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Palate and alveolar ridge development in predental infants: a longitudinal study

ABSTRACT

Aim *To investigate the developmental process of palate morphology, including the alveolar ridge, in healthy infants for the predental period of 7 months from immediately after birth.*
Methods *The subjects were 32 healthy infants. Four or more dental casts were taken of each subject from immediately after birth until 7 months, for a total of 144 dental casts. Twelve characteristics were then measured in order to morphologically study the subjects' palate development. Principal component analysis (PCA) was performed to investigate morphological changes in the palatal vault.*
Results *The 12 characteristics were classified into either the alveolar ridge characteristics group, which determined the size of the alveolar ridge, or the palate characteristics group, which determined palate morphology, with each group showing different growth patterns. The characteristics of width and length increased with age in the alveolar ridge characteristics group; this correlation was maintained throughout the predental period. Meanwhile, in the palate characteristics group, the characteristics showed major developmental changes in the first 2 to 3 months after birth, but the changes were subsequently fewer from 3 to 7 months. The PCA of the palatal vault showed that the first principal component increased until 3 months but subsequently ceased to change.*
Conclusions *In predental infants, growth patterns of palate morphology differed according to their characteristics. There were major developmental changes in the palate during the first 3 months after birth. The study findings suggest that palate growth in the first half of the predental period may affect subsequent palate growth.*

Keywords *Alveolar ridge, Development, Growth, Newborn infant, Palate morphology, Predental period..*

Introduction

Palate development in infants is important because of its impact on milk feeding, food intake function, and occlusion of the primary dentition. However, there are not many studies on palate development in infants. To date, most published literature on the infant palate has involved children with cleft palate. These studies on palate morphology can be attributed to the fact that a dental impression of children with cleft palate is taken soon after birth to fabricate a Hotz plate, etc. [Grayson et al., 1993; Mishima et al., 1996; Ahmed et al., 2012]. Many studies have also addressed subsequent morphological changes, but most of the subjects were beyond infancy [Bugaighis et al., 2010; Kozelj et al., 2012; Ruskova et al., 2013]. However, these studies are not helpful when investigating development of the healthy palate.

To date, many studies on alveolar and other regions of the infant palate have focused on young subjects, but from the primary dentition stage [Moorrees, 1959; Tsai and Tan, 2004; Ovsenik et al., 2007; Ciusa et al., 2007; Thilander, 2009; Yang et al., 2013; Lione et al., 2014], and very little research begins in the predental stage [Sillman, 1951; Sillman, 1964; Bishara, 1997]. These are long-term longitudinal studies that followed subjects from the neonatal period to adulthood, but the observation period was extensive, and the number of subjects was small. Hence, no longitudinal studies have assessed a statistically adequate population of infants from immediately after birth for a brief observation period.

In a longitudinal study of children aged 3 to 12 years, Ovsenik et al. [2007] reported that moderate to severe morphological malocclusion severity scores were already present in 50% of the 3 year olds. Meanwhile, Jaunet et al. [2013] argued that malocclusion-inducing asymmetry occurs before the primary teeth erupt. In research using the bone formation marker serum bone alkaline phosphatase, growth during the prenatal and infancy periods was reportedly more pronounced

than in subsequent stages [Tobiume et al., 1997; Rauchenzauner et al., 2007]. Thus, it is possible that the course of palate development is similarly determined early on.

Ishida et al. [2013] examined in detail the changes in palate morphology from immediately after birth until 1 month and found that not only size but also shape changed over this one-month period after birth. The aim of the present study was to investigate the developmental process of palate morphology, including the alveolar ridge, in healthy infants for the predental period of 7 months from immediately after birth.

Subjects and methods

A total of 144 dental casts were made from impressions of 32 healthy, full-term Japanese infants, 23 males and 9 females (mean weight, 3143 g, males 3174 g, females 3064 g; weight range at birth, 2500–3999 g). The impressions were taken within 7 days after birth (mean age, 3.4 days). One month later, at least four additional monthly impressions were taken until 7 months (M) of age. Heavy body-type silicon impression materials were used. Dental plaster models were subsequently created from the impressions. Special care was taken when taking impressions of the newborns at 0 M [Ishida et al., 2013]. The impressions were taken in 2011–2012.

The 3D measurement of palate morphology was conducted with a laser oscillator (LK-080, Keyence Corporation, Osaka, Japan) and a stage controller (CP-500, COMS Co., Ltd., Amagasaki, Japan), and E-Measure software (COMS Co., Ltd.). The scanning range was 40,000 µm in the X-axis (sagittal plane) and 50,100 µm in the Y-axis (frontal plane). Measurement pitch was set at 200 µm for the X-axis and 300 µm for the Y-axis. The X, Y, and Z coordinates at each measurement point were saved as a text file on a personal computer. The same person (the first author) conducted all of the 3D measurements. Image analysis and statistical analysis of 3D data were conducted using dental cast analysis Dentist 5 software (developed by Yasuo Ukai, unreleased), which was developed independently by the collaborator in this study. The same software is available and was used in our previous study [Ishida et al., 2013].

Measurement points (Fig. 1)

Prior to automated scanning of the cast shape, X, Y, and Z coordinates were determined for the following 5 measurement points, which were selected by the lead author (Fig. 1a).

- M1: the most prominent part of the alveolar crest in the central incisor segments.
- R1: cross point of the right lateral sulcus and the alveolar crest.

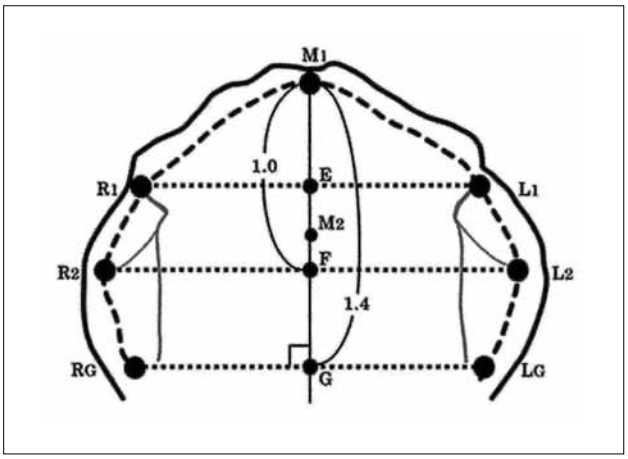


FIG. 1 **a** Definitions of the marker points. M1: The most prominent part of the alveolar crest in the incisive papilla. R1: Cross point of the right lateral sulcus and alveolar crest. L1: Cross point of the left lateral sulcus and alveolar crest. R2: Right point on the alveolar crest where the distal part of the first deciduous molar erupts. L2: Left point on the alveolar crest where the distal part of the first deciduous molar erupts. M2: A point on the clinical median line (midline), positioned at an arbitrary distance between the lines R1-L1 and R2-L2. E: Cross point of the midline and the line R1–L1. F: Cross point of the midline and the line R2–L2. G: The point on the midline at a distance from M1 equal to 1.4 times the length of the segment M1–F.

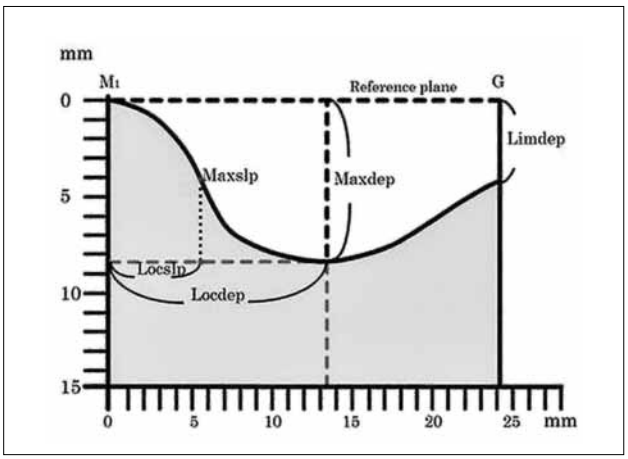


FIG. 1 **b** Sagittal section of palate on the midline. Maxdep: Maximum depth. Locdep: Location of the maximum depth point. Maxslp: Maximum slope. Locslp: Location of the maximum slope point. Limdep: Depth from the reference plane at point G.

- L1: cross point of the left lateral sulcus and the alveolar crest.
- R2: Right point on the alveolar crest where the distal part of the first deciduous molar erupts.
- L2: Left point on the alveolar crest where the distal part of the first deciduous molar erupts.

The following 4 points were defined by computer (Fig.1a).

- M2: A point on the clinical median line (midline), positioned at an arbitrary distance between the lines R1-L1 and R2-L2. The M2 was created in order to draw a straight midline from M1.
- E: Cross point of the midline and the line R1–L1.
- F: Cross point of the midline and the line R2–L2.
- G: The point on the midline at a distance from M1 equal to 1.4 times the length of the segment M1–F.

These points were created to determine the measurement extremities.

- RG, LG: The points where the following intersect: the alveolar crest and the line passing through point G and perpendicular to the midline. R1-L1, R2-L2, and RG-LG are not necessarily parallel to each other. The plane formed by the 3 points M1, R1, and L1, was made the reference plane.

The 12 characteristics were as follows.

Alveolar ridge characteristics group (Fig. 1a).

- Anterior width: Distance from point R1 to L1 (mm).
- Anterior length: Length of the perpendicular line descending from point M1 to line segment R1L1 (mm).
- Canine ratio: Anterior width/Anterior length.
- Posterior width: Distance from point R2 to L2 (mm).
- Posterior length: Distance from point E to F (mm).
- Total length: Anterior length + Posterior length, or the distance from point M1 to F (mm).

Palate characteristics group (Fig. 1b):

- Maximum depth: The maximum depth on the midline (mm).
- Location of the maximum depth point: Location of the point of maximum depth that is measured from M1 (mm).
- Maximum slope: Maximum increase (mm) of the depth per pitch (200 μm) along the midline in the range from M1 to the point of maximum depth.
- Location of the maximum slope point: Location of the midpoint of the slope exhibiting the maximum slope on the midline that is measured from M1 (mm).
- Volume: The portion on the inside of the alveolar ridge with a depth ≥ 2 mm, and volume of the portion forward of the line segment RG-LG (mm^3).
- Volume area: The measured area of the volume constituting the surface area of the plane parallel to the reference plane for the above volume portion (mm^2).

Anterior width, Anterior length, Canine ratio, Posterior width, Posterior length, and Total length comprise the alveolar ridge characteristics group, and Maximum depth, Location of the maximum depth point, Maximum slope, Location of the maximum slope point, Volume, and Volume area comprise the palate characteristics group.

The variables used in Principal Component Analysis were as follows (Fig. 1b).

- Variable 1: Maximum depth (mm).
- Variable 2: Location of the maximum depth point (mm).
- Variable 3: Maximum slope (mm).
- Variable 4: Location of the maximum slope point (mm).
- Variable 5: Depth from the reference plane at point G (mm).

Statistical analysis

3D measurements were carried out with 2 replications on a set of 20 models randomly chosen from the models used in the present experiment. The 12 characteristics were calculated for each model and replication. Analysis of variance based on a randomised complete block design with 2 replications of a single-factor experiment was done. For each characteristic, error variance was estimated from the error sum of squares, and coefficients of variation (C.V. in %) of experimental error were estimated (Table 1). Dentist 5 software was used for the statistical analysis. The significance of differences in means between different months was investigated by the t-test. The correlations between months for the 12 characteristics and the correlations between characteristics at 0 and 7 months were calculated. Analysis of variance based on a completely randomised design of a single factor experiment was applied to the values of the 12 characteristics, and the total sum of squares (SS) of each characteristic was partitioned into SS due to months (factor) and SS due to individuals (error).

		Sqr (Error Var.)	Grand mean	CV(%)
1	AW	0.239	28.18	0.85
2	AL	0.277	7.49	3.70
3	CR	0.162	3.82	4.26
4	PW	2.396	34.43	6.96
5	PL	0.396	9.06	4.36
6	TL	0.430	16.67	2.59
7	Maxdep	0.421	9.06	4.64
8	Locdep	0.738	16.67	4.43
9	Maxslp	0.049	284.68	17.37
10	Locslp	0.869	8.23	10.56
11	Vol	3.637	58.58	9.41
12	Varea	31.836	380.45	8.37

AW: Anterior width AL: Anterior length
CR: Canine ratio (AW/AL) PW: Posterior width
PL: Posterior length TL: Total length Maxdep: Maximum depth
Locdep: Location of the maximum depth point
Maxslp: Maximum slope
Locslp: Location of the maximum slope point
Vol: Volume V area: Volume area

TABLE 1 Estimation of CV for measurement error for the 12 characteristics.

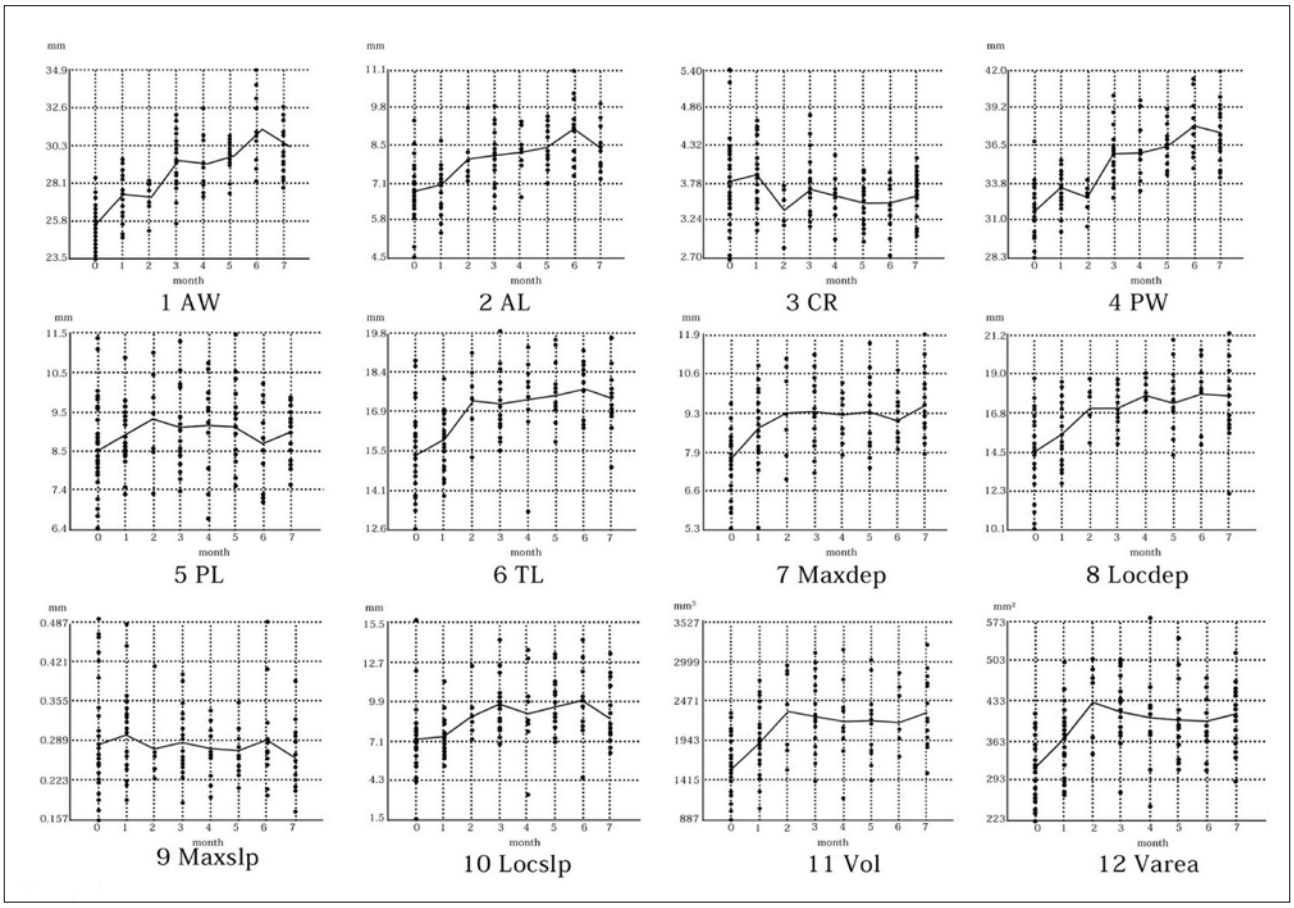


FIG. 2 Age (months)-based changes and mean values of the 12 characteristics. The points in the figure indicate the individuals who were measured. The broken line shows individual means. AW: Anterior width AL: Anterior length CR: Canine ratio (AW/AL) PW: Posterior width PL: Posterior length TL: Total length Maxdep: Maximum depth Locdep: Location of the maximum depth point Maxslp: Maximum slope Locslp: Location of the maximum slope point Vol: Volume Varea: Volume area

Principal component analysis was performed using Dentist 5 based on the aforementioned five variables.

Ethical considerations

This study was conducted with the approval of the Ethics Committee of the Nihon University School of Dentistry at Matsudo (Approval code: EC12-007). Informed consent was obtained from each of the subjects' parents before taking impressions.

Results

Measurement error

The standard deviations of the estimated error distribution and the C.V.s of the 12 characteristics are shown in Table 1. The magnitude of the C.V. differed among the characteristics, ranging from 0.85% for Anterior width to 17.37% for Maximum slope.

Changes in the 12 characteristics with age in months (Fig. 2)

In the alveolar ridge characteristics group, mean Anterior width and Posterior width both increased with age throughout the entire predental period. Anterior length also increased throughout the predental period, but the increase was moderate compared to Anterior width and Posterior width. Posterior length increased up to 2 M, but it subsequently tended to decrease slightly. Canine ratio tended to decrease with age after 1 M. Meanwhile, in the palate characteristics group, Maximum depth, Volume, and Volume area increased to 2 months, Location of the maximum slope point increased to 3 months, and Location of the maximum depth point increased to 4 months, but subsequent changes were limited. Maximum slope exhibited almost no changes with age.

Significance of changes of mean values for the 12 characteristics by age in months (Table 2)

The mean values of the 12 characteristics were compared for 0 and 1 M, 1 and 3 M, and 3 and 7 M. Changes from 0 to 1 M were significant for 5 characteristics (Anterior width, Posterior width, Maximum depth, Volume, and Volume area) ($p <$

		Mean				t-value		
Characteristic (unit)		0M N=32	1M N=25	3M N=20	7M N=19	0M vs 1M	1M vs 3M	3M vs 7M
1	AW (mm)	25.42	27.27	29.24	30.04	5.76**	4.44**	1.50
2	AL(mm)	6.84	7.01	8.07	8.37	0.66	3.84**	1.09
3	CR(-)	3.80	3.94	3.67	3.61	0.96	2.01	0.47
4	PW (mm)	31.66	33.45	35.94	37.54	4.12**	5.04**	2.47*
5	PL (mm)	8.50	8.90	9.11	9.00	1.43	0.80	0.39
6	TL (mm)	15.34	15.91	17.19	17.37	1.61	3.79**	0.54
7	Maxdep (mm)	7.67	8.72	9.31	9.53	3.46**	1.71	0.63
8	Locdep (mm)	14.52	15.52	17.01	17.78	1.93	3.45**	1.41
9	Maxslp (mm)	0.284	0.299	0.285	0.259	0.67	0.68	1.55
10	Locslp (mm)	7.12	7.32	9.68	8.64	0.38	4.88**	1.69
11	Vol (mm^3)	1545.06	1903.44	2259.95	2318.11	3.32**	2.65*	0.40
12	Varea (mm^2)	313.50	363.12	411.80	408.63	3.34**	2.86**	0.18

AW: Anterior width AL: Anterior length CR: Canine ratio (AW/AL) PW: Posterior width PL: Posterior length
TL: Total length Maxdep: Maximum depth Locdep: Location of the maximum depth point
Maxslp: Maximum slope Locslp: Location of the maximum slope point Vol: Volume V area: Volume area

TABLE 2 Changes in the means of the 12 characteristics and the unpaired t-test values for the differences.

0.01). The differences of the mean values at 1 and 3 M were significant for 7 characteristics at the 1% level (Anterior width, Anterior length Posterior width, Total length, Location of the maximum depth point, Location of the maximum slope point, Volume area) and for 1 characteristic (Volume) at the 5% level. Differences between 3 and 7 M were only significant for Posterior width at the 5% level.

		0M vs 1M	1M vs 3M	3M vs 7M	0M vs 7M
	df	23	13	8	17
1	AW	0.50*	0.53*	0.89**	0.65**
2	AL	0.37	0.85**	0.73*	0.14
3	CR	0.20	0.76**	0.83*	0.08
4	PW	0.55**	0.49	0.95**	0.35
5	PL	0.38	0.33	0.62	0.42
6	TL	0.60**	0.46	0.71*	0.49*
7	Maxdep	0.61**	0.30	0.39	0.09
8	Locdep	0.33	0.43	-0.11	-0.03
9	Maxslp	0.43*	-0.06	0.43	0.01
10	Locslp	0.13	-0.11	0.04	-0.05
11	Vol	0.73**	0.51	0.31	0.56*
12	Varea	0.75**	0.52*	0.32	0.77**

AW: Anterior width AL: Anterior length
CR: Canine ratio (AW/AL) PW: Posterior width
PL: Posterior length TL: Total length Maxdep: Maximum depth
Locdep: Location of the maximum depth point
Maxslp: Maximum slope
Locslp: Location of the maximum slope point
Vol: Volume V area: Volume area

TABLE 3 Correlations between age in months and the 12 characteristics.

Correlations between ages in months (Table 3)

Significant correlations were seen in the alveolar ridge characteristics group for 3 characteristics between 0 and 1 M (Anterior width, Posterior width, Total length), 3 characteristics between 1 and 3 M (Anterior width, Anterior length, Canine ratio), and 5 characteristics between 3 and 7 M (Anterior width, Anterior length, Canine ratio, Posterior width, and Total length). The characteristics that showed significant correlations were not necessarily the same with age.

In the palate characteristics group, 4 characteristics showed significant correlations between 0 and 1 M (Maximum depth, Maximum slope, Volume, Volume area), but only 1 characteristic (Volume area) was significantly correlated at 1 and 3 M, and none were significantly correlated between 3 and 7 M. Between the start and end of the observation period (0 M vs 7 M), 4 characteristics were significantly correlated (Anterior width, Total Length, Volume, Volume area). There were no significant correlations for Posterior length, Location of the maximum depth point, and Location of the maximum slope point between any months of age.

Division of SS by age in months for each subject (Table 4)

Statistical analysis of each of the 12 characteristics was performed for each subject from 0 to 7 M using a single factor experiment design via a randomised complete block design. Total SS in the analysis of variance (ANOVA) table was divided into SS due to age in months and SS due to subject differences, and its relative size was expressed as a percentage. The age (months)-based SS ratio differed considerably by

characteristic. The SS ratio attributed to age in months was large for Anterior width and Posterior width, at 63% and 62%, respectively. Conversely, it was small for Posterior length and Maximum slope, at 6% and 3%, respectively.

Correlations between characteristics at 0 M and 7 M (Table 5)

In the alveolar ridge characteristics group, there were significant correlations between 5 of 15 combinations of characteristics at 0 M (Anterior width vs Posterior width, Anterior length vs Canine ratio, Anterior length vs Total length, Canine ratio vs Total length, and Posterior length vs Total length). In these 5 combinations, correlations were also significant at 7 M. Between Anterior length and Posterior length, and Anterior width and Posterior width, there were absolutely no correlations at 0 or 7 M.

In the palate characteristics group, significant correlations were seen at 0 M for 7 combinations (Maximum depth vs Location of the maximum depth

Characteristics		Month (%)	Subject (%)
1	AW	63	37
2	AL	42	58
3	CR	13	87
4	PW	62	38
5	PL	6	94
6	TL	37	63
7	Maxdep	28	72
8	Locdep	36	64
9	Maxslp	3	97
10	Locslp	22	78
11	Vol	31	69
12	Varea	31	69

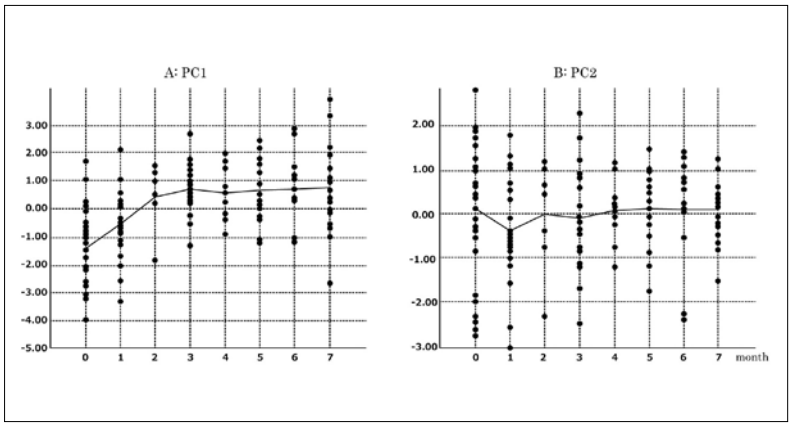
AW: Anterior width AL: Anterior length
CR: Canine ratio (AW/AL)
PW: Posterior width PL: Posterior length
TL: Total length Maxdep: Maximum depth
Locdep: Location of the maximum depth point Maxslp: Maximum slope
Locslp: Location of the maximum slope point Vol: Volume V area: Volume area

TABLE 4 Partition of the total sum of squares (SS) into SS due to month and SS due to subject.

0 M (df=30)												
Characteristics		2AL	3CR	4PW	5PL	6TL	7Maxdep	8Locdep	9Maxslp	10Locslp	11Vol	12Varea
1	AW	0.16	0.08	0.42*	0.18	0.26	0.02	-0.10	0.13	0.07	0.11	0.16
2	AL		-0.94**	-0.23	-0.16	0.59**	-0.10	0.46*	-0.30	0.53**	0.19	0.23
3	CR			0.30	0.26	-0.46**	0.15	-0.52**	0.36	-0.53**	-0.08	-0.12
4	PW				0.16	0.03	0.27	0.09	-0.02	-0.08	0.22	0.16
5	PL					0.70**	0.08	-0.02	0.06	-0.19	0.31	0.48**
6	TL						-0.01	0.31	-0.17	0.23	0.39*	0.56**
7	Maxdep							0.41*	0.14	-0.07	0.78**	0.62**
8	Locdep								-0.23	0.45*	0.45**	0.46**
9	Maxslp									-0.29	0.02	-0.10
10	Locslp										0.17	0.13
11	Vol											0.94**
7 M (df=17)												
1	AW	0.22	0.39	0.72**	0.16	0.28	0.24	0.38	-0.09	0.21	0.35	0.34
2	AL		-0.81**	0.16	-0.08	0.68**	-0.11	-0.08	-0.32	0.00	0.11	0.32
3	CR			0.27	0.18	-0.47*	0.23	0.31	0.28	0.11	0.09	-0.12
4	PW				0.25	0.31	0.57*	0.55*	-0.01	0.46*	0.54*	0.53*
5	PL					0.68**	0.05	0.07	-0.29	-0.22	0.28	0.41
6	TL						-0.04	-0.01	-0.45	-0.16	0.28	0.54*
7	Maxdep							0.58**	-0.06	0.76**	0.84**	0.62**
8	Locdep								-0.20	0.60**	0.40	0.18
9	Maxslp									0.09	-0.36	-0.42
10	Locslp										0.44	0.24
11	Vol											0.92**

AW: Anterior width AL: Anterior length CR: Canine ratio (AW/AL) PW: Posterior width PL: Posterior length TL: Total length
Maxdep: Maximum depth Locdep: Location of the maximum depth point Maxslp: Maximum slope
Locslp: Location of the maximum slope point Vol: Volume V area: Volume area

TABLE 5 Correlations between characteristics at 0 M and 7 M.



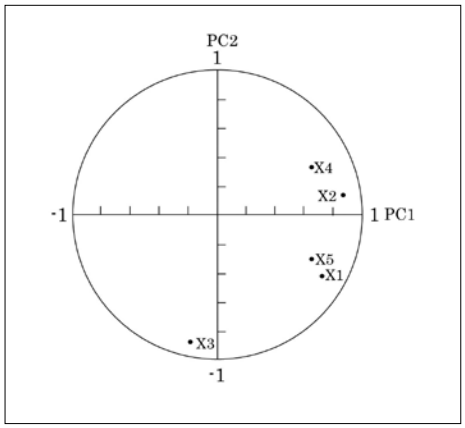


FIG. 3 Results of Principal Component Analysis of the 5 palatal vault variables.
FIG. 3A Principal component scores for different months of the measurement of models. The points in the figure indicate the individuals who were measured. The line shows the individual mean. A: Principal component (PC1), B: Principal component (PC2). Correlation between the 5 variables (X1, X2, X3, X4 and X5) and the first two principal components (PC1 and PC2).
FIG. 3B For instance, the PC1 coordinate of a variable near to the circumference shows that the variation of the variable is mostly explained by PC1, PC2 or PC1 and PC2 in the aggregate. X1: Maximum depth, X2: Location of the maximum depth point, X3: Maximum slope, X4: Location of the maximum slope point, X5: Depth from the reference plane at point G.

point, Maximum depth vs Volume, Maximum depth vs Volume area, Location of the maximum depth point vs Location of the maximum slope point, Location of the maximum depth point vs Volume, Location of the maximum depth point vs Volume area, Volume vs Volume area), and at 7 M for 6 combinations (Maximum depth vs Location of the maximum depth point, Maximum depth vs Location of the maximum slope point, Maximum depth vs Volume, Maximum depth vs Volume area, Location of the maximum depth point vs Location of the maximum slope point, Volume vs Volume area). The correlations of characteristics seen for Location of the maximum depth point vs Volume and Location of the maximum depth point vs Volume area at 0 M disappeared at 7 M. In the combination of Maximum depth vs Location of the maximum slope point, there was no correlation at 0 M, but a high correlation at 7 M.

Among the alveolar ridge and palate characteristics groups, there were 7 significantly correlated combinations of characteristics at 0 M (Anterior length vs Location of the maximum depth point, Anterior length vs Location of the maximum slope point, Canine ratio vs Location of the maximum depth point, Canine ratio vs Location of the maximum slope point, Posterior length vs Volume area, Total length vs Volume, Total length vs Volume area), and 6 significantly correlated combinations at 7 M (Posterior width vs Maximum depth, Posterior width vs Location of the maximum depth point, Posterior width vs Location of the maximum slope point, Posterior width vs Volume, Posterior width vs Volume area, Total length vs Volume area). Posterior width was not correlated with any other characteristic at 0 M, but it was correlated with all palate characteristics except Maximum slope at 7 M.

Results of Principal Component Analysis of the 5 palatal vault variables (Fig. 3)

The contributions (%) of Principal component -1(PC1), PC2, PC3, PC4, and PC5 were 44.6%, 23.6%, 14.2%, 11.8%, and 5.9%, respectively. The cumulative contribution up to PC2 reached 68.2%. Among the 5 variables, changes in Variables 1 (Maximum depth) and 2 (Location of the maximum depth point) were strongly correlated with PC1, and changes in Variable 3 (Maximum slope) were strongly correlated with PC2 (0.6-0.9, df = 142, $p < 0.01$). Growth patterns of the palatal vault along the midline could largely be explained by PC1 and PC2 of PCA. For PC1, age (months of age)-related changes of Variables 1(Maximum depth), 2 (Location of the maximum depth point), and 4 (Location of the maximum slope point) were specifically extracted. Inter-individual variance at 3 M was small compared to the other age (months) groups. The F-test of variance ratios revealed a significant difference in variance between 0 and 3 M and between 3 and 7 M at the 5% level.

Discussion

In the present study, growth patterns differed between the alveolar ridge and palate characteristics groups. Most of the alveolar ridge characteristics increased with age during the predental period, while most of the palate characteristics increased from birth to 3 months, but subsequent changes were moderate. As shown in Table 2, there were significant differences in mean values between 0 M and 1 M for 5 characteristics and between 1 M and 3 M for 8 characteristics. However, there were no differences in

the means of almost all characteristics at 3 M vs 7 M. The results of PCA of the palatal vault also showed increases up to 3 months, but subsequent changes were slight. The above findings showed that the outer alveolar ridge portion grew larger with age in months, while the palate characteristics increased considerably up to approximately 3 months, but they subsequently changed very little.

In children with cleft palate, studies have found that cartilage plasticity was active until 6 weeks after birth, so fitting a device such as the presurgical nasoalveolar molding (PNAM) as soon as possible after birth improved morphological anomalies compared to a group who did not use such devices [Matsuo and Hirose, 1991; Grayson et al., 1993; Isogawa et al., 2010; Jiri et al., 2012]. In the present study, palate development during the predental period was found to be active from the neonatal period until around 3 months. In Principal Component Analysis, variance of PC1 was significantly lower at 3 M than at 0 and 7 M. In other words, individual differences are originally large at birth and change in a constant pattern up to around 3 months.

Nagaishi et al. [2011] reported that there were no differences in palate depth between the 1-2 months group (mean: 2.09 M) and the ≥ 5 months group. Kojo [1988] also found that palate depth had a tendency to increase slightly but continued with virtually no changes from 1 to 12 months. Meanwhile, Lebret [1962] asserted that, in a study of primary dentition to permanent dentition, palate depth did not change between the primary and permanent dentition. Richardson [1967] reported that palatal vault height is almost established at birth, there being only a minimal increase during the first two years of life. In the present study, palate depth increased significantly from the neonatal period until 2 months and was largely unchanged from 3 months onwards. These findings newly demonstrated that morphological changes in the palate vault were pronounced from immediately after birth until 2 months.

In three-dimensional (3D) measurement of the dental casts, the decision on how to set the reference plane is an important issue. The typical method involves measurement based on the teeth [Tsai, 2004; Primozic, 2012; Yang, 2013; Ruskova, 2013]. To date, the reference plane in the predental period has been based on the maxillary tuberosity [Kojo, 1988; Nagaishi et al., 2011]. However, while this point is identifiable in casts of infants that have advanced in age, it is difficult to confirm as a reference point in early neonates due to its low position and lack of development. The points that are clearly identifiable in the dental casts of early neonates are only 3 points: the point of the alveolar crest in the incisive papilla (M1,) and the cross points of the left and right lateral sulci and alveolar crest (R1, L1).

The alveolar ridge changes with age in months throughout the predental period, but only Anterior width and Total Length were found to be correlated with age in months throughout the predental period (Table 3). In other words, in children with a large Anterior width and Total Length at birth, these characteristics remain large throughout the predental period. However, Anterior width and Posterior Width, and Anterior length and Posterior length, have different growth patterns. As shown in Table 5, Posterior Width was not correlated to any characteristics other than Anterior width at 0 M, but it was correlated to 5 characteristics except Anterior width in the palate characteristics group at 7 M. Anterior length also increased with age up to 2 months, but subsequently it increased only moderately. Posterior length increased up to 2 months, but then subsequently decreased moderately. As shown in Table 4, the SS ratio attributable to age in months was large for Anterior width and Posterior Width, slightly small for Anterior length, and very small for Posterior length. In other words, it was suggested that Anterior width and Posterior Width had small individual differences and large age (months)-related changes, while most Posterior length changes were individual differences. The study findings point to the need to consider growth of alveolar width and length separately to that of the anterior and posterior regions. To date, oral characteristics have been assessed without discriminating between differences in the growth patterns of the alveolar ridge and palate and the anterior and posterior regions [Bishara et al., 1987; Nagaishi et al., 2011].

The present study suggested that various characteristics must be comprehensively and carefully analyzed to clarify the growth of palate morphology during the predental period. Future studies now need to analyze the association between the morphologies of the alveolar ridge and palate during the predental period and primary dentition stage.

Conclusions

In predental infants, growth patterns of palate morphology, including the alveolar ridge, differed according to their characteristics. There were major developmental changes in the palate during the first 3 months after birth. The study findings suggest that palate growth in the first half of the predental period may affect subsequent palate growth.

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