Longitudinal observation of the changes of the consecutive curve of the incisal edge, tip and cusp tip from deciduous and permanent dentition — Comparison between normal and crowded dental arch —

Hiroki Imai, Masashi Yakushiji and Seikou Shintani

Department of Pediatric Dentistry, Tokyo Dental College
1-2-2 Masago, Mihama-ku, Chiba 261-8502, JAPAN

Abstract We observed changes in the consecutive curve of the incisal edge, tip and cusp tip using serial dental casts from the deciduous to permanent dentition period in the same 44 individuals showing normal dentition at the time of the completion of deciduous dentition. In addition, in both the maxilla and mandible, the curvature gradually increased from the deciduous to permanent dentition period. Changes in the superoinferior position of each measurement site were similar between the normal and crowded dentition groups; however, at 4 measurement sites, the amount of change from the completion of deciduous dentition to immediately before the transition to mixed dentition significantly differed between the two groups ($P<0.01$); therefore, using values at the 4 measurement sites, discriminant analysis was performed. When the amount of change at the 4 measurement sites showing significant differences was indicated by variables X_1 – X_4 , the discriminant function was: $Z = 0.1233 + 1.2588X_1 - 0.9483X_2 + 0.0612X_3 - 0.7749X_4$. Normal dentition ($Z>0$) could be discriminated from crowded dentition ($Z<0$) with a probability of 77.3%. These results suggest that this amount of change is a factor facilitating discrimination between normal and crowded dentition.

Key words

Crowded dental arch,
Curve of Spee,
Developmental change,
Longitudinal observation,
Normal dental arch

Introduction

Spee¹⁾, a German anatomist, reported in 1890 that the line connecting the buccal cusp tips from the mandibular first premolar to the terminal molar is an anatomical tooth alignment curve showing a nearly perfect arc. This curve is generally called the curve of Spee. Shanahan²⁾ suggested that the flattening of the curve of Spee due to physiological attrition is involved in the prevention of traumatic occlusion and the maintenance of healthy periodontal tissue. In recent years, the so-called curve of Spee that also involves the incisal edge and the canine tip has attracted attention due to its association

with malocclusion. Strang³⁾ reported that the normal overlapping relationship in the anterior tooth area and functionally appropriate occlusal contact are maintained when the curve of Spee is adequate.

Jarabak⁴⁾ stated that the important role of the curve of Spee is to provide occlusal balance to the teeth in all mandibular functional motions, and the curve is shallow in the normal functional occlusal state, but the curvature grows with increases in the horizontal and vertical overlaps. In addition, he reported that correction of an excessive curve of Spee can increase the circumferential length of the dental arch, contributing to improvement of arch length discrepancy.

In most studies on the curve of Spee^{5–17)} in addition to the above studies, permanent dentition was evaluated. During the last decade, it has also

Received on February 24, 2010

Accepted on July 14, 2010

Table 1 Number of observed materials

Denture/occlusal state	Gender		Total number of casts
	Males	Females	
Normal dentition	12	13	25
Crowded dentition	6	13	19
Subtotal	18	26	44
Edge to edge	0	3	3
Anterior cross bite	1	1	2
Others Maxillary protrusion	2	0	2
Mandibular protrusion	0	1	1
Maxillomandibular protrusion	1	0	1

been one of the indicators to evaluate stability after orthodontic treatment in permanent dentition¹⁸⁻²²⁾.

Only Nozaka *et al.*²³⁾ have studied the curve of Spee involving dentition during the growth process, using cross-sectional materials in the deciduous, mixed, and permanent dentition periods; only deciduous dentition has been evaluated in other studies^{24,25)}. In addition, in all studies, excluding that by Kiri-hara *et al.*²⁵⁾ in our department, who longitudinally observed the same individuals from the completion of deciduous dentition to immediately before transition to mixed dentition, only the deciduous dentition period has been investigated. Recently, Marshall *et al.*²⁶⁾ evaluated changes in the curve of Spee from the deciduous to permanent dentition in a Northern European population; however, to our knowledge, there has been no study on such changes in the Japanese population.

Therefore, to clarify serial changes in the curve of Spee from the deciduous to permanent dentition, we performed a survey of serial dental casts obtained from 44 children. In addition, the association between the dentition state observed in casts in the stable permanent dentition period and growth-associated changes in the curvature was evaluated. The curve of Spee originally proposed was the curve connecting the buccal cusp tips from the first premolar to the terminal molar in the mandibular dentition; however, in this study, the anteroposterior curve was evaluated extending from the incisal edge, continuing to the canine tip, and finally to the molar buccal cusp tip in both the maxilla and mandible. To avoid mixing the two definitions, we used the abbreviation, "consecutive curve of incisal edge, tip and cusp tip" in this study, as in Kiri-hara *et al.*²⁵⁾

Materials and Methods

Materials

1) Selection of materials

In this study, serial maxillary and mandibular dental casts obtained from 44 children (18 males and 26 females) were used. These materials were selected from 53 serial dental cast sets collected from children who clinically showed normal occlusion of the deciduous dentition at the time of the initiation of taking impressions, subsequently did not undergo orthodontic treatment during the impression-taking period, and did not show early loss of deciduous or permanent teeth due to caries. Materials were collected with their and their parents' consent at 2-month intervals whenever possible over 18 years (mean) from the age of 3 years to adolescence, and were stored in our department.

As shown in Table 1, the 53 subjects from whom these serial dental casts were obtained were classified according to the dentition/occlusal state in the stable permanent dentition period into 3 groups with normal dentition, crowded dentition, or other malocclusions (edge to edge bite, 3 subjects; maxillary protrusion, 2; mandibular protrusion, 1; and maxillomandibular protrusion, 1). Based on studies suggesting an association between malocclusion and the consecutive curve of the incisal edge, tip and cusp tip³⁻¹⁰⁾, it is important to clarify serial changes of this curve in subjects who showed a change from normal deciduous dentition to malocclusion. However, due to the small number of cases, we performed a survey focusing on changes in this curve from the deciduous to permanent dentition period, which has not previously been reported, and evaluated 25 subjects (12 males and 13 females)

Table 2 Measurement points

< Deciduous teeth >	
Sign	Measurement points
A	Edge of the deciduous central incisor
B	Edge of the deciduous lateral incisor
C	Tip of the deciduous canine
Dmb	Mesiobuccal cusp tip of the first deciduous molar
Ddb	Distobuccal cusp tip of the first deciduous molar
Db	Buccal cusp tip of the maxillary first deciduous molar
Emb	Mesiobuccal cusp tip of the second deciduous molar
Edb	Distobuccal cusp tip of the second deciduous molar
Ed	Distal cusp tip of the mandibular second deciduous molar
< Permanent teeth >	
Sign	Measurement points
1	Edge of the central incisor
2	Edge of the lateral incisor
3	Canine tip
4b	Mesiobuccal cusp tip of the first premolar
5b	Mesiobuccal cusp tip of the second premolar
6mb	Mesiobuccal cusp tip of the first molar
6db	Distobuccal cusp tip of the first molar
6d	Distal cusp tip of the mandibular first molar
7mb	Mesiobuccal cusp tip of the second molar
7db	Distobuccal cusp tip of the second molar
7d	Distal cusp tip of the mandibular second molar

with normal and 19 (6 males and 13 females) with crowded dentition due to the high number of subjects in these states.

2) Extraction of casts for observation

To clarify more detailed changes in the consecutive curve of the incisal edge, tip and cusp tip, of serial dental casts obtained from the 44 subjects, casts at the following 6 time points were selected as materials for measurement: at the time of the completion of deciduous dentition and immediately before the transition to mixed dentition in the deciduous dentition period, at the time of the initiation of intercuspal position of the permanent first molars and at exfoliation of the second deciduous molars in the mixed dentition period, and at the time of the initiation of intercuspal position of the permanent second molars and in the stable permanent dentition period.

Methods

1) Cast standardization

For the comparison and evaluation of serial casts,

cast standardization is necessary. All serial casts used as the materials of this study were standardized as follows based on serial studies in our department^{27,28)}. The plane, including a point in the center of the incisive papilla and the lowest points of the lingual tooth necks of the left and right second deciduous molars in the maxillary cast (total, 3 points), was defined as the reference plane. The basal plane of the cast was adjusted so as to be parallel with and at the same distance from the reference plane. Subsequently, in the maximum intercuspal position of the maxillary and mandibular casts, the mandibular basal plane was adjusted to be parallel to and at the same distance from the maxillary basal plane. In addition, according to the method of Kubodera *et al.*²⁸⁾, from 6 months before exfoliation of the maxillary second deciduous molar, the reference point in the second deciduous molar was moved to the lowest point of the lingual tooth neck of the first molar. When the reference point was moved, the reference plane was adjusted to be the

Fig. 1 Calculation methods for the superoinferior distances of measurement sites

- a : Distance from the basal plane of the mandibular cast to the reference line (mesiobuccal cusp tip of the second deciduous molar)
- b : Distance from the basal plane of the cast to each measurement point
- c : Distance from the reference line to each measurement point
- d : Distance between the basal planes of the maxillary and mandibular casts
- e : Distance from the basal plane of the maxillary cast to the reference line
- K: Mesiobuccal cusp tip of the mandibular second deciduous molar at the completion of the deciduous dentition

same between before and after movement.

2) Measurement sites

Measurement sites in individual teeth were determined as follows. All materials were observed and, for the deciduous and permanent incisors, a point on the incisal edge at almost the same position between the two teeth was selected and marked on each cast. The tip was marked for the deciduous and permanent canines, and the buccal cusp tips were marked for the deciduous molars/premolars and permanent molars. In subjects showing flattening of the canine tip and premolar/molar cusp tips due to attrition, the most protruded site on the worn occlusal plane of each tooth was used as the measurement point. In the maxillary cast, the line connecting the center of the incisive papilla and the most posterior clear point of the median palatine raphe was defined as the median line. Subsequently, in the intercusp position of the maxillary and mandibular casts, the

maxillary median line was marked on the mandibular cast as the mandibular median line.

In the figures and tables in this study, each measurement site was indicated by an abbreviation, as shown in Table 2. The types of deciduous teeth are indicated by capital letters and those of permanent teeth by numbers. Lower-case letters following these abbreviations indicate molar/premolar cusps: mb: mesiobuccal cusp tips of the molars; db: distobuccal cusp tips of the molars; b: buccal cusp tips of the maxillary first deciduous molar and premolar; d: distal cusp tips of the mandibular second deciduous molar and mandibular first molar.

3) Measurement methods

The maxillary and mandibular standard casts marked with measurement sites using the methods described in the above sections were fixed on the cast head devised in our department so that the median line of the cast formed right angles with the long axis of

the body of the improved digital reading microscope PRM-D2 (Pika Seiko). The reading microscope used for measurement was improved in our department by connecting a super-small high-reliability fixation sensor camera and a video monitor to the body of a conventional microscope for detailed observation of the measurement sites by magnifying and projecting them.

Using the mandibular cast at the completion of deciduous dentition, the vertical distance from the basal plane of the cast to the mesiobuccal cusp tip of the second deciduous molar (K) (distance, a) was measured. A line parallel to the cast reference plane at the same distance as (a) from this plane was used as the reference line for the superoinferior position. Subsequently, in the cast at each observation point, the distances from the cast basal plane to the incisal edge, tip, or the cusp tip of each tooth (b) were measured. Prior to measurement, casts after the initiation of first molar intercuspation were observed in detail, and measurement sites not showing intercuspation of the opposing teeth due to incomplete eruption were excluded. The 5th cusp (distal cusp) of the mandibular second molar was excluded from measurement because the distal cusp was observed in only 5 of the 44 subjects.

After measurement, as shown in Fig. 1, in the mandible, the vertical distance from the reference line to the measurement point (c), representing the superoinferior position of the edge, tip, or cusp tip with respect to the reference line, was calculated by subtracting the distance from the cast basal plane to the reference line (a) from the obtained distance of each measurement site (b). In the maxilla, at the maximum intercuspal position, the distance from the basal plane of the maxillary cast to the reference line (e) was calculated by subtracting (a) from the distance between the basal planes of the maxillary and mandibular casts (d), and the superoinferior distance from the reference line to the measurement site (c) was calculated by subtracting (b) from (e). In addition, as the anteroposterior positions of the measurement sites, the horizontal distance to the edge, tip, or the cusp tip of each tooth was measured using the maxillary or mandibular deciduous or permanent central incisor as the origin.

4) Observation items

(1) Mean changes

The 44 subjects were classified according to the dentition state in the stable permanent dentition period into groups with normal or crowded dentition.

In each group, the mean value of the superoinferior position (Y-coordinate value) of the incisal edge, canine tip, or molar buccal cusp tip of each maxillary or mandibular left or right tooth with respect to the reference plane at each time point of observation, and the mean value of its anteroposterior position (X-coordinate value) using the left deciduous or permanent central incisor as the origin were obtained. In addition, differences between males and females were analyzed by Welch's *t*-test.

Subsequently, based on the mean value of each measurement site, graphs of the consecutive curve of the incisal edge, tip and cusp tip were produced. For clearer observation of the state of this curve, a Y-axis scale twice as large as the X-axis scale was used based on Kirihara's study²⁵⁾.

(2) Changes in each subject

The mean changes were the mean serial changes in all subjects in each group, and not all subjects showed changes similar to the mean changes; therefore, based on the classification criteria proposed by Kirihara *et al.*²⁵⁾ in our department, the curvature of the edge-tip-cusp tip in the deciduous dentition period was classified based on the mean superoinferior position value of the deciduous canine tip at the completion of deciduous dentition in both the maxilla and mandible. The curvature in the stable permanent dentition period was classified based on the superoinferior position value of the buccal cusp of the second premolar in the maxilla and based on that of the distal cusp of the first molar in the mandible. The curvature was classified into the following 3 categories:

Gentle curvature: Measurement values ≤ -1 SD of the mean values, showing a gentler curvature than the mean curvature.

Average curvature: Measurement values within ± 1 SD, showing a curvature similar to the mean curvature.

Sharp curvature: Measurement values $> +1$ SD, showing a sharper curvature than the mean curvature.

Subsequently, changes in the curvature from the completion of deciduous dentition to stable permanent dentition in each subject were surveyed and evaluated.

(3) Evaluation of differences between normal and crowded dentition

To evaluate the association between the dentition state in the stable permanent dentition period and changes in the edge-tip-cusp tip curve, differences

Table 3 Measurement points showing significant differences in the superoinferior position between males and females

< Normal dentition >				
Measurement time points				
Maxillary right	Completion of the deciduous dentition	Measurement points Significant difference	Emb **	Edb *
	Immediately before transition to the mixed dentition	Measurement points Significant difference	Emb **	Edb **
	Initiation of first molar intercuspation	Measurement points Significant difference	Emb *	Edb *
	Second deciduous molar exfoliation	Measurement points Significant difference	2 *	6mb *
Mandibular right	Second deciduous molar exfoliation	Measurement points Significant difference	6mb *	6d *
< Crowded dentition >				
Measurement time points				
Maxillary left	Initiation of first molar intercuspation	Measurement points Significant difference	Db *	
Mandibular left	Initiation of second molar intercuspation	Measurement points Significant difference	6mb *	6d *

*: $P < 0.05$, **: $P < 0.01$

in the mean values of all measurement items between the normal (25 subjects) and crowded (19) dentition groups were analyzed by Welch's *t*-test using software for personal computers (Excel 97; Microsoft).

Results

Prior to calculating the mean changes in each group, differences in the mean superoinferior position values between males and females at each observation point were evaluated. As shown in Table 3, significant differences between males and females were observed at only 10 of 193 sites in the normal dentition group and 3 of 192 sites in the crowded dentition group on the left and right sides of the maxilla and mandible at the 6 observation points. Thus, there were no clear gender-related differences in dentition overall. Therefore, the mean values were obtained in the normal (25 subjects) and crowded (19) dentition groups. Tables 4 and 5 show the mean, standard deviation, maximum, and minimum values of the superoinferior position of each measurement site in the normal and crowded dentition groups, respectively. In these tables, measurement values below and above the reference line are indicated by plus and minus values, respectively, in the maxilla and by minus and plus values, respectively, in the

mandible. In addition, since the superimposition of graphs of edge-tip-cusp tip curves at the 6 observation points made the evaluation of serial changes difficult, the 6 observation points were classified into deciduous, mixed, and permanent dentition periods. Curves in each period were superimposed in the figure, and serial changes were evaluated.

Mean changes in the normal dentition group

1) Maxillary dental arch

Table 4-1 and Fig. 2-1 show the measurement values of the superoinferior position of each measurement site in the maxillary dental arch at each observation point and the edge-tip-cusp tip curves produced based on these values, respectively.

2) Mandibular dental arch

Table 4-2 and Fig. 2-2 show the measurement values of the superoinferior position of each measurement site in the mandibular arch at each observation point and the edge-tip-cusp tip curves produced based on these values, respectively.

Mean changes in the crowded dentition group

1) Maxillary dental arch

Table 5-1 and Fig. 3-1 show the measurement values of the superoinferior position of each measurement site in the maxillary arch at each observation point

Table 4-1 Changes in the superoinferior position of the incisal edge, canine tip, and molar cusp tip (normal dentition, maxilla)

		(mm)										
Left/ right	Measurement points		A (1)	B (2)	C (3)	Db(4b)	E (5)		6		7	
	Measurement time point						Emb(5b)	Edb	6mb	6db	7mb	7db
Left	Completion of the deciduous dentition (mean age, 4 years and 0 months)	Number of subjects	25	25	25	25	25	25				
		Mean	-0.01	-0.25	0.61	0.40	0.43	0.46				
		Standard deviation	0.65	0.68	0.73	0.70	0.49	0.51				
		Maximum	1.25	0.98	1.84	1.56	1.11	1.28				
		Minimum	-1.40	-1.90	-1.45	-0.99	-0.52	-0.65				
	Immediately before transition to the mixed dentition (mean age, 6 years and 2 months)	Number of subjects	25	25	25	25	25	25				
		Mean	-0.57	-0.75	0.07	0.09	0.51	0.71				
		Standard deviation	0.81	0.82	0.85	0.85	0.70	0.66				
		Maximum	0.47	0.36	1.45	1.40	1.57	1.89				
		Minimum	-2.97	-3.16	-2.15	-1.74	-0.81	-0.51				
	Initiation of first molar intercuspation (mean age, 7 years and 0 months)	Number of subjects	22	25	25	25	25	25	25	25		
		Mean	-1.07	-1.17	-0.13	0.00	0.50	0.70	-0.72	-1.01		
		Standard deviation	1.02	0.97	0.81	0.87	0.68	0.65	0.73	0.83		
		Maximum	1.55	0.57	1.51	1.83	1.99	2.15	0.99	0.80		
		Minimum	-3.01	-4.02	-2.00	-1.62	-0.74	-0.51	-1.78	-2.69		
	Second deciduous molar exfoliation (mean age, 11 years and 10 months)	Number of subjects	25	25	25	25			25	25		
		Mean	0.56	-0.08	0.02	0.70			0.09	-0.09		
		Standard deviation	1.01	0.93	1.27	1.04			0.81	0.85		
		Maximum	2.16	2.16	1.75	2.79			1.64	1.33		
		Minimum	-2.44	-1.91	-3.08	-1.74			-1.45	-1.96		
	Initiation of second molar intercuspation (mean age, 13 years and 2 months)	Number of subjects	25	25	25	25	25		25	25	25	25
		Mean	0.77	0.00	0.93	1.50	1.38		0.58	0.57	-1.66	-2.76
		Standard deviation	1.02	1.00	1.07	0.98	0.90		0.89	0.95	1.25	1.27
		Maximum	2.29	1.62	2.46	3.09	3.27		2.31	2.31	1.45	0.55
		Minimum	-2.45	-2.13	-1.56	-0.94	-0.56		-1.50	-1.75	-3.98	-4.92
	Stable permanent dentition period (mean age, 21 years and 5 months)	Number of subjects	25	25	25	25	25		25	25	25	25
		Mean	1.96	1.04	1.72	2.27	2.22		1.31	1.48	0.18	-0.44
		Standard deviation	1.45	1.20	1.09	1.06	1.01		1.01	1.20	1.53	1.61
		Maximum	4.99	4.23	4.11	3.97	4.13		3.78	4.31	3.45	3.48
		Minimum	-3.19	-2.20	-0.56	-0.31	-0.05		-0.09	-0.54	-2.28	-2.98
Right	Completion of the deciduous dentition (mean age, 4 years and 0 months)	Number of subjects	25	25	25	25	25	25				
		Mean	-0.03	-0.32	0.58	0.42	0.42	0.42				
		Standard deviation	0.75	0.74	0.67	0.57	0.47	0.51				
		Maximum	1.30	0.99	1.73	1.31	1.04	1.12				
		Minimum	-1.45	-2.12	-1.29	-1.40	-0.71	-0.92				
	Immediately before transition to the mixed dentition (mean age, 6 years and 2 months)	Number of subjects	25	25	25	25	25	25				
		Mean	-0.58	-0.87	0.00	0.16	0.46	0.72				
		Standard deviation	0.88	0.87	0.84	0.79	0.66	0.63				
		Maximum	1.33	0.92	1.52	1.52	1.60	2.03				
		Minimum	-2.63	-3.05	-2.13	-1.74	-1.02	-0.52				
	Initiation of first molar intercuspation (mean age, 7 years and 1 month)	Number of subjects	24	25	25	25	25	25	25	25		
		Mean	-1.21	-1.35	-0.23	-0.04	0.46	0.66	-0.51	-0.85		
		Standard deviation	1.26	1.11	0.57	0.62	0.71	0.75	0.84	1.36		
		Maximum	1.36	-0.01	0.75	1.33	1.73	2.14	1.01	3.34		
		Minimum	-4.92	-5.13	-1.75	-1.63	-0.90	-0.47	-1.85	-3.57		
	Second deciduous molar exfoliation (mean age, 12 years and 0 months)	Number of subjects	25	25	25	25			25	25		
		Mean	0.66	0.04	0.41	0.82			0.18	0.00		
		Standard deviation	0.88	0.81	1.18	1.00			0.93	0.97		
		Maximum	2.10	1.94	2.16	3.53			3.19	3.00		
		Minimum	-1.36	-1.55	-2.36	-1.10			-1.40	-1.62		
	Initiation of second molar intercuspation (mean age, 13 years and 3 months)	Number of subjects	25	25	25	25	25		25	25	25	25
		Mean	0.69	-0.09	0.70	1.38	1.26		0.58	0.60	-1.62	-2.83
		Standard deviation	0.96	0.85	0.89	0.91	0.80		1.00	0.97	1.14	1.14
		Maximum	2.17	1.47	2.59	3.96	3.85		3.49	3.62	0.58	-0.85
		Minimum	-1.60	-2.01	-1.26	-0.30	0.25		-1.32	-1.13	-3.63	-4.65
	Stable permanent dentition period (mean age, 21 years and 5 months)	Number of subjects	25	25	25	25	25		25	25	25	25
		Mean	1.91	0.91	1.49	2.04	1.93		1.21	1.40	0.21	-0.56
		Standard deviation	1.34	1.08	1.02	1.02	0.92		1.11	1.12	1.18	1.36
		Maximum	4.48	3.06	3.74	4.67	4.78		5.06	5.39	4.02	2.97
		Minimum	-2.71	-1.75	-0.17	0.53	0.47		-0.79	-0.47	-1.70	-2.82

Table 4-2 Changes in the superoinferior position of the incisal edge, canine tip, and molar cusp tip (normal dentition, mandible)

Left/ right			(mm)												
	Measurement time point	Measurement points	A (1)	B (2)	C (3)	D (4)		E (5)			6			7	
						Dmb (4b)	Ddb	Emb (5b)	Edb	Ed	6mb	6db	6d	7mb	7db
Left	Completion of the deciduous dentition (mean age, 4 years and 0 months)	Number of subjects	25	25	25	25	25	25	25	25					
		Mean	1.44	1.58	1.60	0.55	0.03	0	0.33	0.12					
		Standard deviation	1.10	1.08	0.82	0.60	0.49	0	0.36	0.47					
		Maximum	3.40	3.40	3.18	1.27	0.94	0	1.33	1.04					
		Minimum	-0.63	-0.39	-0.08	-1.23	-1.20	0	-0.41	-0.97					
	Immediately before transition to the mixed dentition (mean age, 6 years and 2 months)	Number of subjects	25	25	25	25	25	25	25	25					
		Mean	1.46	1.60	1.55	0.56	0.05	-0.14	-0.10	-0.43					
		Standard deviation	1.01	0.90	0.74	0.59	0.55	0.56	0.65	0.63					
		Maximum	3.44	3.18	3.01	1.70	1.56	0.80	0.80	0.59					
		Minimum	-0.55	0.11	0.17	-0.69	-0.85	-1.82	-2.19	-2.23					
	Initiation of first molar intercuspation (mean age, 7 years and 0 months)	Number of subjects	24	24	25	25	25	25	25	25	25	25	9		
		Mean	1.99	1.32	1.67	0.64	0.08	-0.12	-0.17	-0.49	0.47	0.90	0.58		
		Standard deviation	0.79	1.13	0.64	0.56	0.69	0.60	0.65	0.60	0.57	0.64	0.76		
		Maximum	3.02	3.07	2.92	1.53	1.72	1.08	1.28	0.96	1.56	2.25	1.80		
		Minimum	0.50	-0.99	0.47	-0.49	-0.91	-1.82	-2.19	-2.23	-0.59	-0.32	-0.60		
	Second deciduous molar exfoliation (mean age, 11 years and 10 months)	Number of subjects	25	25	25	25					25	25	24		
		Mean	2.11	2.05	1.84	0.71					0.08	0.48	-0.03		
		Standard deviation	1.10	1.12	1.02	1.00					0.72	0.81	0.88		
		Maximum	3.58	3.62	3.09	2.13					1.85	2.33	2.23		
		Minimum	-0.89	-0.74	-0.71	-2.34					-1.81	-1.62	-1.88		
	Initiation of second molar intercuspation (mean age, 13 years and 2 months)	Number of subjects	25	25	25	25		25			25	25	25	25	25
		Mean	2.03	2.04	1.95	0.91		-0.08			-0.40	0.05	-0.34	1.10	1.95
		Standard deviation	1.16	1.14	0.91	0.82		0.72			0.77	0.78	0.85	0.85	1.12
		Maximum	3.83	3.83	3.26	2.68		1.28			1.36	1.98	1.74	2.94	4.36
		Minimum	-0.44	-0.59	-0.35	-0.84		-1.35			-1.54	-1.66	-1.94	-0.60	-0.44
	Stable permanent dentition period (mean age, 21 years and 5 months)	Number of subjects	25	25	25	25		25			25	25	25	25	25
		Mean	0.59	0.83	0.89	0.06		-0.71			-1.10	-0.71	-1.09	-0.17	0.45
		Standard deviation	1.82	1.72	1.37	0.97		0.89			0.82	0.84	0.96	1.18	1.41
		Maximum	3.10	3.81	2.85	1.71		1.00			0.51	0.76	0.76	2.07	2.95
		Minimum	-4.15	-3.33	-3.01	-2.08		-2.24			-2.71	-2.44	-3.20	-3.10	-2.97
Right	Completion of the deciduous dentition (mean age, 4 years and 0 months)	Number of subjects	25	25	25	25	25	25	25	25					
		Mean	1.44	1.60	1.57	0.61	-0.05	0	0.29	0.08					
		Standard deviation	1.12	1.06	0.81	0.51	0.44	0	0.28	0.43					
		Maximum	3.60	3.81	3.39	1.58	0.63	0	0.83	0.78					
		Minimum	-0.64	-0.28	0.30	-0.32	-1.18	0	-0.43	-1.36					
	Immediately before transition to the mixed dentition (mean age, 6 years and 2 months)	Number of subjects	25	25	25	25	25	25	25	25					
		Mean	1.51	1.68	1.61	0.64	0.04	-0.03	0.00	-0.38					
		Standard deviation	1.15	1.08	0.93	0.71	0.66	0.51	0.43	0.42					
		Maximum	3.86	3.80	3.68	2.20	2.06	1.19	0.75	0.38					
		Minimum	-0.59	-0.76	-0.39	-0.77	-1.13	-1.08	-0.85	-1.16					
	Initiation of first molar intercuspation (mean age, 7 years and 1 month)	Number of subjects	23	24	25	25	25	25	25	25	25	25	13		
		Mean	1.93	1.50	1.59	0.59	0.02	-0.09	-0.11	-0.48	0.41	0.71	0.45		
		Standard deviation	0.91	1.01	0.88	0.73	0.78	0.60	0.61	0.67	0.84	1.01	0.86		
		Maximum	3.46	2.99	3.37	1.90	1.81	1.23	1.13	0.70	1.70	2.34	1.63		
		Minimum	0.75	-1.16	0.24	-1.40	-2.25	-1.70	-1.38	-1.75	-1.44	-1.69	-1.43		
	Second deciduous molar exfoliation (mean age, 11 years and 9 months)	Number of subjects	25	25	25	25					25	25	23		
		Mean	2.30	2.17	1.73	0.76					0.10	0.44	-0.13		
		Standard deviation	1.05	1.06	1.34	1.33					0.86	0.91	0.98		
		Maximum	4.16	4.22	4.08	3.25					1.54	1.87	1.79		
		Minimum	-0.29	-0.73	-2.37	-2.04					-2.22	-1.55	-2.16		
	Initiation of second molar intercuspation (mean age, 13 years and 3 months)	Number of subjects	25	25	25	25		25			25	25	24	25	25
		Mean	2.01	1.96	1.90	0.92		-0.01			-0.47	-0.05	-0.54	1.11	1.84
		Standard deviation	1.13	1.11	0.95	0.88		0.80			0.83	0.81	0.85	0.97	1.14
		Maximum	4.17	4.09	3.93	2.59		1.54			0.74	0.97	0.64	2.55	3.95
		Minimum	-0.83	-1.21	-0.65	-1.02		-1.97			-3.13	-2.35	-2.74	-1.35	-0.54
	Stable permanent dentition period (mean age, 21 years and 5 months)	Number of subjects	25	25	25	25		25			25	25	24	25	25
		Mean	0.73	0.83	1.02	0.28		-0.44			-0.91	-0.57	-0.98	-0.05	0.46
		Standard deviation	1.78	1.70	1.32	1.03		0.96			1.01	0.98	1.02	1.12	1.25
		Maximum	3.48	3.16	2.72	1.89		1.27			0.79	0.79	0.49	1.87	2.48
		Minimum	-3.68	-3.52	-2.20	-1.76		-2.55			-4.24	-3.66	-4.30	-3.42	-2.37

Table 5-1 Changes in the superoinferior position of the incisal edge, canine tip, and molar cusp tip (crowded dentition, maxilla)

		(mm)										
Left/ right	Measurement points		A (1)	B (2)	C (3)	Db(4b)	E (5)		6		7	
	Measurement time point						Emb(5b)	Edb	6mb	6db	7mb	7db
Left	Completion of the deciduous dentition (mean age, 3 years and 10 months)	Number of subjects	19	19	19	19	19	19				
		Mean	-0.26	-0.38	0.50	0.38	0.35	0.46				
		Standard deviation	0.76	0.82	0.80	0.60	0.44	0.47				
		Maximum	1.54	1.78	2.29	1.68	1.04	1.20				
		Minimum	-1.20	-1.57	-1.22	-0.80	-0.59	-0.77				
	Immediately before transition to the mixed dentition (mean age, 6 years and 0 months)	Number of subjects	19	19	19	19	19	19				
		Mean	-0.43	-0.54	0.23	0.50	0.67	0.96				
		Standard deviation	0.63	0.69	0.68	0.45	0.47	0.50				
		Maximum	0.64	0.55	1.39	1.69	1.74	2.10				
		Minimum	-1.24	-1.70	-1.17	-0.27	0.06	0.23				
	Initiation of first molar intercuspation (mean age, 6 years and 8 months)	Number of subjects	17	17	19	19	19	19	19	18		
		Mean	-0.87	-0.94	0.08	0.42	0.53	0.82	-0.70	-0.80		
		Standard deviation	1.15	0.79	0.63	0.53	0.52	0.57	0.82	1.23		
		Maximum	0.79	0.74	1.02	1.34	1.77	2.08	0.40	2.06		
		Minimum	-4.11	-2.88	-1.27	-0.73	-0.39	-0.24	-2.30	-2.84		
	Second deciduous molar exfoliation (mean age, 11 years and 9 months)	Number of subjects	19	19	19	19			19	19		
		Mean	0.63	0.27	-0.07	0.75			0.55	0.42		
		Standard deviation	0.74	1.02	1.48	1.22			1.08	1.09		
		Maximum	1.95	2.76	2.29	3.38			3.40	2.89		
		Minimum	-0.54	-1.52	-3.99	-1.41			-1.26	-1.32		
	Initiation of second molar intercuspation (mean age, 13 years and 2 months)	Number of subjects	19	19	19	19	19		19	19	19	18
		Mean	0.81	0.39	0.61	1.38	1.40		0.78	0.75	-1.59	-2.65
		Standard deviation	0.78	1.01	1.06	0.95	1.09		1.22	1.22	1.78	1.67
		Maximum	1.83	3.52	2.25	3.00	3.97		4.11	3.84	0.94	0.15
		Minimum	-0.66	-0.75	-1.95	-0.35	0.28		-1.12	-0.99	-5.32	-5.90
	Stable permanent dentition period (mean age, 21 years and 3 months)	Number of subjects	19	19	19	19	19		19	19	19	19
		Mean	1.72	1.19	1.58	2.19	2.19		1.59	1.80	0.50	-0.15
		Standard deviation	1.02	0.99	1.04	1.04	1.22		1.36	1.40	1.95	2.24
		Maximum	3.18	3.20	3.57	3.89	4.52		4.89	5.09	3.50	2.92
		Minimum	-0.22	-0.81	-0.26	0.71	0.61		-0.23	-0.28	-3.54	-4.59
Right	Completion of the deciduous dentition (mean age, 3 years and 10 months)	Number of subjects	19	19	19	19	19	19				
		Mean	-0.28	-0.45	0.36	0.51	0.51	0.59				
		Standard deviation	1.12	1.11	0.93	0.70	0.55	0.55				
		Maximum	2.79	2.53	2.62	1.96	1.20	1.39				
		Minimum	-2.00	-2.06	-1.39	-1.06	-0.66	-0.47				
	Immediately before transition to the mixed dentition (mean age, 6 years and 0 months)	Number of subjects	19	19	19	19	19	19				
		Mean	-0.43	-0.69	0.08	0.53	0.79	1.07				
		Standard deviation	0.90	0.86	0.83	0.71	0.65	0.64				
		Maximum	1.73	1.25	1.78	1.98	2.15	2.35				
		Minimum	-1.96	-2.22	-1.51	-0.99	-0.39	-0.03				
	Initiation of first molar intercuspation (mean age, 6 years and 11 months)	Number of subjects	17	18	19	19	19	19	19	19		
		Mean	-0.99	-1.03	-0.29	0.29	0.59	0.90	-0.19	-0.53		
		Standard deviation	0.77	0.81	0.88	0.64	0.67	0.71	0.89	1.22		
		Maximum	0.68	0.69	1.40	1.83	2.28	2.59	1.16	1.34		
		Minimum	-2.76	-2.52	-1.85	-0.81	-0.50	-0.36	-1.34	-2.26		
	Second deciduous molar exfoliation (mean age, 11 years and 8 months)	Number of subjects	19	19	19	19			19	19		
		Mean	0.60	0.11	-0.49	0.41			0.42	0.31		
		Standard deviation	1.12	1.07	1.72	1.32			1.30	1.54		
		Maximum	3.04	2.31	3.16	3.80			3.40	4.07		
		Minimum	-0.88	-1.54	-4.07	-2.33			-1.06	-1.39		
	Initiation of second molar intercuspation (mean age, 13 years and 2 months)	Number of subjects	19	19	19	19	19		19	19	19	15
		Mean	0.73	0.28	0.35	1.21	1.31		0.98	1.01	-1.07	-2.08
		Standard deviation	1.10	1.17	1.51	1.03	1.19		1.28	1.41	1.89	2.09
		Maximum	2.99	2.24	3.01	3.51	4.18		3.80	4.08	2.80	1.62
		Minimum	-0.75	-1.58	-2.10	-0.59	-0.30		-0.58	-0.97	-3.71	-5.21
	Stable permanent dentition period (mean age, 21 years and 3 months)	Number of subjects	19	19	19	19	19		19	19	19	19
		Mean	1.69	1.08	1.11	1.82	2.02		1.53	1.89	1.17	0.41
		Standard deviation	1.24	1.25	1.22	1.19	1.34		1.39	1.62	2.00	2.25
		Maximum	4.09	3.13	3.34	4.21	4.93		4.61	5.45	5.94	5.58
		Minimum	-0.47	-0.80	-1.40	-0.62	0.10		-0.51	-0.24	-1.35	-2.35

Table 5-2 Changes in the superoinferior position of the incisal edge, canine tip, and molar cusp tip (crowded dentition, mandible)

Left/ right			(mm)												
	Measurement time point	Measurement points	A (1)	B (2)	C (3)	D (4)		E (5)			6			7	
						Dmb (4b)	Ddb	Emb (5b)	Edb	Ed	6mb	6db	6d	7mb	7db
Left	Completion of the deciduous dentition (mean age, 3 years and 10 months)	Number of subjects	19	19	19	19	19	19	19	19					
		Mean	1.96	2.06	1.88	0.75	0.12	0	0.26	0.02					
		Standard deviation	0.93	0.93	0.68	0.41	0.38	0	0.27	0.39					
		Maximum	3.43	3.57	3.22	1.46	0.66	0	0.71	0.53					
		Minimum	-0.31	0.01	0.20	-0.21	-1.02	0	-0.48	-1.31					
	Immediately before transition to the mixed dentition (mean age, 6 years and 0 months)	Number of subjects	19	19	19	19	19	19	19	19					
		Mean	1.57	1.72	1.55	0.51	-0.07	-0.23	-0.17	-0.50					
		Standard deviation	1.09	0.99	0.77	0.66	0.58	0.45	0.49	0.52					
		Maximum	3.02	3.16	3.12	1.81	1.05	0.88	0.83	0.42					
		Minimum	-0.70	-0.18	0.12	-1.33	-1.68	-1.36	-1.25	-1.40					
	Initiation of first molar intercuspation (mean age, 6 years and 8 months)	Number of subjects	18	18	19	19	19	19	19	19	19	19	6		
		Mean	1.82	1.37	1.36	0.50	-0.10	-0.20	-0.14	-0.45	0.44	0.75	-0.02		
		Standard deviation	1.21	1.14	0.79	0.67	0.63	0.49	0.51	0.56	0.86	0.90	1.19		
		Maximum	3.82	3.64	2.39	1.42	0.76	0.50	0.72	0.54	2.16	2.43	1.14		
		Minimum	-0.73	-0.74	-0.56	-0.64	-1.05	-1.08	-1.15	-1.46	-1.00	-1.05	-2.18		
	Second deciduous molar exfoliation (mean age, 11 years and 11 months)	Number of subjects	19	19	19	19					19	19	18		
		Mean	1.94	1.74	1.26	0.17					-0.26	0.13	-0.08		
		Standard deviation	1.34	1.26	0.86	0.93					1.08	1.16	1.65		
		Maximum	3.74	4.05	2.94	1.53					1.38	2.05	3.88		
		Minimum	-0.76	-0.75	-0.61	-2.18					-3.69	-3.16	-3.40		
	Initiation of second molar intercuspation (mean age, 13 years and 2 months)	Number of subjects	19	19	19	19		19			19	19	19	19	16
		Mean	1.95	1.95	1.78	0.87		-0.14			-0.35	-0.21	-0.51	0.87	1.83
		Standard deviation	1.10	1.13	0.79	0.84		0.82			1.05	1.01	1.04	1.46	1.41
		Maximum	4.36	4.65	3.61	2.29		1.43			1.88	2.20	2.04	3.91	4.95
		Minimum	-0.64	-0.42	0.28	-0.48		-1.68			-1.94	-1.95	-2.29	-2.20	-0.39
	Stable permanent dentition period (mean age, 21 years and 3 months)	Number of subjects	19	19	19	19		19			19	19	19	19	18
		Mean	0.91	0.91	0.95	0.03		-0.88			-1.43	-1.31	-1.54	-0.57	-0.36
		Standard deviation	1.24	1.38	1.08	0.96		0.79			1.15	1.21	1.35	1.87	1.84
		Maximum	2.82	3.57	2.49	1.60		0.49			0.43	0.46	0.51	3.47	3.61
		Minimum	-1.20	-1.63	-1.30	-1.43		-2.15			-4.21	-3.93	-4.42	-3.83	-4.15
Right	Completion of the deciduous dentition (mean age, 3 years and 10 months)	Number of subjects	19	19	19	19	19	19	19	19					
		Mean	1.96	2.15	1.96	0.78	0.22	0	0.25	-0.04					
		Standard deviation	0.98	0.92	0.71	0.45	0.34	0	0.33	0.46					
		Maximum	3.14	3.73	2.97	1.62	0.92	0	0.83	0.55					
		Minimum	-0.65	0.22	0.49	-0.22	-0.51	0	-0.41	-1.12					
	Immediately before transition to the mixed dentition (mean age, 6 years and 0 months)	Number of subjects	19	19	19	19	19	19	19	19					
		Mean	1.56	1.77	1.58	0.61	-0.14	-0.29	-0.23	-0.55					
		Standard deviation	0.96	0.98	0.78	0.72	0.60	0.43	0.47	0.56					
		Maximum	2.78	3.73	2.90	2.17	0.74	0.49	0.73	0.62					
		Minimum	-0.22	0.19	0.11	-0.51	-1.68	-1.26	-0.95	-1.50					
	Initiation of first molar intercuspation (mean age, 6 years and 11 months)	Number of subjects	18	19	19	19	19	19	19	19	19	18	8		
		Mean	2.10	1.19	1.55	0.66	0.02	-0.17	-0.31	-0.73	0.07	0.35	0.46		
		Standard deviation	1.23	1.39	0.70	0.53	0.44	0.40	0.66	0.80	0.98	1.19	0.66		
		Maximum	3.94	2.67	2.95	1.88	0.90	0.68	0.79	0.43	1.69	1.93	1.43		
		Minimum	-0.62	-2.18	0.01	-0.23	-0.69	-0.97	-1.64	-2.44	-1.91	-2.57	-0.47		
	Second deciduous molar exfoliation (mean age, 11 years and 4 months)	Number of subjects	19	19	19	19					19	19	17		
		Mean	2.17	1.98	1.51	0.46					-0.10	0.23	-0.24		
		Standard deviation	1.24	1.14	1.26	0.98					1.14	1.15	1.20		
		Maximum	4.16	3.88	3.67	2.72					1.75	1.68	1.26		
		Minimum	-1.24	-0.84	-1.35	-1.29					-2.62	-2.66	-3.10		
	Initiation of second molar intercuspation (mean age, 13 years and 2 months)	Number of subjects	19	19	19	19		19			19	19	19	19	18
		Mean	2.06	1.89	1.57	0.59		-0.27			-0.68	-0.34	-0.91	0.67	1.27
		Standard deviation	1.21	1.18	1.02	0.94		1.01			1.21	1.33	1.35	1.85	1.89
		Maximum	3.60	3.18	3.32	2.51		1.65			1.41	1.51	1.10	2.84	3.98
		Minimum	-1.22	-1.05	-0.52	-1.43		-2.36			-3.50	-3.45	-3.90	-3.13	-2.71
	Stable permanent dentition period (mean age, 21 years and 3 months)	Number of subjects	19	19	19	19		19			19	19	19	19	19
		Mean	1.02	1.03	0.84	0.07		-0.82			-1.35	-1.11	-1.52	-0.81	-0.48
		Standard deviation	1.33	1.50	1.29	0.95		1.00			1.28	1.41	1.55	2.05	2.10
		Maximum	3.22	3.67	2.60	1.62		0.49			0.52	0.82	0.38	1.67	2.50
		Minimum	-1.48	-1.57	-1.24	-1.72		-2.87			-3.81	-3.98	-4.58	-4.67	-4.96

Fig. 2-1 Mean changes in the edge-tip-cusp tip curve (normal dentition, maxilla)

Fig. 2-2 Mean changes in the edge-tip-cusp tip curve (normal dentition, mandible)

Fig. 3-1 Mean changes in the edge-tip-cusp tip curve (crowded dentition, maxilla)

Fig. 3-2 Mean changes in the edge-tip-cusp tip curve (crowded dentition, mandible)

Table 6 Frequencies according to curvature

Curvature	Completion of the deciduous dentition		Stable permanent dentition period	
	Maxilla	Mandible	Maxilla	Mandible
Gentle	11	15	14	13
Average	66	62	61	62
Sharp	11	11	13	13

Table 7 Changes in curvature and the dentition state in the stable permanent dentition period

cases (%)		
Completion of the deciduous dentition	Stable permanent dentition period	Denture state
Gentle: 26	→ Gentle: 9 (34.6)	→ Normal: 4 (44.4) → Crowding: 5 (55.6)
	→ Average: 15 (57.7)	→ Normal: 12 (80) → Crowding: 3 (20)
	→ Sharp: 2 (7.7)	→ Normal: 0 (0) → Crowding: 2 (100)
Average: 128	→ Gentle: 17 (13.3)	→ Normal: 12 (70.6) → Crowding: 5 (29.4)
	→ Average: 91 (71.1)	→ Normal: 48 (52.7) → Crowding: 43 (47.3)
	→ Sharp: 20 (15.6)	→ Normal: 10 (50) → Crowding: 10 (50)
Sharp: 22	→ Gentle: 1 (4.5)	→ Normal: 1 (100) → Crowding: 0 (0)
	→ Average: 17 (77.3)	→ Normal: 11 (64.7) → Crowding: 6 (35.3)
	→ Sharp: 4 (18.2)	→ Normal: 2 (50) → Crowding: 2 (50)

and the edge-tip-cusp tip curves produced based on these values, respectively.

2) Mandibular dental arch

Table 5-2 and Fig. 3-2 show the measurement values of the superoinferior position of each measurement site in the mandibular arch at each observation point and edge-tip-cusp tip curves produced based on these values, respectively.

Changes in each subject

All serial casts obtained from the subjects of this study showed normal deciduous dentition at the initiation of this study, i.e., at the completion of

deciduous dentition; therefore, in 25 subjects in the normal dentition group and 19 in the crowded group (total, 44 subjects), the numbers of dental arches according to the curvature of the edge-tip-cup tip were investigated in the maxilla and mandible on the left and right sides at the completion of deciduous dentition and in the stable permanent dentition period. In addition, in each subject, changes in the curvature were compared with changes from the deciduous to permanent dentition, and the dentition (normal or crowded) in the permanent dentition period was surveyed.

As shown in Table 6, at the completion of

Table 8 Measurement points showing significant differences between the normal and crowded dentition groups by testing the mean values of the superoinferior positions (mm)

	Measurement point	Db	
Maxillary left	Immediately before transition to the mixed dentition	Normal	0.09
		Crowding	0.50
		Significant difference	*
	Measurement point	3	
Mandibular left	Second deciduous molar exfoliation	Normal	1.84
		Crowding	1.26
		Significant difference	*
	Measurement point	Ddb	
Mandibular right	Completion of the deciduous dentition	Normal	-0.05
		Crowding	0.22
		Significant difference	*

*: $P < 0.05$

deciduous dentition, there were 11 maxillary and 15 mandibular arches (total left and right sides) showing a gentle curvature, 66 maxillary and 62 mandibular arches showing an average curvature, and 11 maxillary and 11 mandibular arches showing a sharp curvature. During the stable permanent dentition period, there were 14 maxillary and 13 mandibular arches showing a gentle curvature, 61 maxillary and 62 mandibular arches with an average curvature, and 13 maxillary and 13 mandibular arches showing a sharp curvature.

The dentition state (normal or crowded) in the permanent dentition period was evaluated according to changes in the curvature of the edge-tip-cusp tip from the completion of the deciduous dentition to the stable permanent dentition period. As shown in Table 7, at the completion of deciduous dentition, the curvature was gentle in 26 maxillary or mandibular dental arches on the left or right side. During the stable permanent dentition period, the curvature remained gentle in 9 dental arches, of which 4 were normal, but the other 5 showed crowding. The curvature became average in 15 dental arches, of which 12 were normal, but 3 showed crowding. The curvature changed to sharp in 2 dental arches, both of which showed crowding. Similarly, at the completion of deciduous dentition, the curvature was average in 128 dental arches. During the stable permanent dentition period, the curvature changed to gentle in 17 dental arches, of which 12 were normal, but 5 showed crowding. The curvature

remained average in 91 dental arches, of which 48 were normal, but 43 showed crowding. The curvature became sharp in 20 dental arches, of which 10 were normal, but 10 showed crowding. At the completion of deciduous dentition, the curvature was sharp in 22 dental arches. During the stable permanent dentition period, the curvature became gentle in 1 dental arch, which was normal. The curvature became average in 17 dental arches, of which 11 were normal, but 6 showed crowding. The curvature remained sharp in 4 dental arches, of which 2 were normal, but 2 showed crowding.

Differences between the normal and crowded dentition groups

To determine whether changes in the consecutive curve of the incisal edge, tip and cusp tip in the growth process of dentition differed between the normal and crowded dentition groups, Welch's *t*-test was performed using the mean value of the superoinferior position of each measurement site in each group as the population mean. As shown in Table 8, significant differences were observed only in the distobuccal cusp of the mandibular right deciduous first molar at the completion of deciduous dentition, buccal cusp of the maxillary left deciduous first molar immediately before transition to mixed dentition, and the tip of the mandibular left canine at exfoliation of the second deciduous molar ($P < 0.05$ for all); therefore, no clear differences in this curve were observed between the two groups.

Discussion

Mean changes in the normal dentition

- 1) Deciduous dentition (completion of deciduous dentition: immediately before transition to mixed dentition)

Sassouni²⁹⁾ and Sim³⁰⁾ reported that the so-called curve of Spee is absent in normal dentition, and the occlusal surface is flat. Subsequently, Nozaka *et al.*²³⁾ clarified the presence of the edge-tip-cusp tip curve even in deciduous dentition. In addition, Kiriara *et al.*²⁵⁾ observed serial changes in the consecutive curve of the incisal edge, tip and cusp tip in the deciduous dentition using serial plaster casts obtained from the same 50 children at 6-month intervals from the age of 3 years 0 months to 6 years 0 months. They reported that maxillary deciduous dental arches showed a concave curve with the deciduous canine at the lowest point, while mandibular deciduous dental arches showed an S-shaped curve consisting of a convex curve with the deciduous canine at the peak and a concave curve with the deciduous first molar at the lowest point, and the curvature gradually decreased with time in both the maxilla and mandible, resulting in flattening, but the degree of flattening was smaller in the mandible.

Changes in the edge-tip-cusp tip curve were compared between our study and that by Kiriara *et al.*²⁵⁾ The most concave site of the mandibular curve was the mesiobuccal cusp of the second deciduous molar in our study, but the distobuccal cusp of the first deciduous molar in Kiriara *et al.*²⁵⁾ This difference may be due to the variation in the reference line between the two studies. Other findings, such as the shape of the maxillary and mandibular edge-tip-cusp tip curves, the position of the most concave site, and clearer flattening in the maxilla than in the mandible were similar between the two studies. These similar changes despite the differences in materials between the two studies support the validity of this study, and suggest that these changes in the edge-tip-cusp tip curve with the growth of dentition during the deciduous dentition period are common.

- 2) Mixed dentition period (initiation of the intercuspation of the first molars: exfoliation of the second deciduous molar)

Nozaka *et al.*²³⁾ surveyed the edge-tip-cusp tip curve of the maxillary dentition in subjects in the following 4 periods: deciduous dentition period, mixed dentition period I (eruption of only the mandibular

central incisor and maxillary and mandibular first molars as permanent teeth: mean age, 6 years and 0 months), mixed dentition period II (replacement of 1–4 teeth in the anterior teeth area in addition to the permanent teeth in mixed dentition period I: mean age, 7 years and 6 months), and the permanent dentition period. As a result, a slightly deeper concave curve was observed with the first deciduous molar at the most concave site in mixed dentition period I and with the second deciduous molar at the most concave site in mixed dentition period II than in the deciduous dentition period. In the permanent dentition period, the curvature increased with the first premolar being at the most concave site; however, they observed no differences between mixed dentition periods I and II.

In this study, the most concave site of the maxillary edge-tip-cusp tip curve was the distobuccal cusp of the second deciduous molar at the time of the initiation of the first molar intercuspation and the buccal cusp of the first premolar at the time of exfoliation of the second deciduous molar. The superoinferior distance of the most concave site from the reference line was longer in the mixed than in the deciduous dentition period. Thus, the curvature of the edge-tip-cusp tip was sharper in the mixed than in the deciduous dentition period, which was consistent with the finding of Nozaka²³⁾; however, differences in the superoinferior position among the measurement sites at the time of exfoliation of the second deciduous molar were smaller than at the initiation of first molar intercuspation, suggesting a decrease in the curvature of the edge-tip-cusp tip in this period. Mixed dentition periods I and II in the study by Nozaka *et al.*²³⁾ represent the early stage of mixed dentition. In addition, as they themselves also suggested, the mandibular central incisor and first molar in the subjects in mixed dentition period I were still in the middle of eruption, and the reference plane differed between mixed dentition periods I and II. These may have been the reasons for the absence of differences in the curvature between the two periods. In our study, from serial casts obtained at 2-month intervals, those when first molar intercuspation was confirmed and when the second deciduous molar was exfoliated were selected as observation data. In addition, areas not showing intercuspation due to incomplete eruption were excluded from measurement. Through these methods, we could observe a decrease in the curvature of the edge-tip-cusp tip in the mixed

dentition period.

Since there have been no studies on the mandibular edge-tip-cusp tip curve in the mixed dentition period, no comparison can be made. In this study, a gentle curvature with the distal cusp of the second deciduous molar at the most concave site was observed at the initiation of first molar intercuspation, but the most concave site was the mesiobuccal cusp of the first molar on both the left and right sides at the exfoliation of the second deciduous molar. In addition, the curvature at both measurement time points was sharper than in the deciduous dentition period.

3) Permanent dentition period (initiation of second molar intercuspation: stable permanent dentition period)

There have been many studies on the consecutive curve of the incisal edge, tip and cusp tip in the permanent dentition; however, this curve in the maxillary dentition has been evaluated only by Nozaka *et al.*²³⁾ and Steadman⁸⁾. Steadman⁸⁾ surveyed differences in the curvature of the edge-tip-cusp tip between subjects with normal occlusion and those with malocclusion, but did not refer to changes in the dentition with growth. Nozaka *et al.*²³⁾ evaluated the maxilla in subjects with a mean age of 16 years and 0 months, and reported that the maxillary dentition showed a curve with the first premolar at the most concave site, and the curvature was sharper than in deciduous or mixed dentition.

In this study, the maxillary edge-tip-cusp tip curve showed a semilunar pattern with the buccal cusp of the first premolar at the most concave site on the left and right sides both at the initiation of second molar intercuspation and in the stable permanent dentition period, and the curvature was sharper than in deciduous or mixed dentition. However, from the initiation of second molar intercuspation to the stable permanent dentition period, the amount of change in the measurement value did not markedly differ among the measurement sites, showing no marked difference in curvature between the time points. This absence of differences in the curvature may be because intercuspation had been achieved in all teeth from the central incisor to the second molar before the initiation of second molar intercuspation in the subjects in this study.

There have been many studies on the mandibular edge-tip-cusp tip curve. In particular, Iwasawa *et al.*¹¹⁾ evaluated the relationship between this curve and the occlusal plane in normal occlusion using

mandibular casts obtained from 30 subjects (11 males and 19 females), and observed a curve with the mesiobuccal cusp tip of the first molar at the most concave site with respect to two types of occlusal plane. Kobayashi *et al.*¹³⁾ performed 3-dimensional analysis of the edge-tip-cusp tip curve in Japanese with normal occlusion using diagnostic casts for mandibular correction obtained from 30 subjects (15 males and 15 females), and reported that the mandibular dentition showed a curve similar to that reported by Iwasawa *et al.*¹¹⁾ with the mesiobuccal cusp tip at the most concave site, but the curve was flatter than that observed in their study. In this study, the most concave site was the mesiobuccal cusp of the first molar on the left side and the distal cusp of the same tooth on the right side both at the initiation of second molar intercuspation and in the stable permanent dentition period, and the difference between the two cusps was only 0.06–0.07 mm. Since the reference planes for measurement differed among our study and studies by Iwasawa *et al.*¹¹⁾ and Kobayashi *et al.*¹³⁾, strict comparison is impossible; however, the position of the most concave site and the shape of the edge-tip-cusp tip curve were similar. From the initiation of second molar intercuspation to the permanent dentition period, the amount of change in the superoinferior position did not markedly differ among the measurement sites in the mandible as well as in the maxilla, showing similar curvature at the two time points.

Mean changes in the crowded dentition group

1) Deciduous dentition period (completion of deciduous dentition: immediately before transition to mixed dentition)

During the deciduous dentition period, the maxillary dentition showed an edge-tip-cusp tip curve with the deciduous canine at the most concave site in the crowded as well as the normal dentition group; however, from the completion of deciduous dentition to immediately before the transition to mixed dentition, the curve showed negligible changes in the anterior tooth area in the crowded dentition group, compared with the normal dentition group showing relatively marked changes, and only slight changes in the molar area. These findings suggested differences in changes in the edge-tip-cusp tip curve from immediately after the completion of deciduous teeth to immediately before transition to mixed dentition between the two groups. Since this curve is affected by the amount of eruption associated

with attrition in the deciduous dentition period and movements of successive permanent dental germs, changes in this curve may be a factor affecting the state of the dentition in the future, to a certain extent.

In the mandibular as well as maxillary dentition, the curve in the crowded group was similar to that in the normal dentition group; however, while slight changes were observed only in the second deciduous molar area in the normal dentition group, similar changes were observed at all measurement sites in the crowded dentition group. Thus, in both the maxilla and mandible, there were area-characteristic differences in the changes in the edge-tip-cusp tip curve in the deciduous dentition period between the normal and crowded dentition groups.

2) Mixed dentition period (initiation of first molar intercuspation: exfoliation of the second deciduous molar)

During the mixed dentition period, the maxillary edge-tip-cusp tip curve showed a concave pattern with the distobuccal cusp of the second molar at the most concave site on both the left and right sides at the initiation of first molar intercuspation in the crowded as well as the normal dentition groups. However, at the exfoliation of the second deciduous molar, the position of the buccal cusp of the first premolar was inferior to the reference line, but the position of the canine tip was superior to the reference line compared with the normal dentition group. Therefore, the curve showed a convex pattern with the canine tip at the most convex site. Differences in the mean changes in the edge-tip-cusp tip curve between the normal and crowded dentition groups in the mixed dentition period may be partly because the degree of eruption of the canine or first premolar markedly differed among individuals in this period, and eruption of the canine tends to be delayed in crowded dentition.

The mandibular edge-tip-cusp tip curve in the crowded as well as normal dentition groups showed a concave pattern, with the distal cusp of the first molar at the most concave site on both the left and right sides at the initiation of first molar intercuspation, and a concave pattern with the mesiobuccal cusp of the first molar at the most concave site at the time of exfoliation of the second deciduous molar. The curve tended to be slightly flattened in the normal dentition group but negligibly changed in the crowded dentition group. The reason for this difference may be similar to that for the maxilla, and

may not represent the dentition state.

3) Permanent dentition period (initiation of second molar intercuspation: stable permanent dentition period)

In the maxilla in the permanent dentition period, the edge-tip-cusp tip curve showed a concave pattern with the buccal cusp of the first premolar at the most concave site in the normal dentition group and a concave pattern with the buccal cusp of the second premolar at the most concave site in the crowded dentition group on both the left and right sides at both observation time points. In the mandible in the permanent dentition period, this curve showed a concave pattern with the distal cusp of the first molar at the most concave site on both the left and right sides at both observation time points in the crowded as well as normal dentition groups. There were negligible changes in the curvature in the maxilla or mandible in this period in the crowded and normal dentition groups; therefore, both maxillary and mandibular edge-tip-cusp tip curves showed similar changes, excluding those in the maxillary dentition immediately before exfoliation of the second deciduous molar between normal and crowded dentition.

The anteroposterior positions of most measurement sites showed anterior movement from the deciduous to permanent dentition period in the crowded and normal dentition groups.

Changes in each subject

Jarabak⁴⁾ described the curve of Spee as being shallow in normal occlusion, but increased with a rise in horizontal or vertical overlaps, suggesting an association between malocclusion and curvature. All serial dentition casts in the 44 subjects involved in this study showed normal deciduous dentition at the completion of deciduous dentition, but showed normal dentition in 25 subjects and crowding in the other 19 in the stable permanent dentition period. Therefore, at the completion of deciduous dentition, maxillary and mandibular dental arches in all subjects were classified according to the curvature of the edge-tip-cusp tip into those with gentle, average, and sharp curvatures. Changes in the curvature from this time point to the stable permanent dentition period are shown in Table 6. In addition, the association between changes in the curvature and the dentition state in the stable permanent dentition period was surveyed.

As a result, as shown in Table 7, of 22 dental arches with a sharp curvature at the completion

Table 9 Results of testing differences in the amount of change between the normal and crowded dentition groups (Welch's *t*-test)

< Deciduous dentition >										(mm)			
Occlusal state			Cases	A	B	C	Db	E					
								Emb	Edb				
Maxilla	Left	Normal	25	0.56	0.51	0.54	0.30	−0.08	−0.25				
		Crowding	19	0.18	0.16	0.27	−0.12	−0.32	−0.50				
		Significant difference						**					
	Right	Normal	25	0.55	0.55	0.59	0.27	−0.04	−0.30				
		Crowding	19	0.15	0.24	0.28	−0.02	−0.28	−0.48				
		Significant difference						*					
Occlusal state			Cases	A	B	C	D		E				
							Dmb	Ddb	Emb	Edb	Ed		
Mandible	Left	Normal	25	−0.01	−0.02	0.06	−0.01	−0.02	0.14	0.43	0.55		
		Crowding	19	0.39	0.34	0.33	0.24	0.19	0.23	0.43	0.52		
		Significant difference			*	*							
	Right	Normal	25	−0.08	−0.08	−0.04	−0.03	−0.08	0.03	0.29	0.45		
		Crowding	19	0.40	0.38	0.38	0.17	0.36	0.29	0.48	0.51		
		Significant difference			*	**	**		**				
< Permanent dentition >										(mm)			
Occlusal state			Cases	1	2	3	4b	5b	6		7		
									6mb	6db	7mb	7db	
Maxilla	Left	Normal	25	−1.19	−1.03	−0.79	−0.77	−0.84	−0.73	−0.90	−1.84	−2.34	
		Crowding	19	−0.91	−0.80	−0.97	−0.80	−0.78	−0.81	−1.05	−2.09	−2.60	
		Significant difference											
	Right	Normal	25	−1.22	−1.00	−0.79	−0.67	−0.67	−0.63	−0.80	−1.83	−2.26	
		Crowding	19	−0.96	−0.80	−0.77	−0.61	−0.71	−0.55	−0.88	−2.24	−2.68	
		Significant difference											
Occlusal state			Cases	1	2	3	4b	5b	6		7		
									6mb	6db	6d	7mb	7d
Mandible	Left	Normal	25	1.44	1.21	1.06	0.85	0.63	0.71	0.76	0.75	1.27	1.50
		Crowding	19	1.04	1.04	0.83	0.84	0.73	1.07	1.10	1.03	1.44	1.99
		Significant difference											
	Right	Normal	25	1.28	1.13	0.88	0.64	0.43	0.44	0.49	0.44	1.16	1.38
		Crowding	19	1.04	0.86	0.73	0.52	0.55	0.68	0.77	0.62	1.48	1.75
		Significant difference											

*: $P < 0.05$, **: $P < 0.01$

of deciduous dentition, only 1 exhibited a change to a gentle curvature and normal dentition in the stable permanent dentition period. Conversely, both arches with a gentle curvature at the completion of deciduous dentition exhibiting a change to a sharp curvature in the stable permanent dentition period showed crowding. Of 17 arches exhibiting a change from an average to gentle curvature, 12 (70.6%) showed normal dentition. An arch exhibiting a change from a sharp to gentle curvature showed normal dentition. In addition, of 17 arches exhibiting a change from a sharp to average curvature, 11 (64.7%) showed normal dentition. These results

suggested that arches exhibiting decreased curvature from the completion of deciduous dentition to the stable permanent dentition period often showed normal dentition.

Differences between the normal and crowded dentition

Kishi *et al.*⁵⁾ and Hoshiai *et al.*⁶⁾ performed a survey to determine whether the curvature of Spee can be applied to screening for malocclusion based on the Treatment Priority Index (TPI) as a classification of the degree of malocclusion proposed by Grainger *et al.*⁷⁾ They described that the curvature of Spee

Table 10 Discriminant coefficients

Variable: x_i	Discriminant coefficient: a_i	Standardized discriminant coefficient: a_i'
x_1 : Maxillary left Db	1.2588	1.3516
x_2 : Mandibular right B	-0.9483	-1.2018
x_3 : Mandibular right C	0.0612	0.0670
x_4 : Mandibular right Ddb	-0.7749	-0.8835
Constant: a_0	0.1233	0

allowed distinction between any two of mild, moderate, severe, and super-severe groups as the criteria for TPI evaluation.

Therefore, we performed a survey to determine whether there are differences in the curvature of the edge-tip-cusp tip and changes in this curve with the growth of dentition between normal and crowded dentition groups. Differences in the superoinferior position of each measurement site between the two groups were analyzed by Welch's *t*-test. As a result, as shown in Table 8, significant differences were observed at only 3 of all measurement sites at the 6 observation points. Thus, there was no marked difference between the two groups.

Therefore, we re-observed the consecutive curve of the incisal edge, tip and cusp tip in both groups in detail, and noted the level of change in the superoinferior position of each measurement site from the deciduous to permanent dentition period. Using the mean values in each group, measurement values immediately before transition to mixed dentition were subtracted from those at the completion of deciduous dentition to calculate the extent of change at each measurement site in the deciduous dentition period. Similarly, measurement values in the stable permanent dentition period were subtracted from those at the initiation of second molar intercuspation to calculate the amount of change at each measurement site in the permanent dentition period. Subsequently, using the obtained values, differences in the mean extent of change among measurement sites were analyzed using Welch's *t*-test.

As a result, as shown in Table 9, in the deciduous dentition period, for the maxilla, the extent of change at the buccal cusps of the left ($P<0.01$) and right ($P<0.05$) first premolars was significantly greater in the normal dentition group. In the mandible, the extent of change at the incisal edge of the bilateral deciduous central incisors and the incisal edge of

Table 11 Correct discrimination rate

		cases (%)	
	Cases	Discrimination results	
		G_1	G_2
G_1 : Normal dentition	25	20 (80.0)	5 (20.0)
G_2 : Crowded dentition	19	5 (26.3)	14 (73.7)
Total	44	34 (77.3)	

the left deciduous lateral incisor ($P<0.05$ for each), and the incisal edge of the right deciduous lateral incisor and canine tip and the distobuccal cusp of the right deciduous first molar ($P<0.01$ for each) was significantly greater in the crowded denture group. During the permanent dentition period, the extent of change at each measurement site did not significantly differ between the two groups.

Thus, in the maxilla, the mean change in the molar area was significantly greater in the normal than in the crowded dentition group. In the mandible, the mean change in the anterior tooth area was significantly greater in the crowded dentition group. Although there were few differences in the superoinferior positions of the measurement sites between the two groups, significant differences were observed in the extent of change at 8 measurement sites between the two groups. Of 4 sites showing markedly significant differences ($P<0.01$), 3 were located on the right side. The reason for this finding could not be clarified in this study, but may involve differences in the amount of attrition due to the so-called "dominant chewing side" and habitual chewing side. To clarify this reason, further studies are necessary.

To determine whether changes at the measurement sites showing significant differences are appropriate factors allowing discrimination between

Table 12 Results of the evaluation of changes in each subject using the discriminant function

Changes according to curvature Completion of the deciduous dentition → Stable permanent dentition period				cases (%)	
		Denture state	Cases	Correct discrimination	Incorrect discrimination
Gentle curvature	→	Normal	3	2 (66.7)	1 (33.3)
		Crowding	4	3 (75.0)	1 (25.0)
		Normal	9	9 (100)	0 (0)
		Crowding	3	3 (100)	0 (0)
		Normal	0		
		Crowding	2	2 (100)	0 (0)
Average curvature	→	Normal	9	6 (66.7)	3 (33.3)
		Crowding	4	3 (75.0)	1 (25.0)
		Normal	20	16 (80.0)	4 (20.0)
		Crowding	16	12 (75.0)	4 (25.0)
		Normal	7	5 (71.4)	2 (28.6)
		Crowding	7	5 (71.4)	2 (28.6)
Sharp curvature	→	Normal	1	1 (100)	0 (0)
		Crowding	0		
		Normal	8	7 (87.5)	1 (12.5)
		Crowding	6	4 (66.7)	2 (33.3)
		Normal	2	1 (50.0)	1 (50.0)
		Crowding	1	0 (0)	1 (100)

normal and crowded dentition, discriminant analysis was performed for multivariate analysis. Normal and crowded dentition were used as criterion variables, and 4 items (buccal cusp of the maxillary left deciduous first molar, incisal edge of the mandibular right deciduous lateral incisor, tip of the mandibular right deciduous canine, and distobuccal cusp of the mandibular right first molar) showing significant differences ($P < 0.01$) by Welch's t -test were used as explanatory variables. The results are shown in Tables 10 and 11.

As shown in Table 10, the absolute value of the standardized discriminant coefficient calculated from the discriminant coefficient of each variable, i.e., the degree of discrimination between normal and crowded dentition, was highest for the buccal cusp of the maxillary left first deciduous molar, followed in order by the incisal edge of the mandibular right deciduous incisor, distobuccal cusp of the mandibular right first deciduous molar, and the tip of the mandibular right deciduous canine. In discriminant analysis, when there was a marked correlation between explanatory variables, its influence on coefficients was considered and the correlation coefficient was evaluated between variables. Even for variables showing the highest correlation, the correlation coefficient was only 0.00083. Thus, no

marked correlation was observed between any two variables, and the coefficients shown in Table 10 could be interpreted directly.

Table 11 shows the results of discrimination between normal and crowded dentition by the discriminant function obtained using the 4 above-described factors. The discriminant function was: $Z = 0.1233 + 1.2588X_1 - 0.9483X_2 + 0.0612X_3 - 0.7749X_4$. Variables X_1 , X_2 , X_3 , and X_4 represents the amount of change in the buccal cusp of the maxillary left first deciduous molar, mandibular right deciduous lateral incisor, mandibular right deciduous canine, and the distobuccal cusp of the mandibular right first deciduous molar, respectively. $Z > 0$ indicates normal dentition (G_1) while $Z < 0$ indicates crowding (G_2). As shown in Table 11, the discrimination was correct in 20 (80.0%) of the 25 subjects with normal dentition and incorrect in the other 5 (20.0%), and correct in 14 (73.7%) of the 19 subjects with crowding and incorrect in the other 5 (26.3%). Of all 44 subjects, 34 (77.3%) were correctly discriminated, showing a high discrimination rate. Therefore, the discrimination of dentition in the future between normal and crowding is possible with a probability of 77.3% by substituting the extent of change in the buccal cusp of the maxillary left first deciduous molar, incisal edge of the mandibular

right deciduous incisor, tip of the mandibular right deciduous canine, and the distobuccal cusp of the mandibular right first deciduous molar from the completion of deciduous dentition to immediately before transition to mixed dentition into the above discriminant function.

Therefore, the dentition state in the stable permanent dentition period was evaluated according to changes in the curvature of the edge-tip-cusp tip from the completion of deciduous dentition to the stable permanent dentition period. Since dental arches were totaled separately on the left and right sides in Tables 7 and 8, subjects showing the same changes between the left and right sides were extracted and analyzed. As presented in Table 12, in the group showing a sharp curvature at both time points, the correct discrimination rate was 50% in 2 subjects showing normal dentition, and the other 1 showing crowding was incorrectly classified; however, in the other subjects, the dentition state was consistent with the results of discriminant analysis, with a probability $\geq 66.7\%$. Therefore, the curvature at the completion of deciduous dentition and its subsequent change can be indicators of the dentition state in the stable permanent dentition period.

Acknowledgments

We express our sincere gratitude to Emeritus Professor Yukio Machida, the former Director of the Department of Pediatric Dentistry of our college, for his valuable instructions and proofreading, the members of this department for their help and cooperation, and Professor Ryuzo Kanno, Director of the Mathematics Laboratory of this college, for his instructions for statistical processing.

References

- 1) Spee, F.G.: Die Verschiebungsbahn des Unterkiefers am Schädel. *Arch F Anat U Physiol*, 1890, pp. 285–294.
- 2) Shanahan, T.E.J.: The individual occlusal curvature and occlusion. *J Prosth Dent* **8**: 230–240, 1958.
- 3) Strang, R.H.W. and Thompson, W.M.: A Textbook of Orthodontia. 4th ed. Lea & Febiger, Philadelphia, 1958, pp. 28–29.
- 4) Jarabak, J.R. and Fizzel, J.A.: Technique and Treatment with the Lightwire Appliance. Mosby, St. Louis, 1963, pp. 176–177.
- 5) Kishi, S., Kadowaki, K., Chin, M., Koyata, H., Koyanagi, I., Yamamoto, M., Asada, K. and Niwa, M.: Dental cast evaluation as a screening tool for malocclusion survey—According to TPI severity estimate—. *Shigaku* **80**: 1368–1374, 1993. (in Japanese)
- 6) Hoshiai, M., Kishi, S. and Niwa, M.: Evaluation of Treatment Priority Index using multivariate approach. *Shigaku* **82**: 77–91, 1994. (in Japanese)
- 7) Grainger, R.M.: The Orthodontic Treatment Priority Index. US Government Printing Office, Washington, D.C., 1967, pp. 1–42.
- 8) Steadman, S.R.: Six different kinds of overbites. *JADA* **27**: 1060–1071, 1940.
- 9) Baldridge, D.W.: Levering the curve of Spee: Its effect on mandibular arch length. *J Pract Orthod* **3**: 26–41, 1969.
- 10) Baydas, B., Yavuz, I., Atasaral, N., Ceylan, I. and Dağsuyu, I.M.: Investigation of the changes in the positions of upper and lower incisors, overjet, overbite, and irregularity index in subjects with different depths of curve of Spee. *Angle Orthod* **74**: 349–355, 2004.
- 11) Iwasawa, T. and Namura, S.: The curve of Spee and occlusal plane in the persons with normal occlusion. *Orthod Waves* **23**: 13–21, 1964. (in Japanese)
- 12) Ferrario, V.F., Sforza, C. and Miani, A. Jr.: Statistical evaluation monson's sphere in healthy permanent dentitions in man. *Archs Oral Biol* **42**: 365–369, 1997.
- 13) Kobayashi, M., Arai, K. and Ishikawa, H.: A three-dimensional analysis of the curve of Spee in Japanese normal occlusions. *Orthod Waves* **57**: 258–267, 1998. (in Japanese)
- 14) Ferrario, V.F., Sforza, C., Poggio, C.E., Serrao, G. and Colombo, A.: Three-dimensional dental arch curvature in human adolescents and adults. *Am J Orthod Dentofacial Orthop* **115**: 401–405, 1999.
- 15) Sengupta, A., Whittaker, D.K., Barber, G., Rogers, J. and Musgrave, J.H.: The effect of dental wear on third molar eruption and on the curve of Spee in human archaeological dentitions. *Archs Oral Biol* **44**: 925–934, 1999.
- 16) Xu, H., Suzuki, T., Muronoi, M. and Ooya, K.: An evaluation of the curve of Spee in the maxilla and mandible of human permanent healthy dentitions. *J Prosthet Dent* **92**: 536–539, 2004.
- 17) Dager, M.M., McNamara, J.A., Baccetti, T. and Franchi, L.: Aging in the craniofacial complex. *Angle Orthod* **78**: 440–444, 2008.
- 18) De Praeter, J., Dermaut, L., Martens, G. and Kuijpers-Jagtman, A.M.: Long-term stability of the leveling of the curve of Spee. *Am J Orthod Dentofacial Orthop* **121**: 266–272, 2002.
- 19) Shannon, K.R. and Nanda, R.S.: Changes in the curve of Spee with treatment and at 2 years posttreatment. *Am J Orthod Dentofacial Orthop* **125**: 589–596, 2004.
- 20) Lie, F., Kuitert, R. and Zentner, A.: Post-treatment development of curve of Spee. *Eur J Orthod* **28**: 262–268, 2006.
- 21) Bernstein, R.L., Preston, C.B. and Lampasso, J.:

- Leveling the curve of Spee with a continuous archwire technique: a long term cephalometric study. *Am J Orthod Dentofacial Orthop* **131**: 363–371, 2007.
- 22) Preston, C.B., Maggard, M.B., Lampasso, J. and Chalabi, O.: Long-term effectiveness of the continuous and the sectional archwire techniques in leveling the curve of Spee. *Am J Orthod Dentofacial Orthop* **133**: 550–555, 2008.
 - 23) Nozaka, K., Kaneko, S., Kanako, Y., Okawa, S. and Sasaki, M.: Morphological relationship between the occlusal plane and edge cusp ridge in deciduous mixed and permanent dentition. (Especially about the maxillary teeth) *Jpn J Ped Dent* **14**: 76–82, 1976. (in Japanese)
 - 24) Baume, L.J.: Physiological tooth migration and its significance for the development of occlusion I. The biogenetic course of the deciduous dentition. *J Dent Res* **29**: 123–132, 1950.
 - 25) Kirihaara, S., Yakushiji, M. and Machida, Y.: Longitudinal observation of change in consecutive curve of incisal edges tip and cusp tips in deciduous dentition. *Shikwa Gakuho* **98**: 235–266, 1998. (in Japanese)
 - 26) Marshall, S.D., Caspersen, M., Hardinger, R.R., Franciscus, R.G., Aquilino, S.A. and Southard, T.E.: Development of curve of Spee. *Am J Orthod Dentofacial Orthop* **134**: 344–352, 2008.
 - 27) Yoshida, H.: Growth and development of the dental arch, alveolar ridge and palate and mutual relationships among the three. With special emphasis on the lateral segment during the period of deciduous dentition. *Shikwa Gakuho* **76**: 879–945, 1976. (in Japanese)
 - 28) Kubodera, T., Sekiguchi, H. and Machida, Y.: Establishment of a reference plane for deciduous dentition, mixed dentition and permanent dentition. *Shikwa Gakuho* **85**: 1695–1701, 1985. (in Japanese)
 - 29) Sassouni, V.: Orthodontics in Dental Practice. Mosby, St. Louis, 1971, p. 34.
 - 30) Sim, J.M.: Miner Tooth Movement in Children. Mosby, St. Louis, 1972, p. 17.