The role of intercuspation in the regulation of transverse maxillary development in *Macaca fascicularis*

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Abstract

The role of intercuspation of the teeth in transverse maxillary growth and dental arch development was investigated radiographically with the aid of implants in *Macaca fascicularis* monkeys. Fourteen animals were randomly allocated to a control group (n=7) and an experimental group (n=7) and were followed from 29 to 100 weeks of age.

Intercuspation was eliminated in the experimental group by grinding the canines and molar cusps in both dental arches as soon as possible after emergence. Maxillary occlusal radiographs were taken at regular intervals. Linear and angular analyses of skeletal changes revealed that midpalatal sutural growth seems to be independent of intercuspation. The developing dental arch, however, showed a significantly greater increase in width in certain areas in the experimental group than in the control group. Most findings support the hypothesis that the width of the maxillary dental arch is guided by the width of the mandible through the intercuspation of the posterior teeth.

Key words

Dentomaxillary complex • *Macaca fascicularis* • Growth and development

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Normal dentofacial growth and development strongly suggest a coordination in the development of the dentition of both jaws. The occlusal anatomy of the posterior teeth or, more specifically, their intercuspation is supposed to play a major role in this process. The cone-shaped cusps of the maxillary posterior teeth and the crater-like occlusal anatomy of their antagonists are responsible for a guided emergence towards each other, by the so-called cone-funnel mechanism,[1,2] leading to the final occlusion. This coordination mechanism might extend its influence beyond the dentition, as hypothesized by Brace.[3] He proposed that intercuspal relationships might act as a guidance system for the growth of bony structures in the developing face.

In 1986 van der Linden[4] developed a more detailed hypothesis, stating that once occlusal contact is established, further transverse development of the maxillary dental arch and its surrounding maxillary structures is regulated by the mandibular dentition via intercuspation. The mandibular dental arch would function as a rail guiding the development of the maxillary arch. In instances where normal vertical contact is lacking in the posterior region (posterior open bite) the transverse development of the maxillary dental arch is disturbed. In those cases the rail mechanism can not be effective, resulting in a narrow maxillary arch in most cases.[4]

Zingeser[5] presented an opposite view when he theorized that the mandible and its dentition accommodate to a so-called upper occluso-facial functional component, which implicates the guidance of mandibular growth by the maxilla.

Sarnat[6,7] presented experimental evidence showing that the occlusion contributes to a harmonious intermaxillary relationship. He resected the median and transverse palatine sutures in *Macaca mulatta* and studied jaw growth thereafter. He found that the surgery did not significantly influence maxillary growth and he concluded that the mandible might guide the growth of the maxilla by means of occlusion and intercuspation.

In an extensive series of experiments in rats, Petrovic and co-workers[8,9,10] influenced growth of the maxillofacial complex in rats by a variety of interventions, including orthopaedic devices, sectioning of the lateral pterygoid muscle, tongue reduction, and the administration of growth hormones. Their experiments resulted in a hypothetical servo-system in which they suggest the importance of a peripheral comparator for the coordination of the growth of the upper and lower jaws and for the maintenance of an optimal occlusal relationship.

On the other hand, Kantomaa and Rönning,[11] also using rats, restricted maxillary growth by creating synostoses of maxillofacial sutures, with or without elimination of intercuspation. In both situations they found that the inhibition of maxillary growth was accompanied by a slowing down of mandibular growth. As the effects appeared to be independent of intercuspation, they concluded, in contrast to Petrovic et al., that intercuspation does not seem to play a role in the coordination of mandibular and maxillary growth.

A drawback of all these experimental studies is that dentofacial development has been impaired surgically or by orthopaedic devices. These may hamper extrapolation of the findings to normal growing human systems due to possible iatrogenic effects or due to marked differences in morphology and physiology of the maxillofacial complex between rodents and humans. Data derived from experiments on nonhuman primates might yield more relevant information.[12,13,14,15]

In particular, growth and development of the maxillofacial complex of members of the *Macaca* species show basic similarities to humans.[15,16,17] *Macaca* and humans have the same number of deciduous and permanent teeth, and comparable dental morphologies, posterior occlusion, and intercuspation, although all dimensions are smaller in *Macaca*. Also, the development of the dentition, including tooth eruption and the sequence of transition, is highly comparable in *Macaca* and humans.[15,16,17]

The purpose of this study, therefore, was to investigate the contribution of intercuspation to the transverse development of the maxilla and its dental arch in an experimental model in which intercuspation was eliminated but growth was not otherwise disturbed.

Materials and methods

Experimental procedures

Eleven male and three female laboratory-born monkeys (*Macaca fascicularis*) were used in this study. All animals showed a neutrocclusion of the posterior teeth and an occlusion in the frontal region between a nearly end-to-end and a slight overjet and overbite. None of the animals had a malocclusion or a skeletal deviation. The mean age of the animals was 29 weeks at the start of the study. At that stage, crypt formation of the mandibular permanent canines had become visible radiographically and the second deciduous molars had recently emerged.[18] The study lasted until the animals were 100 weeks of age, which is after occlusal contact of the first permanent molars was established.

The animals were randomly allocated to a control group (n=7) and an experimental group (n=7). The groups were balanced for dental development, dental arch dimensions, and age. One male animal of the control group died accidentally after 1 year. All animals were housed in the Central Animal Laboratory of the University of Nijmegen, the Netherlands, and received a standard diet of wet compressed pellets and drinking water *ad libitum*.

At the start of the study four tantalum implants (Ole Dich, Hvidovre, Denmark), measuring 1.2 mm in length and 0.5 mm in width, were inserted as bone markers in each monkey.[19,20] The animals were premedicated with 10 mg/kg Ketamine (Nimatek^R, A.U.V., Cuijk, The Netherlands) then brought under general anaesthesia with 0.1 ml Thalamonal^R (Janssen Pharmaceutica, Beerse, Belgium) and 0.25 mg Atropine (Atropine Sulphate 0.5 mg/ml, A.C.F. Pharma B.V., Maarssen, The Netherlands). One pair of implants was inserted into the palate through the mucosa at each side of the midpalatal suture and checked for stability (Figure 1).

As soon as possible after emergence, the deciduous and permanent molars in both groups were provided with tantalum balls with a diameter of 0.5 mm. The animals were again brought under general anaesthesia and a small hole was prepared with a round bur in the buccal surface of each molar in which the implant was secured with composite material. If a radiograph showed that a bone or tooth implant had become loose, a new one was immediately inserted as close as possible to the position of the loose one, and the radiographic procedure was repeated.

In the animals of the experimental group, intercuspation was eliminated by grinding the cusps of the deciduous molars and canines and the first permanent molars so that flat surfaces were obtained in both dental arches. The grinding was performed under general anaesthesia as soon as possible after emergence of the cusps. The cusps were ground without jeopardizing the vitality of the pulp. The proximal contacts of the deciduous and permanent molars were not involved in the grinding.

In both groups standardized occlusal radiographs of the maxilla were taken with the aid of a cephalostat. Initially this was done every 3 weeks, but after the maxillary first permanent molars had attained the level of the occlusal plane, the frequency was reduced to once every 6 weeks. The animals were brought under general anaesthesia prior to fixation in the cephalostat. The radiographic films were attached to a film carrier to prevent bending and placed in the mouth, touching the maxillary teeth. The central beam of the X-ray machine was orientated perpendicular to the occlusal plane and the radiographic film. The distance between the X-ray focus and the occlusal plane was fixed at 4.5 m. The radiographs were made with 100 kV at 20 mA and 5 seconds exposure time. After the maxillary permanent first molars had reached the level of the occlusal plane, exposure time was increased to 7.5 seconds.

Both sexes were combined in the analysis of the data, as sexual differences in craniofacial growth and development in *Macaca fascicularis* become apparent only after the age of 3 years and therefore can be neglected for the purpose of this study.[21]

Measurements (radiographic analysis)

The coordinates of the bone and tooth implants on the occlusal radiographs were digitized with the Optocom measuring instrument.[22] All recordings were performed by the first author. To quantify dental arch dimensions and their changes over time on the radiographs, a Cartesian coordinate system was constructed with the best fit line through the central incisor point and three points at the center of the midpalatal suture as Y-axis and a perpendicular through the central incisor point as X-axis (Figure 1).

In this coordinate system the following measuring points were used to study the transverse maxillary growth and dental arch development (Figure 1):

1. Right anterior palatal bone implant (RAB)
2. Right posterior palatal bone implant (RPB)
3. Left anterior palatal bone implant (LAB)
4. Left posterior palatal bone implant (LPB)
5. Right first deciduous molar implant (RFD)
6. Right second deciduous molar implant (RSD)
7. Right first permanent molar implant (RFP)
8. Left first deciduous molar implant (LFD)
9. Left second deciduous molar implant (LSD)
10. Left first permanent molar implant (LFP)

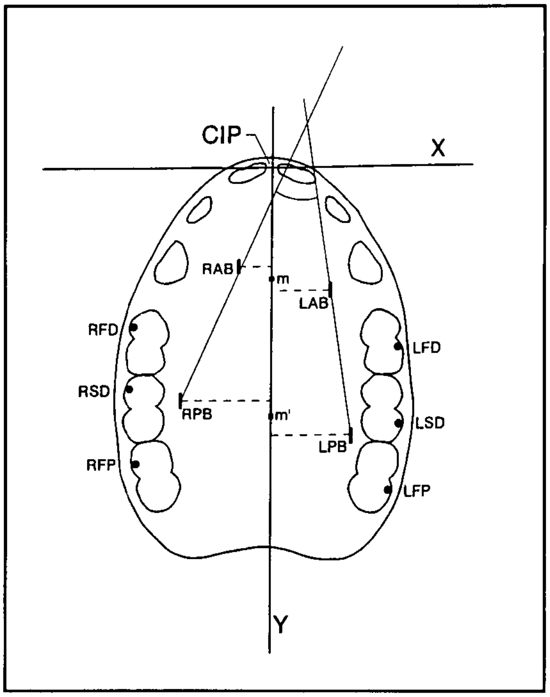

Figure 1

Figure 1
Schematic drawing of the palate and the dentition after emergence of the first permanent molars, showing the coordinate system and the positions of the bone and tooth implants. Initial midsagittal position for anterior and posterior bone implants are indicated as m and m' respectively. For the angular analyses the changes in the angle between the lines connecting the left and right bone implants were calculated.

Measurement error was estimated by measuring all radiographs of one monkey twice with an interval of 2 weeks. The error of the radiographic procedure was determined using the radiographs of two animals at the start and two at the end of the experimental period. For each monkey the radiographic procedure was repeated five times, removing and replacing the animal in the cephalostat each time.

Changes in dental arch width dimensions were studied by calculating the increments of the following distances, parallel to the X-axis: RFD–LFD, RSD–LSD, and RFP–LFP.

Skeletal changes were analyzed in the same coordinate system. Linear data were obtained by calculating the increments of the transverse distances parallel to the x-axis between the anterior (RAB–LAB) and between the posterior bone

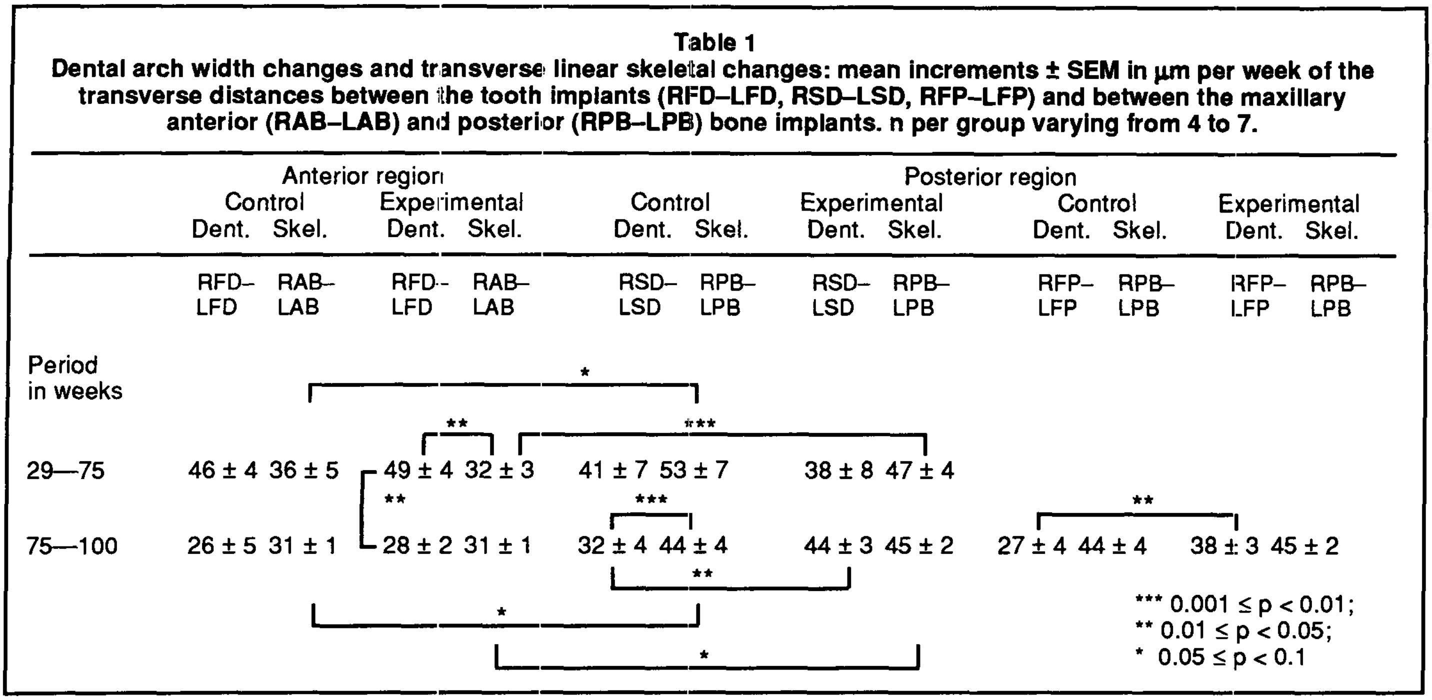

Table 1

Dental arch width changes and transverse linear skeletal changes: mean increments ± SEM in µm per week of the transverse distances between the tooth implants (RFD–LFD, RSD–LSD, RFP–LFP) and between the maxillary anterior (RAB–LAB) and posterior (RPB–LPB) bone implants. n per group varying from 4 to 7.

	Anterior region				Posterior region							
	Control		Experimental		Control		Experimental		Control		Experimental	
	Dent.	Skel.	Dent.	Skel.	Dent.	Skel.	Dent.	Skel.	Dent.	Skel.	Dent.	Skel.
	RFD–LFD	RAB–LAB	RFD–LFD	RAB–LAB	RSD–LSD	RPB–LPB	RSD–LSD	RPB–LPB	RFP–LFP	RPB–LPB	RFP–LFP	RPB–LPB
Period in weeks												
29—75	46 ± 4	36 ± 5	49 ± 4	32 ± 3	41 ± 7	53 ± 7	38 ± 8	47 ± 4				
75—100	26 ± 5	31 ± 1	28 ± 2	31 ± 1	32 ± 4	44 ± 4	44 ± 3	45 ± 2	27 ± 4	44 ± 4	38 ± 3	45 ± 2

*** $0.001 \leq p < 0.01$;
** $0.01 \leq p < 0.05$;
* $0.05 \leq p < 0.1$

implants (RPB – LPB). An angular analysis was applied to detect a possible rotation of the two sides of the palate by calculating the change in the angle between the lines through the left (LAB – LPB) and right (RAB – RPB) bone implants (Figure 1).

Although the markers were placed as accurately as possible in the same region, they could not be considered identical for the different animals. This means that for a description of growth, the distances themselves cannot be used and the increments must be considered. The use of increments has also the advantage that, in case an implant was replaced, the analysis of growth could easily be continued using the new marker.

Statistical procedures

For statistical analysis of dental arch dimensions and linear skeletal parameters, the experimental period was divided into a first period, which lasted from the start at 29 weeks of age until 75 weeks of age (before the first permanent molar could be used in the measurements), and a second period, which lasted from 75 weeks until 100 weeks of age.

Changes in distances between tooth implants in the X-direction for each period were calculated as mean increments and their standard errors in µm per week.

To compensate for size differences among the animals, an analysis of co-variance was performed on the distances between the tooth implants of the first deciduous molars of each monkey at 30 weeks of age. The Student's t-test was used to analyze differences between the control group and the experimental group, and a paired t-test was used within the groups to detect differences between the two periods.

Changes in distances between skeletal implants in the X-direction over each period were calculated as mean increments and standard errors in µm per week.

The situation was complicated by a possible rotation of the two sides of the palate. This means that the local amount of sutural growth might partially depend on the position of the bone marker along the length of the suture. To cope with this problem, the initial midsagittal positions for both the anterior and the posterior bone implants for each animal were calculated (see Figure 1: m and m'). Since these initial midsagittal positions of the anterior and posterior bone implants differed among individuals, an analysis of variance was carried out. Compensation for size differences was also carried out by analysis of co-variance.

Differences between the groups were analyzed using Student's t-test and within the groups using the paired t-test.

For the analysis of the angular measurements, the experimental period was considered as a whole. Mean changes were calculated in degrees/week. Two animals from the experimental group were excluded from this part of the study as their bone implants in one of the palatal halves were too close together to obtain accurate angle measurements. The t-test was used for analysis of the differences between the control and experimental groups.

Results

Error of the method

The total error of the method is made up of the error of the radiographic procedure and the measurement.

The measurement error of the occlusal radiographs was found to be about 50 μm for the distances. The error of the radiographic procedure was found to be about 60 μm for the distances, resulting in a total error of the method of about 80 μm, which was considered to be acceptable.

Dental arch width changes (Table 1)

In the control group no significant differences between the two periods were found for the mean increments of the distances between the first and the second deciduous molars (RFD – LFD and RSD – LSD). In the experimental group the increase of the distance between the first deciduous molars (RFD – LFD) was significantly larger in the first than in the second period ($0.01 \leq P < 0.05$), but such a difference could not be found for the second deciduous molar width (RSD – LSD).

No differences were found between the experimental and the control groups in the first period for any of the changes in arch width dimensions. In the second period the increase in the distance between the second deciduous molars (RSD – LSD) was significantly larger in the experimental group than in the control ($0.01 \leq P < 0.05$). Also, the distance between the first permanent molars (RFP – LFP) tended to increase more in the experimental group ($0.05 \leq P < 0.1$). However, such a trend did not occur for the distance between the first deciduous molars (RFD – LFD).

Transverse linear skeletal changes (Table 1)

Neither the control nor the experimental group showed significant differences in the rate of sutural growth between the two periods. This applies for the anterior as well as for the posterior regions (RAB – LAB and RPB – LPB).

The increase in the distance between posterior implants (RPB – LPB) tended to be larger than the increase between anterior implants (RAB – LAB) in both the experimental and control groups and in both periods (Table 1). However, the only significant difference was found in the experimental group, where in the first period the posterior bone markers (RPB – LPB) diverged significantly more than the anterior ones (RAB – LAB; $P < 0.01$).

Dental arch width changes versus transverse linear skeletal changes (Table 1)

The increments of dental and skeletal dimensions were of the same order of magnitude, indicating an important contribution of sutural growth activity in the widening of the dental arch. However, in the first period a significant buccal drift of the first deciduous molars (RFD – LFD > RAB – LAB) occurred in the experimental group ($0.01 \leq P < 0.05$). Such a drift could not be detected in the control group.

In the second period, all deciduous and first permanent molars in the experimental group seemed to undergo only a passive buccal displacement, while in the control group the second deciduous molars showed significantly less lateral displacement than the corresponding bone implants (RSD – LSD > RPB – LPB; $0.001 \leq p < 0.01$). Comparison of the lateral displacement of the first permanent molars with that of the bone implants only suggests a phenomenon comparable to that found for the second deciduous molar area.

Angular skeletal changes

The angular changes were limited. In the control group the mean increase of the angle between the lines RAB – RPB and LAB – LPB amounted 0.11 ± 0.01° per week; in the experimental group the mean increase was 0.15 ± 0.02° per week. Student's t-test revealed no significant differences between the groups, but both values differed significantly from zero ($P < 0.01$).

Discussion

Animal experiments on the role of intercuspation in the regulation of dental arch width increase and transverse maxillary growth involve surgical intervention or mechanical influence by means of orthopaedic appliances.[6-11] This limits the reliability of extrapolating the findings to normal, growing individuals. In the present study iatrogenic growth disturbances were avoided and *Macaca fascicularis* was used, as data obtained from occlusal research in this species are particularly suited for extrapolation to the human situation.[12-17]

The current study demonstrated that midpalatal sutural growth in *Macaca fascicularis* occurs at a faster rate posteriorly than anteriorly, leading to rotation of the maxillary halves. This observation is in agreement with the findings of Björk and Skieller[23] who called this phenomenon, when they observed it in humans, "transverse mutual rotation." No significant differences in transverse maxillary skeletal growth were found between the experimental and control groups, indicating that neither sutural growth nor transverse mutual rotation is controlled by intercuspation. This contradicts the concept of the rail mechanism as suggested by van der Linden,[4] which also assumes an effect of intercuspation on maxillary sutural growth.

In the first period no differences in increase of dental arch width between the control and the experimental animals was found. In the second period the dental arch width of the deciduous second molars and the first permanent molars increased faster in the experimental group than in the control animals.

If the skeletal and the corresponding dental data are combined, differences between the groups become more apparent. In the first period the deciduous first and second molars in the control group seem to move passively with the bone. In the experimental group, however, buccal movement of the deciduous first molars is significantly faster than that of the bone. In the second period the deciduous molars and the permanent first molars seem to move passively in the experimental animals, while in the control animals the buccal movements of the second deciduous molars and the first permanent molars are slower than the bone.

This means that in monkeys in which intercuspation was eliminated, the maxillary dental arch width increased relatively more than in animals with a normal intercuspation.

These findings do not fit the concept of Kantomaa and Rönning[11] who stated that the maxilla acts as a carrier for mandibular growth in the sagittal direction, or the idea of Zingeser[5] that the maxilla serves as a template to which mandibular growth adapts.

Our findings are in agreement with the concept of Sarnat,[6,7] which states that, in monkeys, intercuspation plays a guidance role in maxillary dental arch development. Our findings also support the idea of some sort of rail mechanism, but in contrast to the concept of van der Linden,[4] which assumes a stimulation of transverse growth of the maxillary dentition by the growing mandible, intercuspation in monkeys seems to act as a restraining factor.

For a proper interpretation of the data, spatial relationships between the jaws must to be considered. In juvenile monkeys, unlike in humans, the base of the maxillary structures is wider than the base of the mandibular structures in the premolar and molar region, as revealed by CT-scans (unpublished data). Adjustment of the dental arch width dimension of the two jaws in humans requires a widening of the maxillary arch and thus a propulsive action of the mandibular dentition, while in monkeys the maxillary dentition has to adapt to a narrow mandibular dental arch. A further indication that this indeed might be the case is found in the inclination of the posterior teeth. In humans the mandibular posterior teeth are lingually inclined and the maxillary ones buccally inclined, while in monkeys a reversed inclination of the posterior teeth is found.

The findings of our study suggest that the concept of van der Linden[4] must be modified: The transverse development of the maxillary dental arch seems to be guided in a stimulating or restraining way by the mandibular arch by means of the intercuspation of the posterior teeth. The ratio of the transverse growth capacities of both jaws might determine the trend of the interaction.

Another necessary modification in the rail mechanism hypothesis might be that the coordinating role is restricted to the development of the dental arch and that midpalatal sutural growth is not involved.

Conclusions

This experiment in *M. fascicularis* on the role of intercuspation in the transverse maxillary development leads to the following conclusions:

1. Intercuspation is likely most responsible for guiding the teeth into their occlusal relationships with the opposing arch.
2. Intercuspation does not contribute to the transverse growth and development of the maxillary bone in *M. fascicularis*.

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References

1. Schwartz AM. Lehrgang der Gebissregelung. 2nd ed. Wien-Innsbruck: Urban and Schwarzenberg, 1951.
2. van der Linden FPGM. Development of the Dentition. Chicago: Quintessence, 1983.
3. Brace CL. Occlusion to the anthropological eye. In: McNamara JA Jr, editor. Biology of Occlusal Development. Monograph 7, Craniofacial Growth Series, Ann Arbor: Center for Human Growth and Development, University of Michigan 1977: pp 179-209.
4. van der Linden FPGM. Facial growth and facial orthopaedics. Kingston-upon-Thames: Quintessence, 1986.
5. Zingeser MR. Occlusofacial morphological integration. In: Zingeser MR, editor. Craniofacial Biology of Primates. Symp. IVth Int. Congr. Prim. Vol. 3 . Basel: S. Karger, 1973; 241-257.
6. Sarnat BG. Palatal and facial growth in *Macaca rhesus* monkeys with surgically produced palatal clefts. Plast Reconstr Surg 1958; 22: 29-41.
7. Sarnat BG The postnatal maxillary-nasal-orbital complex: some considerations in experimental surgery. In: McNamara JA Jr, editor. Factors affecting the growth of the midface. Monograph 6, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development. University of Michigan, 1976: pp 101-129.
8. Petrovic AG, Stutzmann JJ, Oudet CL. Control processes in the postnatal growth of the condylar cartilage of the mandible. In McNamara JA Jr, editor. Determinants of mandibular form and growth. Monograph 4, Craniofacial Growth Series, Ann Arbor, Center for Human Growth and Development, University of Michigan, 1975: pp 101-153.
9. Stutzmann JJ, Petrovic AG. Experimental analysis of general and local extrinsic mechanisms controlling upper jaw growth. In: McNamara JA Jr, editor. Factors affecting the growth of the midface. Monograph 6, Craniofacial Growth Series, Ann Arbor, Center for Human Growth and Development, University of Michigan, 1976: pp 205-238.
10. Petrovic AG, Stutzmann JJ. Further investigations into the functioning of the peripheral comparator of the Servo System (Respective positions of the upper and lower dental arches) in the control of the condylar cartilage growth rate of the lengthening of the jaw. In: McNamara JA Jr, editor. The biology of occlusal development, Monograph 7, Craniofacial Growth Series, Ann Arbor, Center for Human Growth and Development, University of Michigan 1977: pp 255-291.
11. Kantomaa T, Rönning O. Effect of growth of the maxilla on that of the mandible. Eur J Orthod 1985; 7: 267-272.
12. van der Linden FPGM. The significance of growth research for orthodontics. In: Transactions of the European Orthodontic Society 1971: pp 61-68.
13. Moffett B. Remodeling of the craniofacial skeleton produced by orthodontic forces. In: Zingeser MR, editor. Craniofacial biology of primates. Symp. IVth Int. Congr. Prim. Vol. 3 - Basel: S Karger, 1973; 180-190.
14. Watts ES. Adolescent growth and development of monkeys, apes, and humans. In: Watts ES, editor Non-human primate models for human growth and development. Monographs in Primatology, 6. New York: Alan R Liss Inc, 1985: pp 41-65.
15. Sirianni JE. Non-human primates as models for human craniofacial growth. In: Watts ES, editor. Non-human primate models for human growth and development. Monographs in Primatology 6. New York: Alan R Liss Inc, 1985: pp 95-124.
16. Duterloo HS, Enlow DH. A comparative study of cranial growth in *Homo* and *Macaca*. Am J Anat 1970; 127: 357-368.
17. Enlow DH. Facial growth and development in the Rhesus monkey. In: Enlow DH, editor. Handbook of Facial Growth, 3rd ed. Philadelphia: Saunders. 1990: 241-250.
18. Ostyn JM, Maltha JC, van der Linden FPGM. Age assessment in infant crab-eating monkeys (*Macaca fascicularis*) based on tooth development. 1994; J Zool 1995;235:247-252.
19. Björk A. Facial growth in man, studied with the aid of metallic implants. Acta Odontol Scand 1955; 13: 9-34.
20. Björk A. The use of metallic implants in the study of facial growth in children: method and application. Am J Phys Anthrop 1968; 29: 243-254.
21. Swindler DR, Sirianni JE. Palatal growth rates in *Macaca nemestrina* and *Papio cynocephalus*. Am J Phys Anthrop 1973; 38: 83-92.
22. van der Linden FPGM, Boersma H, Peters KA, Raaben J. Three-dimensional analysis of dental casts by means of the Optocom. J Dent Res 1972; 51: 1100.
23. Björk A, Skieller V. Postnatal growth and development of the maxillary complex. In: McNamara JA Jr, editor. Factors affecting the growth of the midface. Monograph 6. Craniofacial Growth Series. Ann Arbor: Center for human growth and development, University of Michigan 1976; 61-99.