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Three-dimensional longitudinal changes of maxilla and mandible morphology during the predental period

ABSTRACT

Aim *The purpose of this study was to longitudinally analyse the morphology of maxilla and mandible over time in infants using a three-dimensional (3D) surface scanner.*
Materials and methods *Seventeen Japanese full-term infants participated in the study. Dental plaster models were fabricated every 3 months from 1 month of age to 12 months. The plaster models were scanned using the 3D surface scanner to create 3D models. The arch width, arch length, arch angle, palatal depth and palatal area of the 3D models were analysed.*
Results *The arch width and length of maxilla and mandible increased as the arch angle decreased. The arch width and length of the maxilla were greater than those of the mandible. The total alveolar ridge morphology increased in size in the occlusal view, with marked growth in the sagittal direction. The palatal depth remained virtually unchanged although the palatal area increased as a result of buccal growth of the alveolar ridge.*
Conclusions *The morphological growth pattern of the maxilla and mandible in infants can be evaluated quantitatively using 3D analysis. Knowledge about the healthy development of children and their orofacial growth patterns during the predental period can be applied as an index for diagnostic criteria.*

Keywords *Dental morphology, Growth, Longitudinal study, Predentition, Three-dimensional analysis*

Introduction

Appropriate management of the developing dentition and occlusion is a fundamental and essential component for the oral health care of all paediatric patients. Dentition and oral function are influenced by the sucking milk or food eating pattern as an infant [Leighton, 1982; Narbutytė et al., 2013; Traisman and Traisman, 1958]. Therefore, dental intervention and guidance during the predental period are important factors in the development of orofacial morphology and oral function [Ranly, 1998].

Traditionally, diagnostic measurements have been obtained from plaster models to ascertain the morphological changes that occur during oral growth in infants. Previous cross-sectional studies have assessed the palatal and alveolar shape during the predental period [Bishara et al., 1987; Katayama et al., 2012; Kojo, 1988; Nagaishi et al., 2011; Prasad et al., 2000; Richardson et al., 1967; Sillman, 1964; Sillman, 1953; Yang and Hisaaki, 2001]. Yang et al. [2001] evaluated growth changes in the dental arch width from the predental period to the mixed dentition period. Another study measured changes in the dental arch from birth to early childhood [Sillman, 1964]. Richardson et al. [1967] observed changes in the maxillary and mandibular dentition from birth to 2 years of age. The influence of different sucking patterns on the development of the dental arch was also researched in a previous report [Bishara et al., 1987]. However, the majority of studies on growth changes in the morphology of the palate and alveolar region of the Japanese children, during the predental period, have mainly concentrated on the maxilla [Ishida et al., 2014; Ishida et al., 2016; Katayama et al., 2012; Nagaishi et al., 2011; Prasad et al., 2000]. This implies that there are almost no longitudinal studies concerning both the maxilla and mandible. Therefore, it is still unclear as to how the maxilla and mandible grow during the predental period and whether there is a difference between developmental patterns of the maxilla and mandible. Thus, the growth pattern of the dental arch during the predental period is not fully understood; this limits the information available regarding the healthy development of children and reduces the scope for development of diagnostic criteria. Research involving diagnostic measurements over short intervals is necessary because of the rapid changes in the dental arch during growth.

Methods of measuring the dental arch usually involve

FIG. 1 3D scanning of the dental plaster model: dental plaster model (a), 3D model of the dental plaster model (b).

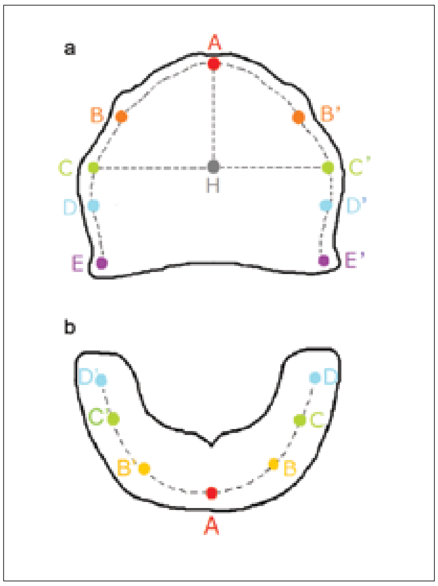

FIG. 2 Landmarks in the palate and alveolar arch: maxillary landmarks (a), mandibular landmarks (b).

A The most anterior point on the incisive papilla or the mid-line of the crest of the alveolar ridge
B The point at which the lateral sulcus crosses the crest of the alveolar ridge (B: Right point, B′: Left point)
C The widest point of the arch at the crest of the alveolar ridge (C: Right point, C′: Left point)
D The most posterior point on the distal border at the crest of the alveolar ridge (D: Right point, D′: Left point)
E The point at which the maxillary ridge terminates (E: Right point, E′: Left point)

direct measurement on a dental cast or a photo using a caliper [Keating et al., 2008; Morris et al., 1993]. However, these methods only provide two-dimensional information. A three-dimensional (3D) measurement method is necessary to analyse the stereoscopic growth change in detail [Ciusa et al., 2007; Ishida et al., 2013; Kaihara et al., 2005; Kato et al., 2009; Kato et al., 2010; Primo et al., 2009]. A measurement method generating 3D models of the dental arch with sufficient system accuracy for clinical application is required [Bell et al., 2003; Canto et al., 2015; Kaihara et al., 2013; Kaihara et al., 2014; Santoro et al., 2003].

The purpose of this study was to analyse three-dimensionally the morphology of the maxilla and mandible over time in infants. In this study, dental models were measured and analysed longitudinally from 1 month to 12 months of age using a 3D surface scanner.

Materials and methods

Seventeen Japanese full-term infants with no craniofacial deformity (7 males and 10 females) weighing 3,245 ± 434.89 g at birth were selected as participants for this study. The study was approved by the Ethical Committee for Epidemiology of Hiroshima University (No. 329).

Dental models of the participants were fabricated at intervals of 3 months from the first month after birth to 12 months. Impressions were taken using a silicone impression material (Exafine, GC, Tokyo, Japan), and dental casts were fabricated from a hard plaster (Elephastone, Shimomura Gypsum, Tokyo, Japan). Individual trays were fabricated in alignment with the dental model using a resin-based material (Trayresin II, Shofu, Kyoto, Japan).

3D scanning of the dental plaster model

The dental plaster models were scanned using a non-contact 3D surface scanner (RexcanDS, Solutionix, Seoul, Korea) to create corresponding 3D models (Fig. 1). The generated 3D models of the palate and alveolar ridge were exported to the stereolithography (STL) format containing the 3D coordinates. The STL format has a polygonal mesh and identifies triangular surfaces that describe the generated 3D model.

Landmarks and reference plane

Maxillary and mandibular landmarks in the palate and alveolar arch were defined according to previous reports [Bishara et al., 1987; Kojo, 1988] (Fig. 2).

A: The most anterior point on the incisive papilla or the midline of the crest of the alveolar ridge.

B: The point at which the lateral sulcus crosses the crest of the alveolar ridge (B: Right point, B′: Left point).

C: The widest point of the arch at the crest of the alveolar ridge (C: Right point, C′: Left point).

D: The most posterior point on the distal border at the crest of the alveolar ridge (D: Right point, D′: Left point).

E: The point at which the maxillary ridge terminates (E: Right point, E′: Left point).

H: The point on the median palatal raphe with a perpendicular from the straight line C-C′ of the maxilla.

Reference plane: The plane including A, E and E′.

Measurement parameters

The 3D models were imported to a computer, and the following parameters were measured using 3D processing software (Rapidform 2006, INUS Technology, Seoul, Korea).

1) Arch width.
   A straight line between the points at which the lateral sulcus crosses the crest of the alveolar ridge (B-B′), a straight line between the widest points of the arch at the crest of the alveolar ridge (C-C′), a straight line between the most posterior points on the distal

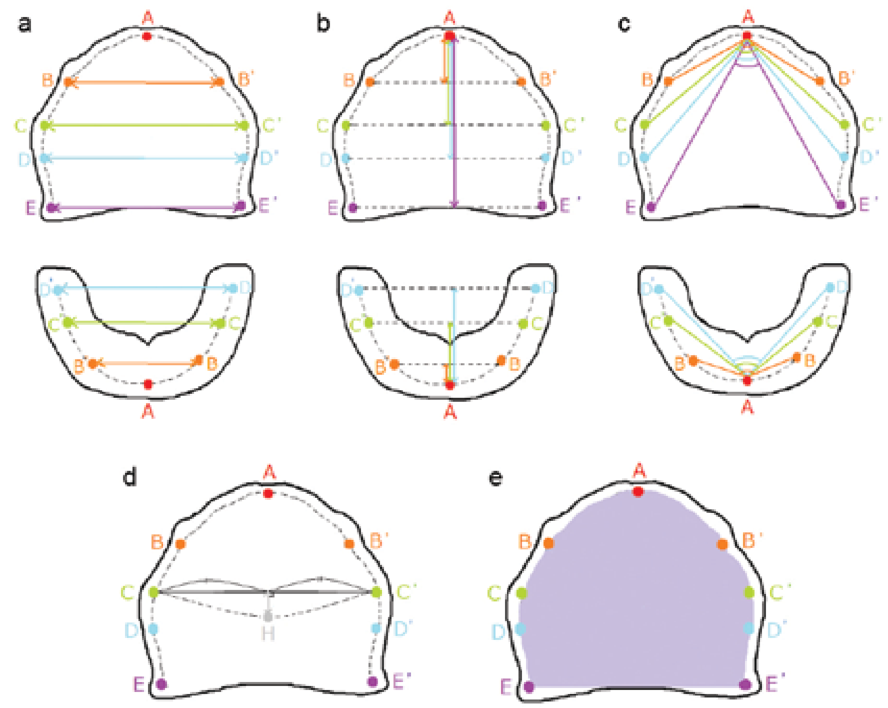

FIG. 3 Measurement parameters: arch width (a), arch length. c Arch angle. d Palatal depth. e Palatal area

border at the crest of the alveolar ridge (D-D′), and a straight line between the points at which the maxillary ridge terminates (E-E′) were measured on 3D models as the arch width (Fig. 3a).

2) Arch length.
   Straight lines connecting points A to B-B′ (A-BB′), A-CC′, A-DD′ and A-EE′ were measured on 3D models as the arch length (Fig. 3b).
3) Arch angle.
   The arch angles between the straight lines A-B and A-B′ (∠B-A-B′), ∠C-A-C′, ∠D-A-D′, ∠E-A-E′ were measured on the 3D models (Fig. 3c).
4) Palatal depth.
   The distance between point H and the reference plane was measured on the 3D model as the palatal depth (Fig. 3d).
5) Palatal area.
   The palatal area of the polygon connecting all points on the alveolar ridge (E, D, C, B, A, B′, C′, D′, E′) was measured on the 3D maxillary models (Fig. 3e).

Statistical methods

The morphological parameters of the palate and alveolar ridge in infants were evaluated by averaging the distances measured. Statistical differences between the time periods were analysed for growth. The paired t-test was carried out to compare the data from each parameter between the periods up to 12 months after birth, using IBM SPSS Statistics for Windows (version 19; SPSS Inc., Tokyo, Japan) to evaluate the growth of the palate and alveolar ridge. Test results were considered significant if p values were ≤ 0.05.

Results

Arch width

Changes in the arch width over time are shown in Figure 4. The arch widths of the maxilla were greater than those of the mandible. However, the dimensions of the maxilla and mandible in all areas measured (B-B′, C-C′, D-D′, E-E′) increased from 1 month after birth to 12 months. Moreover, marked changes were observed in the periods from 1 month after birth to 3 months and 6 months. In particular, the changes from 1 month to 3 months in D-D′ of the maxilla and mandible were 1.89 mm and 3.26 mm, respectively (Fig. 4c).

All arch widths at 12 months in both the maxilla and mandible were significantly greater than at 1 month ($p < 0.01$).

Arch length

The arch lengths of the maxilla were greater than those of the mandible (Fig. 5). However, the dimensions of the maxilla and mandible in all areas measured (A-BB′, A-CC′, A-DD′, A-EE′) increased from 1 month after birth to 12 months. Significant changes in the arch length of the mandible were observed from 1 month after birth to 3 months. The arch lengths for A-BB′, A-CC′ and A-DD′ of the mandible from 1 month after birth to 3 months were 1.09 mm, 1.56 mm, 3.34 mm, respectively. Growth in the arch length of the mandible after 3 months was less marked. A statistically significant difference was observed in the arch length between 1 month and 12 months, and 3 months and 12 months in the maxilla ($p < 0.05$). The arch lengths for A-BB′ and A-DD′ in the maxilla were statistically

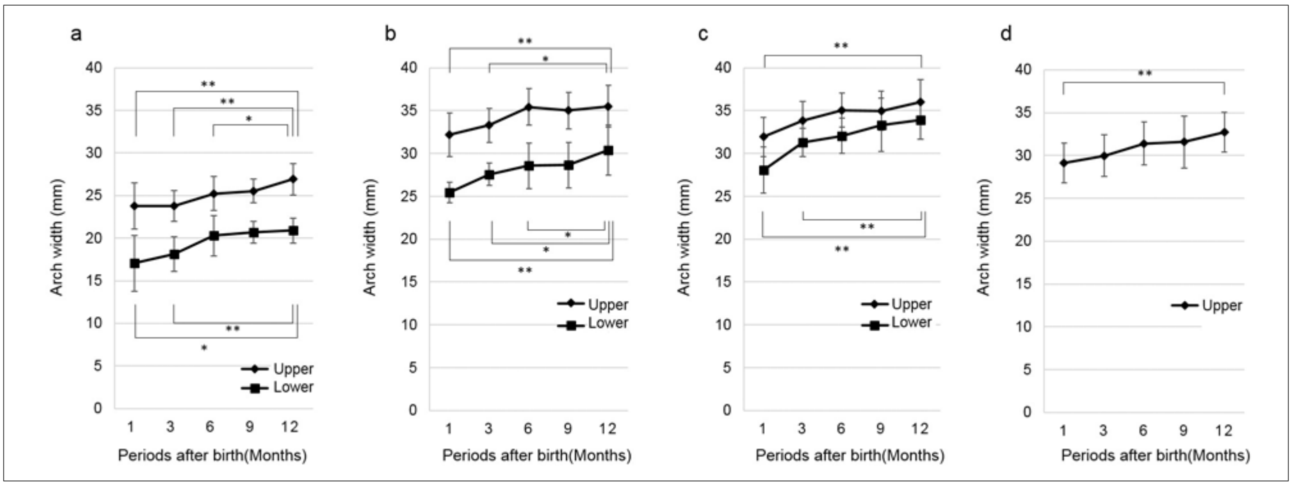

FIG. 4 Growth pattern of arch width during the predental period. a B-B′. b C-C′. c D-D′. d E-E′. *p<0.05; **p<0.01 using paired t-test. Significant difference between each group and the control group (12 months after birth).

significantly greater between 6 months and 12 months ($p < 0.05$), but there were no significant differences between the other time periods.

Arch angle

The arch angles showed a marked change between 1 month and 3 months in the mandible (Fig. 6), with the arch angles of ∠ BAB, ∠ CAC and ∠ DAD decreasing by 8.42°, 4.69°and 8.09°, respectively. The arch angles also decreased significantly between 6 months and 9 months in the mandible, with the arch angles of ∠ BAB, ∠ CAC and ∠ DAD decreasing by 10.78°, 5.70° and 4.82°, respectively. Growth in the maxilla was less than that of mandible. At ∠ CAC and ∠ DAD, the arch angles were different between the maxilla and mandible at 1 month, but matched from 3 months to 12 months. There were no significant differences between any of the time periods and 12 months after birth.

Palatal depth

Figure 7 shows the changes over time in the palatal depth. In contrast with the changes in the other parameters, palatal depth was almost unchanged from 1 month to 12 months. No significant differences were found in the palatal depth between any of the time periods.

Palatal area

The growth pattern of the palatal area is shown in Figure 8. The palatal area from 1 month to 12 months increased significantly from 759.9 mm2 to 956.4 mm^2 (21%). Moreover, the palatal area increased significantly from 1 month to 3 months (80.6 mm^2) and from 3 months to 6 months (63.1 mm^2). After 6 months, growth in the palatal area slowed. The palatal area at 12 months was

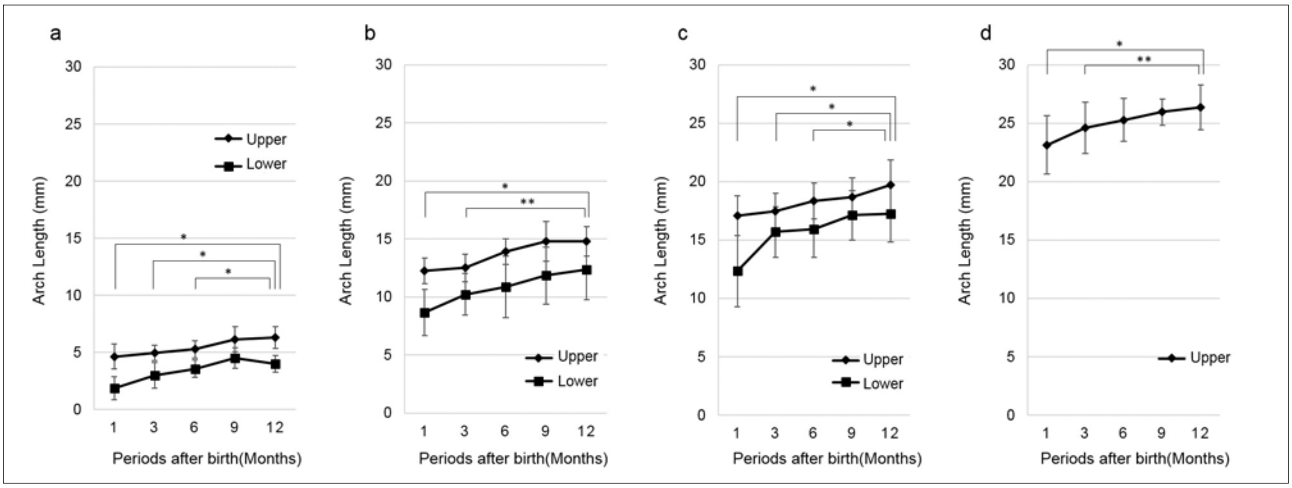

FIG. 5 Growth pattern of arch length during the predental period. a A-BB′. b A-CC′. c A-DD′. d A-EE′. *p<0.05; **p<0.01 using paired t-test. Significant difference between each group and the control group (12 months after birth).

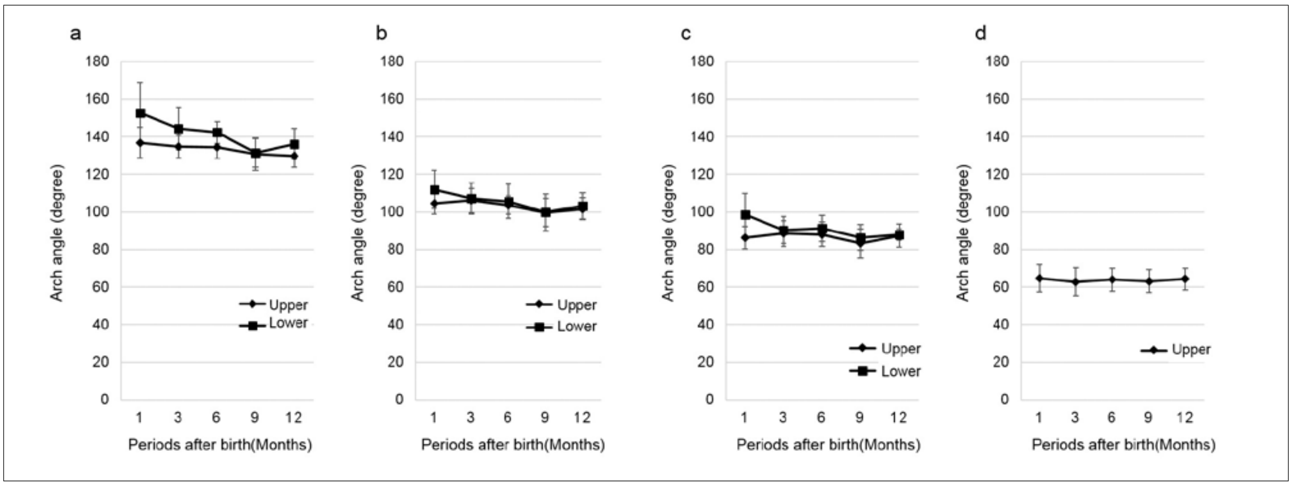

FIG. 6 Growth pattern of arch angles during the predental period. a ∠BAB′. b ∠CAC′. c ∠DAD′. d ∠EAE′. Significant difference between each group and the control group (12 months after birth).

significantly greater than at 1 month ($p < 0.01$), 3 months ($p < 0.01$) and 6 months ($p < 0.05$), but there was no significant difference in the palatal area between 9 months and 12 months ($p = 0.165$).

Discussion

This study used dental models of participants taken at intervals of 3 months from the first month after birth to 12 months. The participants were children with healthy growth after birth. The dental models were analysed without distinction between male and female participants because it has been reported that there is no significant difference in palatal morphology between sexes [Kojo, 1988].

The non-contact 3D surface scanner used in the study works on the principle of phase-shifting optical triangulation. An object is scanned with halogen light stripes, and twin cameras receive the light reflected from the surface of object. Measurements taken from 3D predental models using a non-contact 3D surface scanner are highly accurate and precise, and are comparable to measurements taken using the gold standard method [Kaihara et al., 2014; Kaihara et al., 2013].

Landmarks to be used as measurement points on the dental models should be established observable marks present from birth to adulthood [Kojo, 1988; Sillman, 1964]. The landmarks we chose were based on a previous report [Kojo, 1988]. To measure change in palatal depth, the reference plane consisted of the incisive papilla through to the maxillary tuberosity because this area is not subject to morphological change caused by the eruption of deciduous teeth. Furthermore, all measurements taken in this study provide clarification of growth changes, which could be useful during future research into the dentition.

Our findings revealed differences in the growth pattern by taking measurements at different points on the maxilla and mandible. Because the arch width and length increased and the arch angle decreased, the alveolar and palatal morphology in an axial view may have increased as a whole, with particular growth in the sagittal direction. A previous report found that sagittal growth of the frontal alveolus and palate occurred from 7 days after birth to 12 months of age [Katayama et al., 2012]. As reported previously, the arch width and length of the maxilla and mandible increased each month [Kojo, 1988], and the lower arch length and the upper and lower arch width increased significantly from 1 month to 6 months. Sillman [1964] observed that the arch length and width increased after birth to 2 or 3 years, and noted significant growth in the anterior segment of the maxilla and mandible between birth and 12 months. Richardson et al. [Richardson et al., 1967] observed changes in the upper and lower dentition

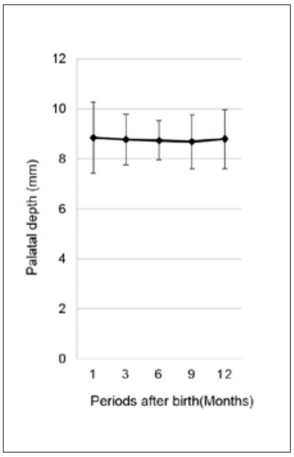

FIG. 7 Growth pattern of palatal depth during the predental period.

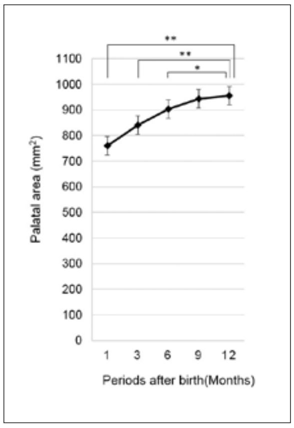

FIG. 8 Growth pattern of palatal area during the predental period. *$p<0.05$; **$p<0.01$ using paired t-test

between birth and 2 years, and recorded similar results. Our findings that arch length and width increased significantly in a sagittal direction between 1 month and 6 months are consistent with the findings of these previous studies.

In the coronal or sagittal view, the alveolar ridge increased in size on the buccal and frontal sides, because the palatal area increased while the palatal depth remained constant. The unchanged palatal depth could be related to the fact that infants are able to perform a stable suck by fixing a nipple to a sucking fossa. A previous study [Kojo, 1988] reported that the palatal depth was almost flat, and the incremental change in palatal depth between birth and 1 year was 0.7–0.8 mm. Nagaishi et al. [2011] found no significant difference in palatal depth in groups aged from 1–2 months, 3–4 months and over 5 months. Richardson et al. [1967] reported that the palatal depth increased by approximately 1.0 mm up to the age of 1 year. Although the change in palatal depth recorded in their study was greater than that of the present study, the difference was insubstantial. According to these previous reports and the results of our study, the increase in the palatal depth between birth and 1 year can be regarded as insignificant.

Previous research reported that growth of the palatal area increased significantly until 3 months, and then increased more slowly from then on [Katayama et al., 2012]. Our findings are consistent with this report. In contrast to these findings, another study [Nagaishi et al., 2011] found that there was little growth in the palatal area during the predental period. However, we found that the palatal area increased in size because the arch width and arch length increased, even though the palatal depth remained unchanged. To reveal the growth pattern of infants during the predental period, the dental morphology should be measured over a significant time period. Furthermore, the relationship between the palate and the alveolar ridge and its role in malocclusion and oral function should be researched in the future.

Conclusions

In this study, dental models were measured and analysed longitudinally from 1 month after birth to 12 months of age using a 3D surface scanner. Morphological analysis revealed that the arch width and length of the maxilla and mandible increased, while the arch angle decreased. The arch width and length of the maxilla were greater than those of the mandible. The palate and alveolar ridge increased in size from the occlusal aspect, with marked growth in the sagittal direction. The palatal depth remained essentially unchanged, but the palatal area increased as a result of buccal growth of the alveolar ridge.

Changes of the maxilla and mandible morphology during growth in infants can be evaluated quantitatively using 3D analysis. This provides important information about the healthy development of children and acts as an index for diagnostic criteria.

References

- Bell A, Ayoub AF, Siebert P. Assessment of the accuracy of a three-dimensional imaging system for archiving dental study models. J Orthod 2003;30:219-223.
- Bishara SE, Nowak A, Kohout FJ, Heckert DA, Hogan MM. Influence of feeding and non-nutritive sucking methods on the development of the dental arches -longitudinal study of the first 18 months of life. Pediatr Dent 1987;9:13-21.
- Canto Gde L, Pachêco-Pereira C, Lagravere MO, Flores-Mir C, Major PW. Intra-arch dimensional measurement validity of laser-scanned digital dental models compared with the original plaster models: a systematic review. Orthod Craniofac Res 2015;18:65-76.
- Ciusa V, Dimagglo FR, Sforza C, Ferrario VF. Three-dimensional palatal development between 3 and 6 years. Angle Orthod 2007;77:602-606.
- Ishida F, Mashiko M, Shimabukuro I, Yamamoto S, Shimizu K, Maeda T. 3-D image analysis on palate growth changes from birth to 1 month in normal infants. Ped Dent J 2013;23:37-43.
- Ishida F, Ukai Y, Shimizu T. Palate and alveolar ridge development in predental infants: a longitudinal study. Eur J Paediatr Dent 2016;17:155-163.
- Kaihara Y, Amano H, Miura K, Kozai K. Three-dimensional analysis of the effects of the treatment on anterior crossbite in the primary dentition. Ped Dent J 2005;15:20-27.
- Kaihara Y, Kihara T, Katayama A, Amano H, Nikawa H, Kozai K. Accuracy of a non-contact 3D measuring system for dental model analysis. Ped Dent J 2013;23:71-78.
- Kaihara Y, Katayama A, Iwamae S, Kihara T, Ono K, Kurose M, Amano H, Nikawa H, Kozai K. Application of three-dimensional digital models for the morphometric analysis of predentition plasters: accuracy and precision. Eur J Paediatr Dent 2014;15:360-366.
- Katayama A, Kaihara Y, Kihara T, Iwamae S, Amano H, Nikawa H. A preliminary study for analysis of three dimensional change of childrens palates and alveolar ridges in pre-dentition period. J Jpn Acad CAD/CAM Dent 2012;2:87-98.
- Kato M, Watanabe K, Kato E, Hotta H, Daito M. Three dimensional measurement of the palate using the semiconductor laser: On the influences of the palate of maxillary protrusion with finger sucking. Ped Dent J 2009;19:25-29.
- Kato M, Ito M, Niito T, Kato E, Ishikawa H, Daito M. Three dimensional measurements of the palate using a semiconductor laser: The influence of anterior cross bite on the palate in deciduous dentition. Ped Dent J 2010;20:40-44.
- Keating AP, Knox J, Bibb R, Zhurov AI. A comparison of plaster, digital and reconstructed study model accuracy. J Orthod 2008;35:191-201.
- Kojo H. Study on Growth and Development of the Dentition during the First One Year of Life - Three-Dimensional Measurement on Maxillary and Mandibular Alveolar Arch Morphological Palate. Jpn J Pediatr Dent 1988;26:112-130.
- Leighton BC. A preliminary study of the morphology of the upper gum pad at the age of 6 months. Swed Dent J Suppl 1982;15:115-122.
- Morris KM, Seow WK, Burns YR. Palatal measurements of prematurely born, very low birth weight infants: comparison of three methods. Am J Orthod Dentofacial Orthop 1993;103:368-373.
- Nagaishi K, Ogura H, Nishida Y, Kondo T, Tamura Y. Changes of Palatal and Alveolar Arch Form during Predental Period in Infants. Jpn J Pediatr Dent 2011;29:439-451.
- Narbutytė I, Narbutytė A, Linkevičienė L. Relationship between breastfeeding, bottle-feeding and development of malocclusion. Stomatologija 2013;15:67-72.
- Prasad CN, Marsh JL, Long RE Jr, Galic M, Huebener DV, Bresina SJ, Vannier MW, Pilgram TK, Mazaheri M, Robison S, Bartell T. Quantitative 3D maxillary arch evaluation of two different infant managements for unilateral cleft lip and palate. Cleft Palate Craniofac J. 2000;37:562-570.
- Primo zic J, Ovsenik M, Richmond S, Kau CH, Zhurov A. Early crossbite correction -a three-dimensional evaluation. Eur J Orthod 2009;31:352-356.
- Ranly DM. Early orofacial development. J Clin Pediatr Dent 1998;22:267-275.
- Richardson AS, Cranbrook BC, Castaldi CR, Winnipeg M. Dental Development during the first two years of life. J Can Dent Assoc 1967;33:418-429.
- Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop 2003;124:101-105.
- Sillman JH. An analysis and discussion of oral changes as related to dental occlusion. Am J Orthod 1953;39:246-261.
- Sillman JH. Dimensional Change of the dental arches: Longitudinal study from birth to 25 years. Am J Orthod Dentofacial Orthop 1964;50:824-842.
- Traisman AS, Traisman HS. Thumb- and finger-sucking: a study of 2,650 infants and children. J Pediatr 1958;52:566-572.
- Yang J, Hisaaki S. Study on developmental changes of dental arch from pre-dental period to mixed dentition -Part 1. Changes of dental arc widths-. Ped Dent J 2001;11:67-84.