6	1.2	1.7	0.7	1.9**
	0–4	5.1	1.1	2.7	1.0	2.4***
P_1	0–1	−1.5	1.1	0.4	0.5	1.9**
	0–2	−1.7	1.2	0.4	0.8	2.1*
	0–4	−1.4	1.3	0.7	1.2	2.3*

M_1 = first permanent molar; P_1 = first premolar; − = distal movement.
*$P<0.05$; **$P<0.01$; ***$P<0.001$.

closed in the maxilla and 80 per cent in the mandible, leaving a mean residual extraction space of 0.9 and 2 mm respectively.

During the 4-year period, the maxillary and mandibular molars on the extraction side migrated mesially, on average 5.2 mm, while on the non-extraction side they moved mesially 2.3 and 2.7 mm respectively (Table 3 and Fig. 4). The difference between the extraction and non-extraction sides was statistically significant in the two arches ($P<0.001$). Both the maxillary and mandibular premolars on the extraction sides moved distally during year 1, on average 2.0 and and 1.5 mm respectively, after which they remained stable. Maxillary and mandibular premolars on the non-extraction sides moved mesially 0.7 mm during the 4-year follow-up. The difference between extraction and non-extraction sides was statistically significant, the level of significance being higher for the maxilla ($P<0.001$) than for the mandible ($P<0.05$). The mandibular canines on the extraction side moved distally on average 1 mm, while on the non-extraction side the canines moved mesially 0.5 mm, the difference being statistically significant ($P<0.05$).

The maxillary first permanent molars on the extraction sides rotated mesially, on average 2.6, 5.1 and 9.1 degrees during years 1, 2 and 4 respectively, while on the non-extraction sides the first permanent molars rotated 0.9 degrees during the 4-year period (Table 4). The differ-

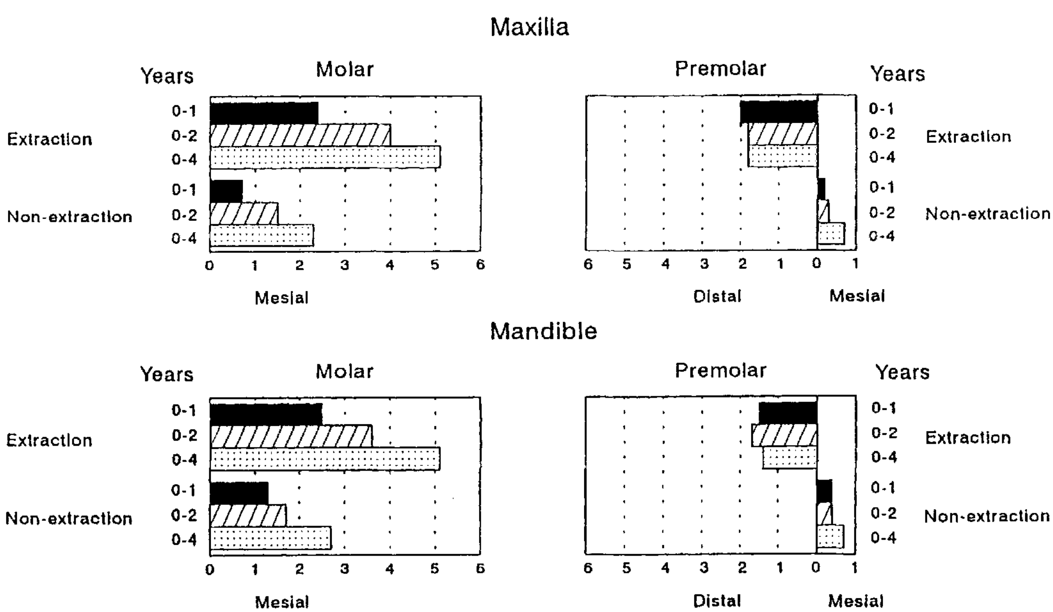

Figure 4 Sagittal movements (mm) of the first permanent molars and premolars in nine subjects with unilateral agenesis. The bars show changes from years 0–1, years 0–2 and years 0–4.

Table 4 Rotational movements (degrees). Comparison between extraction and non-extraction sides of nine subjects with unilateral agenesis.

	Year	Extraction side		Non-extraction side		Differences (mm) between means
		Mean	SD	Mean	SD	
Maxilla						
M_1	1–0	2.6	3.6	0.4	3.8	2.2
	2–0	5.1	3.5	0.8	4.1	4.3*
	4–0	9.1	3.0	0.9	3.7	8.2***
P_1	1–0	−6.3	5.5	−1.0	4.1	5.3*
	2–0	−8.6	5.3	−1.5	4.5	7.1**
	4–0	−8.6	5.8	−1.2	2.3	7.4**
Mandible						
M_1	1–0	2.7	3.4	−0.9	3.3	3.6
	2–0	4.0	3.9	−0.1	3.7	4.1
	4–0	5.9	4.5	0.1	3.7	5.8*

M_1 = first permanent molar; P_1 = first premolar; − = distal rotation.
*$P<0.05$; **$P<0.01$; ***$P<0.001$.

Table 5 Tipping of the first premolar and the first molar (degrees). Comparison between extraction and non-extraction sides of nine subjects with unilateral agenesis at the end of the 4-year period.

	Extraction side		Non-extraction side		Differences (mm) between means
	Mean	SD	Mean	SD	
Maxilla					
P_1–M_1	11.8	6.0	6.1	3.6	5.7
P_1–OL	−7.2	4.8	−3.2	3.0	4.0
M_1–OL	4.6	3.6	3.1	2.0	1.5
Mandible					
P_1–M_1	14.7	6.4	2.6	5.1	12.1***
P_1–OL	−5.7	2.5	0.8	3.0	6.5**
M_1–OL	9.0	6.7	3.4	2.8	5.6*

M_1 = first permanent molar; P_1 = first premolar; OL = occlusal line; − = distal tipping.
*$P<0.05$; **$P<0.01$; ***$P<0.001$.

ence was statistically significant for year 2 ($P<0.05$) and for year 4 ($P<0.001$). The maxillary first premolars on the extraction sides rotated distally 8.6 degrees, and most of the rotation occurred during year 1 (6.3 degrees), and no further rotation took place after year 2. The differences in rotation of the maxillary first premolars between extraction and non-extraction sides were statistically significant for year 1 ($P<0.05$) and for years 2 and 4 ($P<0.01$). The mandibular first molars on the extraction sides rotated mesially during the observation periods, 2.7, 4.0 and 5.9 degrees respectively, while on the non-extraction sides they remained almost stable. The difference was statistically significant ($P<0.05$) for year 4.

A mandibular dental midline shift of 0.8 mm on average to the extraction side was found after 4 years ($P<0.05$). In the maxilla, the dental midline shift was on average 0.3 mm (not significant).

The amount of tipping of the first permanent molar and the first premolar on the extraction and non-extraction sides between years 0 and 4 in the 9 subjects with unilateral agenesis is presented in Table 5. When the extraction and the non-extraction sides were compared at year 4, the differences were statistically significant in the mandible only. The tipping of the maxillary first premolar and first molar on the 12 extraction sides at 4 years of observation was 7.2 and 4.6 degrees, respectively, and 11.8 degrees in relation to each other. The mandibular premolar and first molar on the 13 extraction sides tipped during the 4 years 5.7 and 9.0 degrees respectively, and 14.7 degrees in relation to each other. Most of the tipping occurred during year 1. When the extraction and the non-extraction sides were compared, statistically significant differences were found for the angle between the first permanent molar and first premolar ($P<0.001$), for the tipping of the first premolar ($P<0.01$) and for the tipping of the first molar ($P<0.05$).

Cephalometric values describing the dentofacial morphology of all subjects at the start of treatment and the changes of dentofacial morphology during the 4-year follow-up period are presented in Table 1. On average, the SNA angle remained stable during the follow-up period while SNB and SNPg increased by 1.3 ($P<0.05$) and 1.8 degrees ($P<0.01$) respectively, and ANB decreased by 0.9 degrees ($P<0.05$). The maxillary incisors retroclined 3.5 degrees ($P<0.01$) during the follow-up period in relation to the maxillary plane and 3.1 degrees ($P<0.001$) in relation to the nasion–sella plane. The mandibular incisors retroclined 3.0 degrees ($P<0.05$) in relation to the mandibular plane and 5.8 degrees ($P<0.01$) in relation to the nasion–sella plane. The interincisal angle increased by 8.9 degrees ($P<0.001$). On average, the mandibular incisal edges moved poster-

Table 6 Sagittal changes (mm) in the position of the permanent incisors within the maxilla and the mandible occurred parallel to the occlusal plane from the start of treatment to year 2 in 10 subjects and from year 2 to the end of the follow-up period in nine subjects. At year 2, one lateral encephalogram was missing and at year 4, two lateral encephalograms were missing.

	Year 0–2		Year 0–4	
Variable	Mean	SD	Mean	SD
Is–A	0.0	0.7	0.3	0.5
Is–B	1.1**	0.8	1.6**	1.2
Pg–Ii	2.1*	0.9	3.5***	1.8
Overjet	0.2	0.9	0.0	0.9
A–Pg	1.9***	1.0	3.7***	2.1

$*P<0.05$; $**P<0.01$; $***P<0.001$.

iorly 0.9 mm ($P<0.05$) in relation to the A–Pg line.

Changes within the maxilla and the mandible are presented in Table 6. The upper incisal edges remained stable in relation to the maxilla during the 4-year period while the lower incisal edges moved backwards 1.6 mm ($P<0.01$) in relation to point B and 3.5 mm ($P<0.001$) in relation to the Pg point. The Pg point moved forward 3.7 mm in relation to point A ($P<0.001$)). The overjet remained stable during the follow-up period.

Discussion

The results of this study show that the extraction therapy performed was effective in promoting space closure. More than 80 per cent of the extraction space was closed. The sample of this study might be considered small but homogeneous. The subjects enrolled had a normal occlusion or minor deviations, which excluded subjects with agenesis of mandibular second premolars and malocclusion. The homogeneity of the sample was further confirmed by their stage of skeletal and dentofacial morphology. Regarding skeletal maturity, all subjects except one, were before or close to the peak of the pubertal growth spurt at the start of the treatment. According to Björk and Skieller (1972), this is a favourable factor for space closure, since the growth in facial height allows eruption, which stimulates mesial dental drifting of the molars.

Analysis of dentofacial morphology at the start of treatment showed that 10 out of 11 subjects had a normal sagittal jaw relationship and one subject had an ANB angle of 5.9 degrees. Dermaut *et al.* (1986) showed that subjects with tooth agenesis exhibited a significantly higher prevalence of normal sagittal jaw relationship when compared with subjects without agenesis. Cookson (1971) found that spontaneous space closure after extraction of mandibular first premolars is larger in cases with normal sagittal jaw relationship than in cases with postnormal sagittal jaw relationship.

In the present study, the ANB angle decreased on average almost 1 degree during the 4-year follow-up period (Table 1). This was caused by an increase in mandibular prognathism (SNB), on average almost 1 degree during the 4-year follow-growth development (Björk and Skieller, 1972; Riolo *et al.*, 1974). Similar changes in basal jaw relationship were reported in males with minor hypodontia (Roald *et al.*, 1982). However, in subjects with agenesis of more than four teeth (except the third molars), the ANB angle decreased as a result of maxillary retrognathism (Sarnäs and Rune, 1983).

Vertical jaw relations showed a tendency to low mandibular plane angle and two subjects exhibited a skeletal deep bite pattern. In one study (Dermaut *et al.*, 1986) it was found that skeletal deep bite occurred more often in subjects with agenesis of teeth, although no significant differences were found between subjects with and without agenesis. In the present study, the mandibular plane angle decreased on average 2.9 degrees (Table 1) indicating an anterior rotation of the mandible during the 4-year period, as a result of normal growth development of the mandible (Riolo *et al.*, 1974). This result is confirmed by other studies (Sarnäs and Rune, 1983; Stephens and Houston, 1985). Furthermore, it was suggested that the greater the anterior rotation of the mandible, the greater the space closure would be (Stephens and Houston, 1985). The anterior rotation of the mandible influences the direction of eruption of the posterior teeth (Björk and Skieller, 1972) and significant correlations between components of mandibular growth and mesial migration of the lower molars in the intact dental arches were found (Björk and Skieller, 1983). Thus, the marked space closure observed in this study may be due to a favourable growth pattern and the fact that the treatment started in a period of intensive facial growth.

In this study, the overjet decreased on average 0.5 mm (from 3.1–2.6 mm) during the 4-year follow-up. Reference values for subjects of the same age-groups with normal occlusion (Moyers *et al.*, 1976) show a decrease in overjet of 0.4 mm (from 3.8–3.4 mm). The average change in overbite was also small and in accordance with normal values (0.2 mm, Moyers *et al.*, 1976). Consequently, the extraction therapy performed in this sample had no negative effect on overjet and overbite.

Most of the extraction space closed during the first year, on average 55 per cent in the maxilla and 46 per cent in the mandible. This is in agreement with studies concerning spontaneous space closure after extraction of first mandibular premolars in subjects with crowding. Space closure seems to occur at a higher rate shortly after tooth removal (Berg and Gebauer, 1982; Stephens, 1983). In the present study, the residual extraction space at the 4 year follow-up period was on average 0.9 mm in the maxilla and 2.0 mm in the mandible (Table 2). The amount of space closure was on average the same for the two jaws but the residual extraction space was larger in the mandible due to the fact that the mandibular second primary molar has a larger mesiodistal tooth width than the maxillary one, 9.8 versus 8.8 mm (Moyers *et al.*, 1976). Lindqvist (1980) reported the same values after extraction of the primary second molar in subjects with agenesis of mandibular second premolar. However, in that study no description of the occlusion and space conditions of the sample was given, factors which could possibly affect the amount of space closure. Moreover, in some subjects only the mandibular second primary molar was extracted, and in other subjects compensatory extraction of the maxillary second primary molar and second premolar was performed.

In the evaluation of the results of sagittal tooth movement of first permanent molars, first premolars and mandibular canines, the amount of sagittal movement of these teeth was measured to a line perpendicular to the maxillary and mandibular midlines passing through the midpoint of the central incisors. Any movement of the incisors might thus influence the evaluation of mesio–distal movement of the posterior teeth. Regarding the sagittal changes measured on lateral cephalograms parallel to the occlusal plane (in the position of the incisors within the maxilla and the mandible), it was shown that the maxillary incisal edges remained almost stable, while the mandibular incisal edges moved posteriorly 3.5 mm (Table 6). Since the maxillary incisal edges remained stable, the measurements of sagittal movement of the posterior maxillary teeth may be considered valid, but the recorded sagittal movement of the posterior mandibular teeth may be less for mesial movement and greater for distal movement. A direct comparison between the cephalometric measurements and the occlusal photographic measurements can, however, not be made because of the magnification factor and the anterior rotation of the mandible (Björk, 1969).

During the first year of the study, the extraction space in the maxilla was reduced by 4.6 mm. Half of the space closure was due to mesial drift of the first permanent molars and the other half to distal drift of the first premolars. At the 4-year follow-up the space closure was 70 per cent on average, due to mesial drift of the molars. Accordingly, the maxillary first molars continued to migrate mesially throughout the follow-up period (0–4 years), while the maxillary first premolars drifted distally only during the first year (Fig. 5). Although the amount of mesial movement was found to be on average 5.1 mm for both maxillary and mandibular molars, it could be assumed that the mandibular molars drifted less mesially than the maxillary molars, because of the above mentioned posterior movement of the mandibular incisal edges. The space closure continued at a decreasing rate during the 4-year observation period (Table 2) which may indicate that further space closure will occur.

The amount of rotation of the first permanent molars and maxillary first premolars showed great individual variations. However, maxillary and mandibular molars rotated on the extraction sides through the observation period, while the maxillary premolars rotated only during the first year (Table 4). The sagittal movement of the permanent molars was not only mesial drifting forwards, but rotational movements as well. On the non-extraction sides, only minor rotations occurred and they were less than the method error. The mandibular first molars on the extraction side rotated less than the maxillary molars. A statistically significant difference

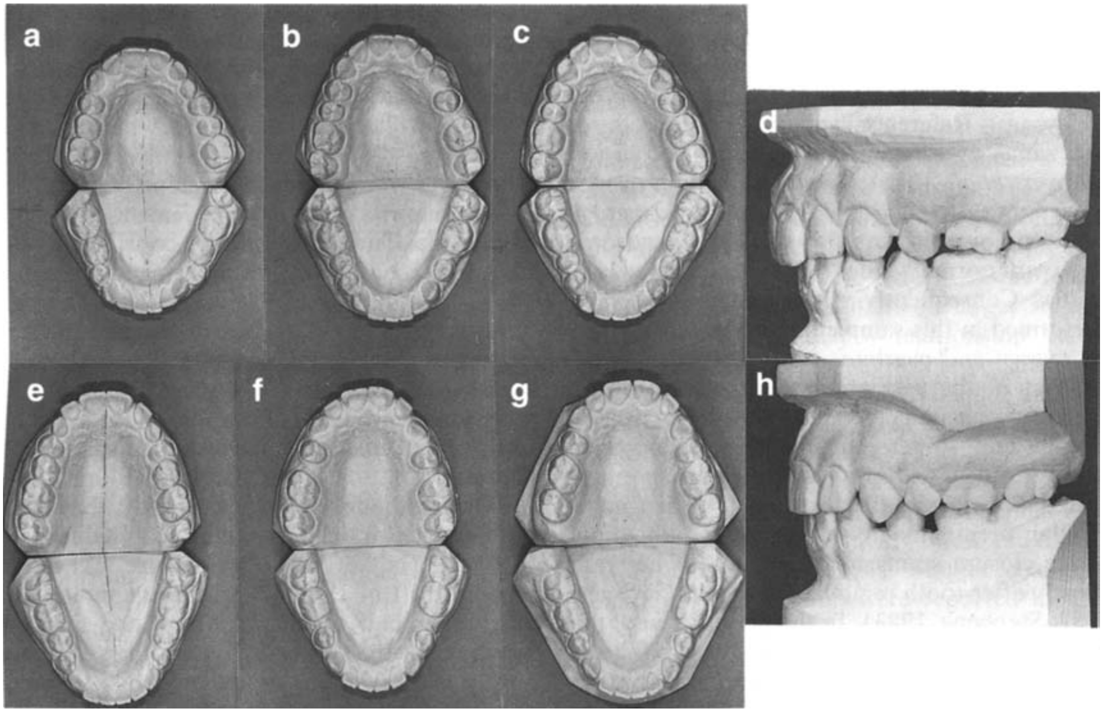

Figure 5(a–d) One case with unilateral aplasia: (**a**) at start; (**b**) after 2 years; (**c–d**) after 4 years. (**e–h**) One case with bilateral aplasia: (**e**) at start; (**f**) after 2 years; (**g–h**) after 4 years.

was found for the mandibular molars between extraction and non-extraction sides only at the end of the follow-up (Table 4). The rotation of mandibular premolars was not included in the results because of the large method error. This could be due to less reliable measuring points since this tooth is round, and has a small mesiodistal width, so that a small deviation in locating the points will affect the angular measurements.

A dental midline shift of 0.3 and 0.8 mm to the extraction side was found in the maxilla (not significant) and the mandible ($P<0.05$), respectively. The stability of the maxillary dental midline could be due to the eruption in most of the subjects of the maxillary canines after the start of treatment and the fact that the maxillary incisal edges remained stable during the 4-year period (Table 6). The mandibular incisors were retroclined during the 4-year period (Table 1) and for the mandibular canines there was a small but significant difference in sagittal movement between extraction and non-extraction sides, which may explain the significant shift of the mandibular dental midline.

The amount of tipping of maxillary premolars and mandibular molars showed great individual variation. There was no difference in tipping of the maxillary molars between extraction and non-extraction sides. The difference observed in the tipping of maxillary premolars, and also reflected in the angle between the teeth, was not statistically significant (Table 5). The average difference of extraction and non-extraction sides in the angle between the premolars and molars in the mandible was 12.1 degrees. This is in accordance with Lindqvist (1980), who found a tipping of 13.5 degrees. The results also showed that there was no difference in the amount of distal tipping of the mandibular premolars and the mesial tipping of the molars on the extraction side. This is not in accordance with Lindqvist (1980), who stated that tipping of the mandibular molar was greater than tipping of the premolar. However she did not explain how this was found since only the angle between the teeth was measured on lateral cephalograms and no values were presented.

In the method used in the present study, the tipping of each posterior tooth was measured in relation to an occlusal line passing from the distobuccal cusps of the first molars and the incisal edge of the central incisor on the same side. Thus, mesial tipping of the first molar could change the inclination of the occlusal line and affect the angular measurements made in relation to the occlusal line. This applies more to the mandible, where tipping of the first permanent molar was observed, and it should be kept in mind when evaluating the results.

During the 4-year follow-up the maxillary incisors were retroclined 3.5 degrees on average in relation to the maxillary plane and 3.1 degrees in relation to the nasion–sella line, while the maxillary incisal edges remained almost stable (Table 6). These findings indicate uprighting of the teeth with forward movement of the roots. The mandibular incisors were, on average, retroclined 3.0 degrees in relation to the mandibular plane, and 6 degrees in relation to the nasion–sella line. These differences could be due to the anterior rotation of the mandible, which was 2.9 degrees on average (Table 1). The mandibular incisal edges on average moved posteriorly 3.5 mm in relation to the pogonion (Pg) point, and 1.6 mm in relation to point B (Table 6). Of the two, the pogonion is more valid because there is no bone apposition during growth (Björk, 1969). The position of point B might, however, be affected when there is a change in the inclination of the mandibular incisors. Accordingly, the differences in the posterior movement of the incisal edges in relation to point B and the pogonion might be due to the fact that in subjects with an anterior rotation of the mandible, the pogonion comes more forward than point B. Although the mandibular incisors have been retroclined, the incisal edges moved posteriorly only 0.9 mm on average in relation to the A–Pg line. Although maxillary incisal edges remained stable and the mandibular incisal edges moved backwards 3.5 mm on average, the overjet measured on the lateral cephalograms remained stable, possibly as a result of forward mandibular growth (on average, the pogonion moved forward 3.7 mm in relation to point A) (Table 6). The mandibular incisors might thus be retroclined to compensate for the forward mandibular growth (Björk and Skieller, 1972). Accordingly, it seems that the movements of the mandibular incisors were part of growth changes during the 4 years of the study rather than the result of the extraction treatment (Hansen and Pancherz, 1992).

The findings of this study show that in subjects with normal occlusion and agenesis of mandibular second premolars, extraction of the mandibular second primary molar and compensatory extraction of the maxillary second premolar can be recommended as the treatment of choice at the time when occlusion of the first premolars is secured. However in some cases additional active space closure may be required.

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