The role of interdigitation in sagittal growth of the maxillomandibular complex in Macaca fascicularis

J. M. Ostyn, DDS,[a] J. C. Maltha, PhD,[b] M. A. van 't Hof, PhD,[c] and F.P.G.M. van der Linden, DDS, PhD[d]
Nijmegen, The Netherlands

The role of the interdigitation of posterior teeth in maxillomandibular growth and development was studied longitudinally in *Macaca fascicularis* monkeys. Fourteen monkeys were divided into a control group ($n = 7$) and an experimental group ($n = 7$). At the start of the study, the mean age of the animals was 29 weeks. At that stage the interdigitation in the experimental group was eliminated by grinding the cusps of the molars and canines. The animals were followed until 143 weeks of age and studied with the aid of tantalum implants and lateral radiographs. The findings indicated that elimination of the interdigitation resulted in a deviating anteroposterior relationship between the jaws and a significant inhibition of the vertical growth of the maxilla in the second half of the experimental period, while total face height was not noticeably affected. As a result, a more prognathic mandible and a more mesial occlusion developed. It can be concluded that the interdigitation plays a role in the regulation of vertical and anteroposterior facial growth and constitutes an important factor in the jaw relation in *Macaca fascicularis* monkeys. (AM J ORTHOD DENTOFAC ORTHOP 1996;109:71-8.)

The anteroposterior and transverse development of the jaws in human beings is assumed to be, at least partly, coordinated by the occlusion and interdigitation of the posterior teeth. This view emerged from physical, anthropologic, as well as clinical considerations.[1,2] Further, it has been suggested on a hypothetical basis that occlusion and interdigitation influence nasomaxillary and alveolar growth.[3]

Various animal experiments have been performed to study the role of interdigitation in the coordination of facial growth in sagittal direction. After superior repositioning of the maxilla in *Macaca fascicularis*, Nanda and co-workers[4,5] found a reduction in growth of both jaws that led to the assumption that interdigitation played a role in maxillomandibular growth. Petrovic and co-workers,[6-8] performed a variety of experiments in rats, leading to the conclusion that the occlusion is an important factor in the coordination of the lengthening of the jaws.

In experiments on *Macaca mulatta*, Sarnat[9,10] noted no significant gross difference in maxillary growth after resection of the median and transverse palatine sutures, and he stated that the mandible may have guided the maxillary growth by means of the occlusion. On the other hand, Kantomaa and Rönning[11] did not find evidence in experiments on rats for the assumption that the relation between the jaws is regulated by interdigitation, and they stated that the mandible may be carried forward passively with the growth of the maxilla.

However, in all experimental approaches so far, the original craniofacial development has been disturbed by surgical intervention or by growth restriction or stimulation, which limits extrapolation of these findings to normal growing systems.

To meet this shortcoming, in the present study the contribution of interdigitation to sagittal development of the maxillomandibular complex is investigated by using an experimental set-up in which growth centers are not directly disturbed or affected. As experimental animal, the *Macaca fascicularis* species was used since its basic plan of growth of face and cranium parallels that found in human beings.[12,13]

MATERIALS AND METHODS

Eleven male and three female laboratory-born monkeys *(Macaca fascicularis)* were used in this study. The animals were randomly divided in a control group ($n = 7$) and an experimental group ($n = 7$). The sexes were combined in the analysis of the data. This is

---

[a] In private practice.

[b] Associate Professor in Oral Biology, Department of Orthodontics and Oral Histology, University of Nijmegen, Nijmegen, the Netherlands.

[c] Senior Consultant in Medical Statistics, Department of Medical Statistics, University of Nijmegen, Nijmegen, the Netherlands.[d]

Professor and Chairman of the Department of Orthodontics and Oral Histology, University of Nijmegen, Nijmegen, the Netherlands.[d]

0889-5406/96/$5.00 + 0 8/1/56267

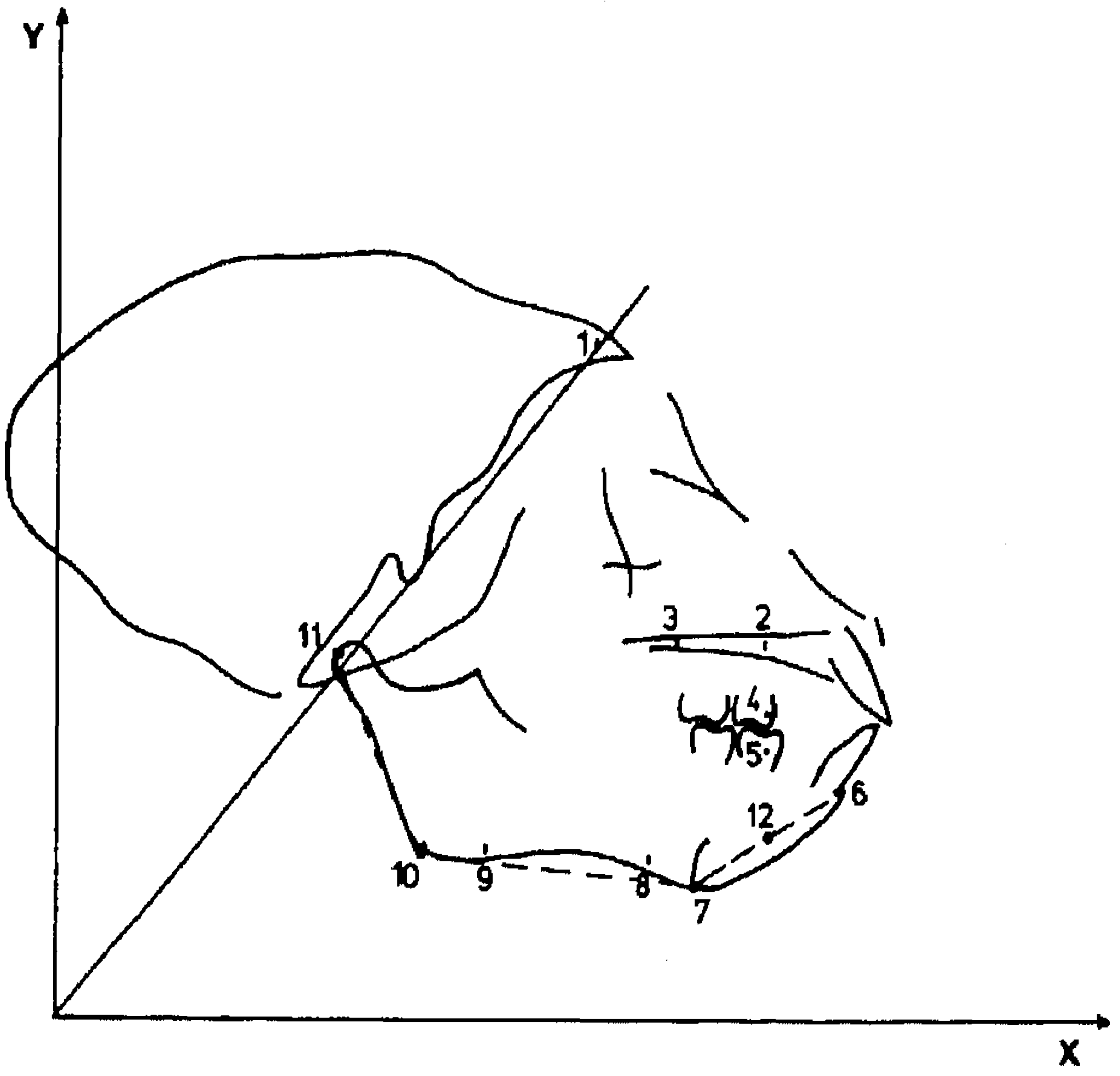

Fig. 1. Schematic drawing of skull of *Macaca fascicularis* and Cartesian coordinate system defined by anterior cranial base line and occlusal plane. Landmarks and positions of implants in bones and teeth are indicated. See text for definitions.

legitimate as sexual dimorphism in the Macaca species becomes apparent only after the age of approximately 3 years and therefore could be neglected for this study. All animals showed a neutroocclusion of the posterior teeth and an occlusion in the anterior region between a nearly end-to-end to a slight overjet and overbite. None of the animals had a malocclusion or a skeletal deviation.

At the start of the study, the mean age of the animals was 29 weeks. At that time, the onset of crypt formation of the mandibular permanent canines had just started, and the second deciduous molars had recently emerged.[14] All animals were followed until 143 weeks of age except for one male animal from the control group, which accidentally died at the age of 80 weeks.

The animals were housed in the Central Animal Laboratory of the University of Nijmegen, and they received a standard diet of wet compressed pellets and drinking water ad libitum.

Before the start of the study, tantalum implants (Ole Dich, Hvidovre, Denmark), which measured 1.2 mm in length and 0.5 mm in width, were inserted as bone markers in each monkey.[15,16] Before implantation, the animals were anesthetized with 10 mg/kg Ketamine (Nimatek, A.U.V., Cuijk, The Netherlands). Subsequently 0.1 ml Thalamonal (Janssen Pharmaceutica, Beerse, Belgium) and 0.25 mg Atropine (Atropine Sulphate 0.5 mg/ml, A.C.F. Pharma BV, Maarssen, The Netherlands) were administered intramuscularly. Skin incisions were made along the lower border of the mandible and, after preparing a small hole, two implants were hammered into the bone. The same procedure was followed for inserting implants in the frontal bone. Further implants were inserted in the palate through the mucosa (Fig. 1).

As soon as possible after emergence, all deciduous and permanent molars were provided with tantalum balls, with a diameter of 0.5 mm. To that end a small hole was prepared in the buccal surface of each molar in which the implant was secured with composite material.

In the animals of the experimental group interdigitation was eliminated by grinding successively the cusps of the deciduous molars and canines and those of the first permanent molars in both dental arches until a flat surface was obtained. The grinding was carried out under general anesthesia at the first regular session after emergence. The cusps were gound without jeopardizing the vitality of the pulp. The grinding did not affect the approximal contacts of the deciduous and permanent molars.

Initially, standardized lateral cephalometric radiographs were taken 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 central beam of the x-ray machine (Philips Practix, The Hague, The Netherlands) was orientated perpendicular to the midsagittal plane of the cranium and the film. The distance between the x-ray focus and the midsagittal plane was fixed at 4.5 m and the distance between the latter and the x-ray film at 9 cm.

The radiographs were made with 70 kV at 20 mA and 8-second exposure time. After the maxillary first permanent molars had reached the level of the occlusal plane, the exposure time was increased to 12 seconds. The radiographs were taken with the teeth in occlusion.

If a radiograph showed that a bone or tooth implant had became loose, a new one was inserted immediately, and the radiographic procedure was repeated. This was necessary for 8 of 70 bone implants and for 24 of 84 tooth implants over the total experimental period of 2.5 years. Growth changes and displacements were analyzed in a constructed Cartesian coordinate system, which is comparable to the coordinate system as used by McNamara and Bryan[17] and Nanda et al.[18] (Fig. 1). On the last collected lateral radiograph, the functional occlusal plane was determined, with the mesial anatomic contact points of the mandibular first and second deciduous molars. A line parallel to the occlusal plane, but out of the measuring area was constructed that served as the x-axis. The origin was defined as the point of intersection between the x-axis and the line through the frontal bone implant and the floor of Sella turcica (anterior cranial base line). A line perpendicular to the x-axis through the origin served as the y-axis.

All preceding radiographs were superimposed on the frontal bone marker and the anterior cranial base line, and the same coordinate system served as a reference frame. This means that skeletal and dental changes and displacements of the maxillary and mandibular structures could be quantified in relation to the position of the frontal bone implant. Also mutual distances between other implants could be calculated. The coordinates of the landmarks and the bone and tooth implants were digitized with an electronic measuring table equipped with a microscope, resulting in a 10-fold magnification.

The following measuring points were used (Fig. 1):

1. frontal bone implant (FB)
2. anterior maxillary bone implant (AU)
3. posterior maxillary bone implant (PU)
4. tooth implant in the maxillary first deciduous molar (TU)
5. tooth implant in the mandibular first deciduous molar (TL)
6. infradentale = junction point between the anterior outline of the mandibular central incisor and the adjacent alveolar bone (ID)
7. menton = lowermost point of the symphysis (Me)
8. anterior mandibular bone implant (AL)
9. posterior mandibular bone implant (PL)
10. gonion = construction point located on the intersection of the bisector of the angle of the posterior ramal plane and the mandibular plane, and the mandibular contour (Go)
11. condylion = the most postero-superior point on the condyle (Co)
12. symphyseal point = construction point on the middle of a line between infradentale (ID) and menton (Me): (Sy)[17]

Nearly all growth parameters as calculated from these points are related to bone or tooth implants. Although those markers are placed as accurately as possible in the same regions, they cannot be considered as identical for the different animals. This means that for the description of growth not the distances themselves can be used, but that the increments, i.e., the changes in distances in time have to be considered. The use of increments has also the advantage that in case an implant was replaced, the analysis of the growth could easily be continued.

For analysis of differences in changes of maxillary structures between the two groups relative to the frontal bone implant, increments in vertical and horizontal direction of the distances FB-AU and FB-PU were calculated. A comparable approach was followed for differences in position of the maxillary dentition in relation to maxillary structures by calculating increments of distance PU-TU in vertical and in horizontal direction.

To study differences between both groups in mandibular position relative to the frontal bone implant, increments of distances FB-AL and FB-PL were calculated in vertical and horizontal direction. Further increments of the overall length of the mandible (Co-Sy) and the changes in the gonial angle (Me-Go-Co) were determined. To describe changes in position of the mandibular dentition within the mandible, increments of distance TL-PL in vertical and horizontal direction were calculated.

To quantify differences in the jaw relation between both groups and in the position of the mandible in relation to the maxillary dentition, increments in vertical and horizontal direction of the distances PU-AL, PU-PL, and TU-PL were calculated.

Differences between the two groups of changes in occlusion were studied by calculating increments of distances TU-TL in horizontal direction.

The mean increments of the experimental group were compared with those of the control group by using the t test.

For the interpretation of the findings, the total period under study (29 to 143 weeks of age) was divided in five subperiods: An initial one covering the first 10 weeks and four subperiods of 26 weeks each. The initial period, the four subperiods, and the main period (consisting of the four subperiods) were analyzed separately. The data obtained from the initial period showed such a large variation that it was not meaningful to include them in the statistical analysis of the experiment. This large variation was mainly due to difficulties with the positioning of the youngest animals in the cephalostat. Facial growth was analyzed by calculating mean increments in micrometers per week over each period studied.

The total error of the method, which is composed of the positioning and measurement error, was determined by measuring five sets of independent radiographs from two animals of 86 weeks, and two other animals of 110 weeks of age. Between the exposures, the animals were removed and replaced in the cephalostat.

The measurement error was studied by double determination of all variables recorded in a longitudinal series of one monkey.

RESULTS

Error of the method

The total error of the method is composed of the error of the radiographic procedure and the measurement error due to inexact defining of the measuring points, to inaccuracy of the measuring instrument, and the error of the observer. A suitable description of the errors could be obtained by specifying the error in vertical and in horizontal direction, separately for all distances and increments used. In total, eight categories of errors were analyzed. Most of the errors were 20 μm or less. Only the errors in the distances and increments in a horizontal direction in relation to the frontal bone implant showed comparatively high values of 38 and 60 μm, respectively. This error was mainly caused by inaccuracies associated with the determination of the anterior cranial base line.

The total error of the gonial angle was found to

Table I. Mean increments (m) and SEM in μm per week of the distances between maxillary bone implants and the frontal bone implant

Age (in weeks)	*Vertical*												*Anteroposterior*											
	FB-AU						*FB-PU*						*FB-AU*						*FB-PU*					
	Control			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*		
	n	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*
29-39	7	54	±11	6	43	±20	7	68	±11	6	42	±11	7	102	±24	6	83	±8	7	98	±25	6	84	±7
39-65	7	42	±8	7	32	±4	7	50	±8	7	42	±5	7	64	±7	7	74	±6	7	62	±7	7	70	±6
65-91	6	31	±4	6	28	±5	6	43	±4	7	35	±4	6	71	±14	7	62	±7	6	69	±5	7	65	±5
91-117	6	35	±8	7	20	±2	6	43	±6	7	25	±3*	6	45	±8	7	47	±4	6	43	±9	7	48	±4
117-143	6	34	±3	6	19	±3*	6	40	±4	7	24	±4*	6	57	±8	6	46	±4	6	55	±8	7	41	±8
39-143	6	35	±4	6	25	±3	6	43	±5	7	32	±3	6	60	±7	6	57	±3	6	58	±7	7	55	±3

$^{*}p < 0.05$.

Table II. Mean increments (m) and SEM in μm per week of the distances between the maxillary tooth implant and the posterior maxillary bone implant

Age (in weeks)	*Anteroposterior*					
	PU-TU					
	Control			*Experimental*		
	n	*m*	*SEM*	*n*	*m*	*SEM*
29-39	6	59	±8	5	54	±11
39-65	7	36	±3	7	37	±4
65-91	6	44	±3	7	34	±6
91-117	6	21	±2	7	29	±4
117-143	6	18	±5	6	18	±4
39-143	6	29	±1	6	31	±2

be 1.1° and that of the mandibular length 32 μm, which was considered to be acceptable. The measurement error in the increments was calculated as duplicate error and varied for all categories between 12 and 18 μm. The measurement error in the gonial angle showed a value of 0.7°.

Findings

In all considered periods, the mean vertical displacement of the maxillary structures relative to the frontal bone implant (FB-AU and FB-PU) was larger in the control group than in the experimental group (Table I). The more the experiment proceeded, the more these differences became obvious, resulting in quite a divergent course of displacement of the maxillary structures for both groups. Significant differences in increments were found for distance FB-AU in the period from 117 to 143 weeks of age and for distance FB-PU from 91 to 143 weeks of age. Over the main period, both maxillary bone implants showed smaller mean inferior displacements in the experimental than in the control group, but these differences were only borderline significant.

Comparing anterior (FB-AU) and posterior (FB-PU) vertical changes, nearly all posterior vertical increments seemed to be larger than the anterior ones in both groups, although a paired *t* test revealed no significant differences for separate periods or for the main period of the experiment. The mean increments per week of the anteroposterior displacement of the maxillary structures reduced for all animals when growth proceeded. No difference could be noted between both groups, neither for any period nor for the main period of the experiment (Table I).

The mesial migration of the maxillary dentition in relation to the posterior maxillary bone implant, (distance PU-TU) (Table II) was about the same in both groups. This conformity applied to the different periods, as well as to the main period of the experiment. Generally, the migration rate decreased with age in all animals.

The inferior displacement of the mandible relative to the frontal bone implant, as measured by the distances FB-AL and FB-PL in vertical direction revealed no significant difference between the two groups (Table III).

In the anteroposterior direction, larger anterior displacement of the mandible relative to the implant in the frontal bone (FB-AL, FB-PL) could be suggested for the initial period more in the control group than in the experimental group. Over the

Table III. Mean increments (m) and SEM in μm per week of the distances between mandibular bone implants and the frontal bone implant

	Vertical												*Anteroposterior*											
	FB-AL						*FB-PL*						*FB-AL*						*FB-PL*					
	Control			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*		
Age (in weeks)	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*
29-39	7	189	±24	6	171	±34	7	221	±22	6	202	±36	7	164	±34	6	141	±18	7	154	±32	6	137	±20
39-65	7	146	±15	7	154	±9	7	170	±17	7	171	±9	7	99	±15	7	133	±6	7	94	±14	7	127	±5
65-91	6	101	±6	7	121	±12	6	125	±7	7	133	±12	6	102	±15	7	100	±10	6	100	±16	7	100	±1
91-117	6	105	±10	7	90	±6	6	110	±10	7	96	±6	6	57	±12	7	71	±9	6	52	±11	7	70	±9
117-143	6	95	±5	7	80	±8	6	110	±6	7	89	±9	6	72	±10	7	69	±5	6	73	±10	7	69	±6
39-143	6	110	±4	7	111	±6	6	127	±4	7	122	±7	6	82	±8	7	93	±2	6	80	±8	7	92	±2

Table IV. Mean increments (m) and SEM in μm per week of the mandibular length; mean increments (m) and SEM in degrees per week of the gonial angle; mean increments (m) and SEM in μm per week of the distance between the mandibular tooth implant and the mandibular posterior bone implant

	Co-Sy						*Me-Go-Co*						*Anteroposterior*					
													TL-PL					
	Control			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*		
Age (in weeks)	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*
29-39	7	250	±20	6	264	±42	7	−1.14	±1.74	6	0.92	±1.64	6	−9	±10	7	−12	±8
39-65	7	200	±19	7	207	±15	7	−0.70	±0.26	7	−0.74	±0.45	7	−10	±6	7	4	±4
65-91	6	150	±10	7	175	±11	6	−0.57	±0.29	7	0.38	±0.16*	6	−13	±4	7	−12	±4
91-117	6	154	±10	7	140	±7	6	0.68	±0.28	7	0.05	±0.32	6	−9	±4	7	−1	±2
117-143	6	140	±18	7	117	±14	6	0.48	±0.32	7	−0.36	±0.21	6	9	±7	7	9	±4
39-143	6	160	±9	7	160	±5	6	−0.06	±0.14	7	−0.17	±0.13	6	−6	±3	7	0	±2

Negative changes indicate a closure of the gonial angle or a decrease in a distance.
*$p < 0.05$.

main period, the anterior displacement of the mandible in the experimental group seemed to be larger than in the control group. However, these differences were not significant, probably due to the large standard errors for measurements in horizontal direction when the frontal bone implant is involved. For both groups, the decrease in growth rate and the pattern of displacement were comparable.

The length of the mandible, as represented by distance Co-Sy, also showed a continuously decreasing growth rate throughout the experimental period and seemed not be affected by the elimination of interdigitation (Table IV). That also applies to the gonial angle (Me-Go-Co) for which no significant differences were found except from 65 to 91 weeks of age (Table IV).

None of the recordings of the mandibular dentition within the mandible, as measured by variable TL-PL, in the anteroposterior direction, showed any significant differences between both groups (Table IV).

The increase in the distances in vertical direction between the maxillary and the mandibular bone implants (PU-AL) and (PU-PL) tended to be larger in the experimental than in the control group in almost every period. However, significant differences were only found for variable PU-AL from 65 to 91 weeks of age and for the main period of the experiment. For the distance PU-PL, no significant differences between the groups were found for any of the periods (Table V).

In the experimental as well as in the control group, the mandible moves more anteriorly than

Table V. Mean increments (m) and SEM in μm per week of the distances between the maxillary bone implants or the maxillary dental implants, and the mandibular bone implant

Age (in weeks)	*Vertical*												*Anteroposterior*																	
	PU-AL						*PU-PL*						*PU-AL*						*PU-PL*						*TU-PL*					
	Control			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*			*Control*			*Experimental*		
	n	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*	*n*	*m*	*SEM*
29-39	7	120	±21	6	129	±25	7	152	±21	6	159	±27	7	66	±11	6	57	±13	7	56	±8	6	52	±15	6	3	±15	5	−3	±19
39-65	7	95	±8	7	112	±7	7	120	±10	7	129	±7	7	37	±9	7	63	±7*	7	32	±9	7	57	±6*	7	4	±7	7	−20	±6*
65-91	6	58	±7	7	86	±9*	6	83	±6	7	97	±10	6	33	±6	7	36	±6	6	31	±6	7	36	±6	6	12	±5	7	−2	±7
91-117	6	62	±5	7	65	±4	6	67	±4	7	71	±5	6	14	±3	7	23	±5	6	8	±4	7	23	±6	6	12	±3	7	6	±6
117-143	6	56	±5	6	57	±7	6	70	±3	6	66	±8	6	17	±4	6	27	±5	6	18	±4	6	28	±6	6	0	±5	7	−6	±5
39-143	6	66	±1	6	81	±5*	6	84	±2	6	93	±5	6	25	±3	6	39	±3*	6	22	±2	6	37	±3**	6	8	±3	7	−6	±3**

Negative changes indicate a decrease in distance.
*$0.01 \leq p < 0.05$.
**$p < 0.01$.

Table VI. Mean increments (m) and SEM in μm per week of the distances between the tooth implants

Age (in weeks)	*Anteroposterior*					
	TU-TL					
	Control			*Experimental*		
	n	*m*	*SEM*	*n*	*m*	*SEM*
29-39	6	0	±10	5	20	±18
39-65	7	6	±3	7	17	±6
65-91	6	0	±2	7	13	±6
91-117	6	−4	±3	7	−5	±5
117-143	6	−9	±10	7	0	±3
39-143	6	−1	±2	7	6	±2*

Negative changes indicate a decrease in distance.
*$p < 0.05$.

the maxilla. This difference is significantly more pronounced in the experimental than in the control group, if the main period is considered (Table V).

As could be expected from the data in Table II and V, the maxillary dentition in the control group moved more in the anterior direction than did the mandibular bone (TU-PL > 0). In the experimental group, on the contrary, the maxillary dentition moved less anteriorly than the mandible (TU-PL < 0). This results in significant differences between the groups for the period from 39 to 65 weeks of age and for the main period (Table V).

Distance TU-TL in the anteroposterior direction is a measure for the occlusion. This distance showed a significantly larger increment for the experimental group than for the control group over the main period of the experiment. This indicates that a more mesioocclusion developed in the experimental than in the control group, as the mandibular tooth implant became more mesially positioned relative to the maxillary one (Table VI).

DISCUSSION

The role of the interdigitation in the sagittal development of the maxillomandibular complex was studied in an experimental set-up without surgical intervention, growth restriction, or stimulation. Skeletal, as well as dental, parameters were used for the analysis.

Findings from this longitudinal study indicate that elimination of the interdigitation results in a deviating maxillomandibular development.

The development of the maxillary structures in a vertical direction was reduced by the elimination of the interdigitation. This inhibition became more pronounced as the follow-up advanced. At the posterior region, the reduction became significant at week 91, and at the anterior region from week 117 on.

Because the differences between the control and the experimental group only became significant more than 65 weeks after the start of the experiment, the grinding of the cusps of the teeth itself could not be held responsible for this effect. Although a quite divergent course in vertical development at the maxillary structures of both groups existed, no significant inhibition of development was found if the total experimental period is taken into account. This might be due to relative large individual variation at the start of the experiment.

Since the establishment of the initial occlusal contact of the first permanent molars more or less coincides with the start of a significant decrease in vertical development of the posterior part of the maxillary structures, the experimental findings seem to confirm the assumption of Moyers and Wainright[3] that the occlusion of these teeth influences the nasomaxillary and alveolar growth.

In the experimental animals, the smaller increase in vertical development of the maxillary structures at the end of the experimental period coincides with a larger increase in height at the maxillary and mandibular alveolar process, resulting in a seemingly unaffected development of the vertical facial height.

As described elsewhere, the palatal plane in the young and adolescent untreated *Macaca fascicularis* tends to tilt in an upward and forward direction during growth.[18,19] The palatal plane of the experimental group seemed to undergo an accentuated tilting as compared with the control group, because the vertical growth reduction at the anterior part of the maxillary structures was slightly larger than at the posterior part.

In the anteroposterior direction, the development of the maxillary structures in the experimental group seemed to be unaffected. The same applies to the structure of the mandible, as represented by its total length and gonial angle, as the mandible attained a significantly more anterior position in relation to the maxilla. This indicates that adaptations necessary for proper functioning of the temporomandibular joint probably take place at the glenoid fossa, which is in accordance with the findings of Hinton and McNamara[20] in *Macaca mulatta*. The final outcome is that a more prognathic face developed in the experimental than in the control group.

From these findings, it can be concluded that interdigitation is an important factor in the control of the anteroposterior relationship between the jaws and, as such, supports the ideas of Brace,[1] Van der Linden,[2] Nanda et al.,[4,5] and Sarnat.[9,10] That also applies to the cybernetic model of Petrovic et al.[6-8] in which it is assumed that the occlusion is the basis for the adjustment of the relationship between the jaws. It further suggests that, if occlusion is eliminated, the correlation in anteroposterior growth between the jaws is lost.

The fact that the structure and size of the mandible did not seem to adapt to its deviating position, might indicate that its growth is more or less independent of the interdigitation. The more prognathic facial development in the experimental groups resulted in a more mesial occlusion as the mandibular molars did not show signs of mesiodistal migration in relation to the mandibular basal structure.

It is most likely that in the untreated *Macaca fascicularis* the adjustment of the anteroposterior growth between the jaws is mainly realized by positional adaptation of the mandible and of the mandibular posterior teeth.

CONCLUSIONS

This experiment on juvenile *Macaca fascicularis* on the role of the interdigitation in the development of the maxillomandibular complex leads to the following conclusions:

1. Interdigitation plays a role in the vertical development of the maxillary structures but seems not to influence their anteroposterior development.
2. Interdigitation plays a role in the anteroposterior positioning of the mandible, but seems not to affect its growth.
3. Elimination of interdigitation results in a skeletal Class III pattern. Lack of distal migration of the posterior teeth through the mandibular basal structures leads indirectly to mesioocclusiòn.
4. Under normal conditions, interdigitation contributes to growth and development of the maxillomandibular complex in *Macaca fascicularis*.

REFERENCES

1. Brace CL. Occlusion to the anthropological eye. In: McNamara JA Jr, ed. The biology of occlusal development. Monograph 7, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1977.
2. Van der Linden FPGM. Facial growth and facial orthopedics. Chicago: Quintessence Publishing, 1986.
3. Moyers RE, Wainright RL. Skeletal contributions to occlusal development. In: McNamara JA Jr, ed. The biology of occlusal development. Monograph 7. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1977.
4. Nanda R, Sugawara J, Topazian R. Effect of maxillary osteotomy on subsequent craniofacial growth in adolescent monkeys. AM J ORTHOD 1983;83:391-407.
5. Nanda R, Sugawara J. Mandibular adaptations following total maxillary osteotomy in adolescent monkeys. AM J ORTHOD 1983;83:485-94.
6. Petrovic AG, Stutzmann JJ, Oudet CL. Control processes in

the postnatal growth of the condylar cartilage of the mandible. In: McNamara JA Jr, ed. Determinants of mandibular form and growth. Monograph 4, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1975.

7. Stutzmann JJ, Petrovic AG. Experimental analysis of general and local extrinsic mechanisms controlling upper jaw growth. In: McNamara JA Jr, ed. Factors affecting the growth of the midface. Monograph 6, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1976.
8. Petrovic AG, Stutzmann JJ. Further investigations into the functioning of the peripheral 'comparator' of the servosystem (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, ed. The biology of occlusal development. Monograph 7, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1977.
9. Sarnat BG. Palatal and facial growth in Macaca rhesus monkeys with surgically produced palatal clefts. Plast Reconstr Surg 1958;22:29-41.
10. Sarnat BG. The postnatal maxillary-nasal-orbital complex: some considerations in experimental surgery. In: McNamara JA Jr, ed. Factors affecting the growth of the midface. Monograph 6, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1976.
11. Kantomaa T, Rönning O. Effect of growth of the maxilla on that of the mandible. Eur J Orthod 1985;7:267-72.
12. Moffett B. Remodeling of the craniofacial skeleton produced by orthodontic forces. In: Zingeser MR, ed. Craniofacial biology of primates. Vol. 3. New York: S. Karger, 1973.
13. Enlow DH. Facial growth and development in the Rhesus monkey. In: Enlow DH, ed. Handbook of facial growth. Philadelphia: WB Saunders, 1990.
14. Ostyn JM, Maltha JC, Van der Linden FPGM. Estimation of age in young monkeys (Macaca fascicularis) based on dental development. J Zool 1994 [in press].
15. Björk A. Facial growth in man, studied with the aid of metallic implants. Acta Odontol Scand 1955;13:9-34.
16. Björk A. The use of metallic implants in the study of facial growth in children: method and application. Am J Phys Anthropol 1968;29:243-54.
17. McNamara JA Jr, Bryan AF. Long-term mandibular adaptations to protrusive function: an experimental study in Macaca mulatta. AM J ORTHOD DENTOFAC ORTHOP 1987; 92:98-108.
18. Nanda R, Baume RM, Tanne K, Sugawara J. Longitudinal study of craniofacial growth in Macaca fascicularis. Am J Phys Anthropol 1987;73:215-25.
19. Ostyn JM, Maltha JC, Van der Linden FPGM. A longitudinal study of dento-craniofacial growth in Macaca fascicularis. A radiographic study. Zool 1994 [in press].
20. Hinton RJ, McNamara JA, Jr. Temporal bone adaptations in response to protrusive function in juvenile and young adult rhesus monkeys (Macaca mulatta). Eur J Orthod 1984;6:155-74.

Reprint requests to:
Dr. J. C. Maltha
Department Orthodontics and Oral Histology
University of Nijmegen
P.O. Box 9101
6500 HB NIJMEGEN
The Netherlands