

Effects of altered mandibular function on mandibular growth after condylectomy

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SUMMARY The purpose of this study was to investigate the effect of protruded mandibular function on bilaterally condylectomized mandibles of growing rats. Sixty 4-week-old rats were divided into three experimental and two control groups each consisting of 12 animals as follows: (A) bilateral condylectomy was performed and the mandible was left to function normally; (B) the mandible was protracted forward without any condylectomy; (C) after bilateral condylectomy, the mandible was forced to function in a protruded position; (D) the animals were used as controls without any operation or appliance; and (E) a sham operation was performed in the condylar area but no appliance was used.

Mandibular protraction was achieved by means of a specific appliance acting via rubber bands pulling the mandible in a straight, forward direction with a force of 25 g for 12 hours/day. The experimental period was 30 days. Lateral and dorsoventral radiographs were taken and vital dyes were administered on days 1 and 30 for all animals. Cephalometric analysis included 10 measurements.

Findings resulting from statistical analysis of measurements in the five groups are summarized as follows: (i) between group A and groups D and E, less growth was found in group A; (ii) between group B and groups D and E, more growth was found in group B; (iii) between group A and group B, more growth was found in group B; (iv) between group A and group C, more growth was found in group C; and (v) between group B and group C, more growth was found in group B. These findings support the conclusion that although mandibular propulsion enhances growth even after condylectomy, the condyle seems to be an essential element for normal growth and development.

Introduction

Although the effect of experimentally altered mandibular function on craniofacial growth and specifically on the growth of the mandible has been extensively studied, there is as yet no definite answer as to whether this effect is directly influenced by the absence of the condyle or whether the presence of the condyle remains a crucial factor for the expression of the effect of altered mandibular function.

Factors involved in the control of the growth process include genetic control, differential cellular responses, neurotrophic control, membrane control, oxygen tension, bioelectric potentials, pH levels, temperature effects, chalone-like inhibitors and stimulators, cyclic AMP, vasomotor control, nutrition, and

enzymatic and hormonal factors. The important question is which are the specific trigger factors and which are subordinate or secondary (Enlow, 1973).

Mandibular growth is presumably regulated by specific combinations of all the above factors that control the mandible's size, morphology and position in the craniofacial skeleton. For many years the condyle was thought to be the most important control centre of the mandible (Sicher, 1947; Scott, 1958), and a great deal of research has been directed towards attempts to prove or disprove its primary regulatory role in mandibular growth. Two basic theories which have stemmed from the historic controversies regarding mandibular growth suggest that the condyle is either the major growth centre controlling overall mandibular growth (Rushton,

1944; Sicher, 1947; Robinson and Sarnat, 1955; Scott, 1958) or that the condyle is simply another local site that contributes only regionally to overall mandibular growth (Moss, 1960; Enlow, 1975, 1980; Petrovic *et al.*, 1975; McNamara, 1980). However, Johnston (1986) supported a broader view concerning the contribution of the mandibular condyle to the growth of the lower jaw. From his standpoint, the condyle behaves as if it were a growth centre whilst being incapable of generating the force usually attributed to an epiphysis. Being a mechanical supporter for sustaining the result of the growth changes, the condyle acts as a functional rectifier.

Several studies of condylar resection have been carried out in order to ascertain the role of mandibular cartilage in mandibular growth (Jarabak *et al.*, 1949; Sarnat, 1957; Das *et al.*, 1965; Gianelly and Moorrees, 1965; Sarnat and Muchnic, 1971; Pimenidis and Gianelly, 1972; Fuller, 1974; Bernabei and Johnston, 1978; Yozwiak, 1979). Numerous investigators have also studied the effects of induced functional or passive forward shift of the mandible on the overall mandibular growth (McNamara, 1972; Petrovic *et al.*, 1975; Tonge *et al.*, 1982; Ghafari and Degroote, 1986; Tewson *et al.*, 1988). The lack of an experimental combination of both absence of the condyle and induced mandibular protrusive position is probably the missing link in the chain of evidence concerning the role of the condyle.

Purpose of the study

The purpose of this study was to investigate the condyle's contribution on the mandibular growth of the rat, and to test Johnston's (1986) hypothesis supporting the role of the condyle as a functional rectifier. The difference from previous experimental works is that it combines the evaluation of two different parameters: (i) a genetic one, which is represented by the intrinsic condylar growth capability; and (ii) a functional one, which is represented by an induced protrusive mandibular movement. Furthermore, a hyperpropulsive appliance for the rat mandible was designed and used in order to provide a secure and reproducible forward shift of the lower jaw (Tsolakis and Spyropoulos, 1997).

Materials and methods

Sixty 4-week-old male Wistar rats were used in this study. The experiments took place in the Orthodontic Department of the Dental School in collaboration with the Experimental Laboratory of the Second Preparatory Clinic of Surgery of the Medical School of the University of Athens. The animals were obtained from the Greek Pasteur Center. The initial weight of the animals ranged from 42 to 47 grams. The animals were divided into five different groups each consisting of 12 animals—two control and three experimental—as follows: group A (experimental) included 12 rats in which bilateral condylectomy was performed and the mandible was left to function normally; group B (experimental) included 12 rats in which the mandible was protracted forwards without any previous intervention to the condyles; group C (experimental) included 12 rats in which, after bilateral condylectomy, the mandible was forced to function in a protracted position by application of the hyperpropulsive appliance; group D (control) included 12 rats that were not subjected to any operation or mandibular protraction; and group E (control) included 12 rats that were sham-operated in the right and left condylar areas, but no appliance was used. The experimental period was 30 days. The protruding appliance, whose efficacy was tested radiographically, was worn by the animals for 12 hours each day. Lateral radiographs were taken for all animals on days 1 and 30 following condylectomies and mandibular protraction.

Weight of the animals

The animals were weighed at the beginning of the experiment and every third day thereafter. The final body weight was determined immediately prior to killing (Table 1).

Protruding appliance

The mandibular protraction was achieved by an appliance described previously (Tsolakis and Spyropoulos, 1997), which consisted of an acrylic collar brace fitted to the animal's neck and incorporating wire extensions, supporting rubber bands which pulled on a band cemented to the animal's lower incisors. These rubber

Table 1 Initial and final weight data (g).

Group	Initial		Final		Difference	
	Mean	SD	Mean	SD	Mean	SD
A	43.75	1.60	120.00	2.73	76.25	2.05
B	43.50	1.83	117.83	1.53	74.33	2.35
C	43.17	2.04	116.00	1.28	72.83	1.59
D	43.67	1.67	125.58	1.31	81.92	1.31
E	43.00	1.81	124.58	1.31	81.58	1.51

Group A: bilateral condylectomy; group B: protruded mandibular function; group C: bilateral condylectomy plus protrusion; group D: controls; and group E: sham-operated.

Table 2 Statistical analysis: changes in weight gain (g) of the animals by *t*-test.

Group	B	C	D	E
A	$t = 2.13, P = 0.04^*$	$t = 4.57, P < 10^{-3}***$	$t = -8.07, P < 10^{-4}***$	$t = -7.26, P < 10^{-4}***$
B		$t = 1.83, P = 0.08$	$t = -9.77, P < 10^{-4}***$	$t = -9.00, P < 10^{-4}***$
C			$t = -15.29, P < 10^{-4}***$	$t = 13.86, P < 10^{-4}***$
D				$t = 0.58, P < 0.57$

* $P < 0.05$, *** $P < 0.001$.

bands exerted 25 g of pulling force for 12 hours per day.

Condylectomy

Through a preauricular approach, the condyle was totally exposed and a radical excision was performed. Great care was taken not to injure the surrounding anatomical parts. Trauma from the external dermic incision was kept to a minimum and suturing was performed in a most cautious fashion. The postsurgical administration of 50 mg/kg body weight of Terramycin Oxytetracycline for each rat followed, in order to prevent infection and as a vital stain for further investigations planned in this project.

Cephalograms

Lateral cephalometric radiographs were obtained for each animal on days 1 and 30, using a specifically designed cephalostat (Figure 1). The radiographs were enlarged $\times 9$ to reduce tracing errors. Tracings were carried out on 0.003 inch acetate using an England Eagle Turquoise 10 pencil with 1H drawing leads.

Radiographic method and procedure

A special cephalometer was designed consisting of a Plexiglas base with plastic vertical projections, where holes were drilled at a distance of 5 mm and through which two ear posts were inserted. The entire Plexiglas part was mounted on a wooden base, bearing, at the distal edge, a wooden vertical extension on which a film holder was constructed. On the top of the wooden extension another wooden horizontal post was mounted at an angle of 90 degrees, with a hanger at its end from where the animal was positioned by means of string tied to the upper anterior teeth (Figure 1). The animals were hung via their upper incisors from the horizontal wooden post and the ear posts were placed in a position corresponding to the animal's earholes at the plastic vertical projections. This cephalometer was mounted on a Siemens OP3 cephalometric apparatus used for regular clinical cephalometric radiographs. Thus, fixed object–film and target–film distances were obtained. All the standards for a human lateral or postero-anterior cephalometric radiograph were followed

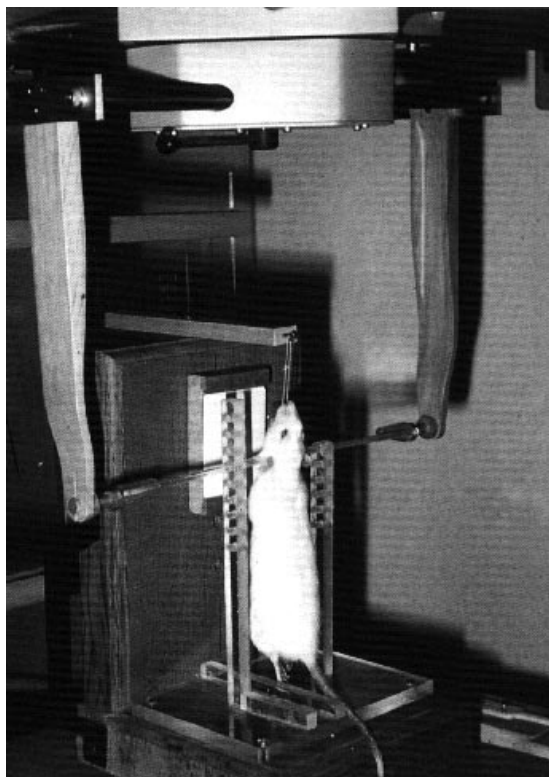


Figure 1 Cephalostat specifically designed for obtaining cephalometric radiographs of the rats.

in this procedure. The exposure was under 90 KVP, 15 mA and for 3 seconds. Standard Kodak occlusal films were used and were manually developed with a developing time of 5 minutes and a fixing time of 8 minutes. The films were washed for 1 hour after fixation and air-dried.

Cephalometric landmarks

The enlarged radiographs were traced and the following landmarks were identified in each lateral cephalometric radiograph to be used in the analysis of the skeletal changes.

- A the anterior edge to the alveolar bone on the concavity of the lower incisor
- B the most anterior point of the crown of the first lower molar
- V the most posterior point of the crown of the first lower molar
- Δ [Cd] the most superior point of the coronoid process

- E [Co] the most superior and posterior point of the condyle
- Z [Go] the most posterior apex of the angular process
- MF the posterior edge of the mandibular foramen
- I the most anterior edge of the alveolar bone on the convexity of the lower incisor
- Me the most inferior point of the lower border of the mandible
- Go' the most inferior point of the angular process
- Pa the most superior point of the parietal bone
- T the most inferior point of the tympanic bone
- Oc the most posterior point of squama occipitalis
- Na the most anterior point of nasal bone

Cephalometric measurements

A total of 10 measurements were recorded in order to evaluate the size of the cranium and the size and position of the mandible (Figure 2): Pa-T, Oc-Na, A-Me, E-A, E-I, E-Me, E-Mf, Z-Me, Go'-Me and E/Go'-Me measurements were performed on each initial and final lateral radiograph.

Error of the method

The error of the method was estimated by replicating and double recording 25 lateral and 25 dorsoventral cephalometric radiographs of 25 different rats according to the formula $Se = \sqrt{(\Sigma d^2/2n)}$ proposed by Dahlberg (1940). This is the mean square error and is identical to the error variance only where there is no bias (Houston, 1983).

The detected identification error was in a range of 0.26–0.83, and since this is lower than 1.5 (Major et al., 1994), the cephalometric technique can be accepted as reliable and reproducible.

Results

Weight gain

There were individual differences in animal

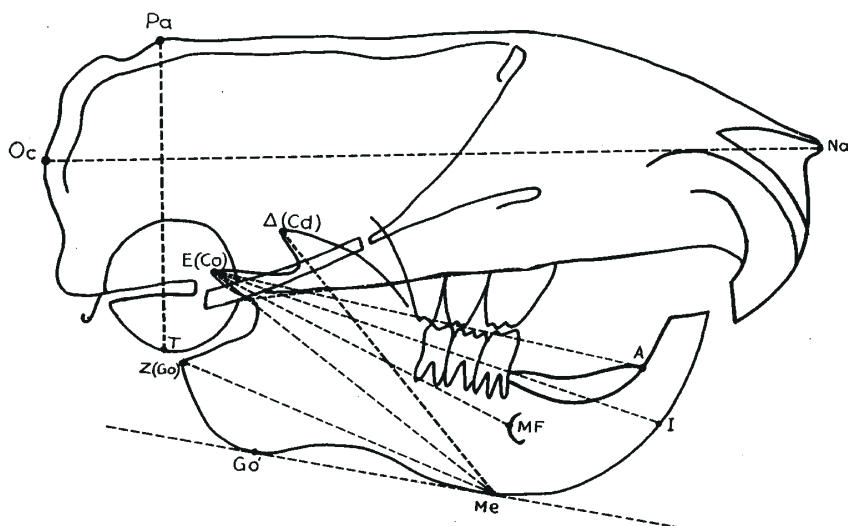


Figure 2 Tracing of the lateral cephalometric radiograph with the 10 measurements used in this study.

weight gain throughout the experimental period. The analysis of variance (Table 3) showed significant weight differences between most groups at the 5 per cent level of confidence. However, the *t*-test between groups A and B as well as the Bonferroni *t*-test between groups A and B did not show any significant differences (Table 2). Since there was no statistically significant weight gain difference between groups A and B, one can interpret that the animals' strain due to the bilateral condylectomy was equal to that during the wearing of the hyperpropulsion appliance. Furthermore, animals subjected to mandibular protrusion after condylectomy did not show any significant weight gain compared with animals that were subjected only to mandibular protrusion. It is worth noting that all the animals grew and functioned normally, and that the weights of all experimental groups were within the normal range for their age (Donta, 1981).

Cephalometric results

The findings are based on statistical analysis according to the Wilcoxon test and superimposition of mean tracings for each group of animals. Since no statistically significant differences were found between groups E (sham-operated animals) and D (animals that were not subjected to any operation or man-

Table 3 Statistical analysis: changes in weight gain (g) of the animals by analysis of variance.

Source of variation	Sum of squares	Degrees of freedom	Mean square	<i>F</i> value	<i>P</i>
Between groups	833.767	4	208.442	64.24	10 ^{-4***}
Within groups	178.417	55	3.244		
Total	1012.183	59			

dibular protraction) when data obtained from radiographs (days 1 and 30) were compared, both groups were used as controls.

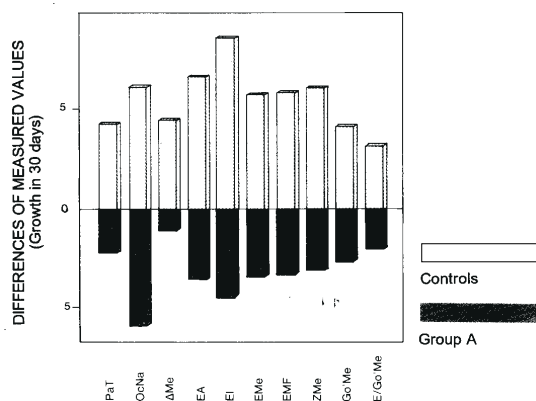
Comparison of differences of measurements on days 1 and 30, in lateral cephalograms, between group A (bilateral condylectomy) and groups D and E (control) revealed statistically significant differences for all cephalometric measurements of the mandible, with lower values for group A (Table 4, and Figures 3 and 4).

Comparison of differences of lateral cephalogram measurements on days 1 and 30 between group B (mandibular protrusion) and groups D and E (controls) revealed statistically significant differences for all cephalometric measurements, with higher values for group B (Table 5, and Figures 5 and 6).

Table 4 Differences (mm) between growth changes in controls and group A (bilateral condylectomy).

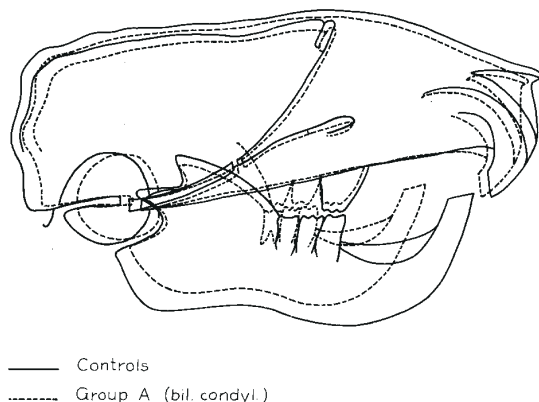
Measurements (differences)	Controls			Group A			<i>P</i>
	Mean	SD	SE	Mean	SD	SE	
Pa-T	4.15	0.28	0.08	2.19	0.29	0.08	***
Oc-Na	6.00	0.41	0.11	3.94	0.38	0.10	**
A-Me	4.34	0.37	0.10	1.05	0A0	0.11	***
E-A	6.40	0.37	0.10	3.47	0.27	0.07	***
E-I	8.38	0.59	0.17	4.37	0.42	0.12	***
E-Me	5.59	0.41	0.11	3.35	0.37	0.10	***
E-Mf	5.71	0.35	0.10	3.21	0.43	0.12	***
Z-Me	5.84	0.87	0.25	3.21	0.43	0.12	***
Go-Me	4.08	0.64	0.18	2.54	0.24	0.06	***
E-GoMe	3.11	0.44	0.12	1.88	0.27	0.07	***

0.001 < *P* < 0.01. **P* < 0.001.

**Figure 3** Comparison of growth changes between controls and group A (bilateral condylectomy).

Comparison of differences of measurements on days 1 and 30, in lateral cephalograms, between group C (bilateral condylectomy and protruded mandibular function) and groups D and E (controls) revealed statistically significant differences for all cephalometric measurements, with lower values for group C (Table 6, and Figures 7 and 8).

Comparison of differences of lateral cephalogram measurements on days 1 and 30 between group A (bilateral condylectomy) and group C (bilateral condylectomy and protruded mandibular function) revealed statistically significant differences for all except one cephalometric

**Figure 4** Superimposition of average lateral radiographs of the control group and group A (bilateral condylectomy).

measurement, with higher values for group C. The measurement that did not show any significant difference was the E/Go'Me (Table 7, and Figures 9 and 10).

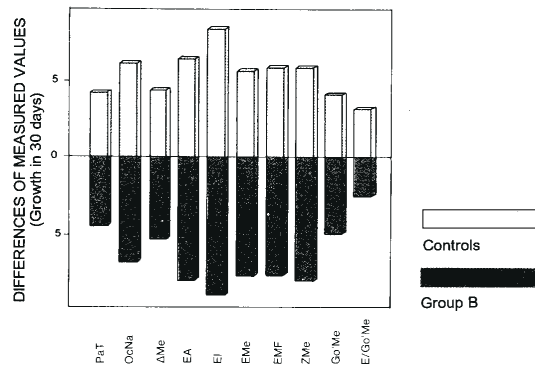
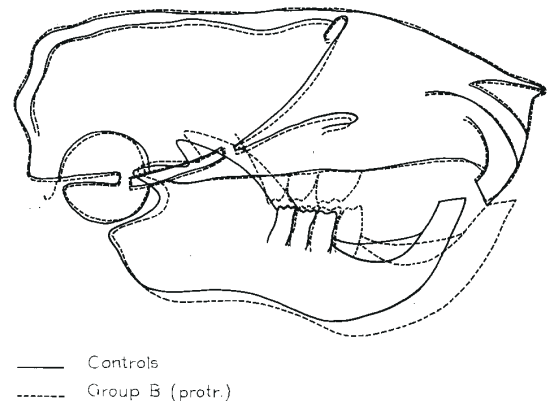
Discussion

The purpose of this study was to investigate the contribution of the condyle to the growth and development of the lower jaw, i.e. by a combination of experimental condylectomy and experimentally protruded mandibular function. The findings of the present investigation indicate that the absence of the condyle has a substantial

Table 5 Differences (mm) between growth changes in controls and group B (protruded mandibular function).

Measurements (differences)	Controls			Group B			P
	Mean	SD	SE	Mean	SD	SE	
Pa-T	4.15	0.28	0.08	4.50	0.35	0.10	**
Oc-Na	6.00	0.41	0.11	6.95	0.52	0.15	**
A-Me	4.34	0.37	0.10	5.44	0.26	0.07	***
E-A	6.40	0.37	0.10	7.85	0.37	0.10	***
E-I	8.38	0.59	0.17	9.02	0.34	0.09	**
E-Me	5.59	0.41	0.11	8.07	0.38	0.10	***
E-Mf	5.71	0.35	0.10	7.96	0.39	0.11	***
Z-Me	5.84	0.87	0.25	8.32	0.33	0.09	***
Go-Me	4.08	0.64	0.18	5.24	0.24	0.06	***
E-GoMe	3.11	0.44	0.12	2.59	0.40	0.11	**

0.001 < P < 0.01. *P < 0.001.

**Figure 5** Comparison of growth changes between controls and group B (protrusion).**Figure 6** Superimposition of average lateral radiographs of the control group and group B (protrusion).

effect on the amount of mandibular growth. This is obvious from the animal group subjected to bilateral condylectomies, where a statistically significant difference in mandibular growth was observed, with lower values in the condylectomized group than in the controls. These results are in accordance with the findings of Jarabak *et al.* (1949), Sarnat (1957), Gianelly and Moorrees (1965), Sarnat and Muchnic (1971) and Pimenidis and Gianelly (1972).

In contrast with Das *et al.* (1965), who reported normal size but different shape in rat mandibles subjected to condylectomies, we found changes in shape as well a smaller size in all rats with bilaterally condylectomized mandibles.

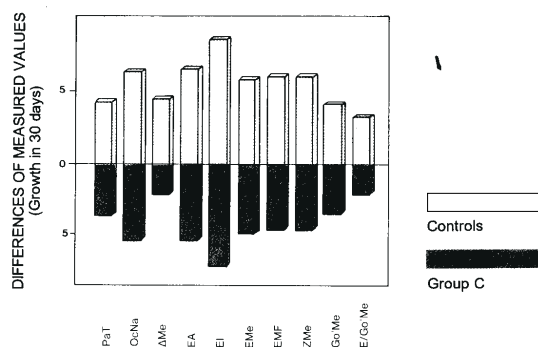
However, our findings support the concept that the condyle contributes only to a certain percentage of the growth of the lower jaw. Our findings document the concept that the condyle is not the dominant element that controls and directs the growth of the mandible whenever the rat condylectomized mandibles continue to participate in the functions of mastication, deglutition and respiration throughout the growing period.

The findings in the bilaterally condylectomized rat group do not agree with the hypothesis of Belhobek (1974), Whetten (1979), Bernabei (1975, 1976), Bernabei and Johnston

Table 6 Differences (mm) between growth changes in controls and group C (bilateral condylectomy plus protrusion).

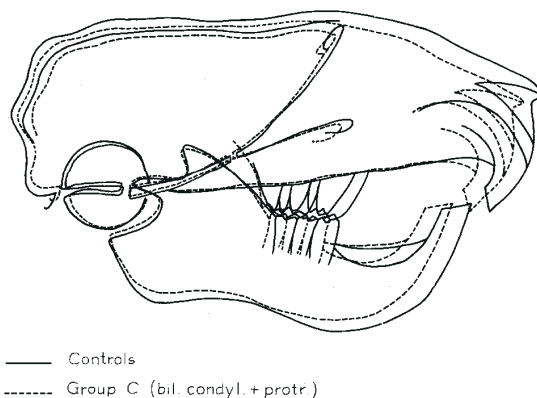
Measurements (differences)	Controls			Group B			<i>P</i>
	Mean	SD	SE	Mean	SD	SE	
Pa-T	4.15	0.28	0.08	3.49	0.49	0.14	***
Oc-Na	6.00	0.41	0.11	5.33	0.72	0.20	**
A-Me	4.34	0.37	0.10	3.97	0.20	0.05	***
E-A	6.40	0.37	0.10	5.20	0.36	0.10	***
F-I	8.38	0.59	0.17	6.70	0.52	0.15	***
E-Me	5.59	0.41	0.11	4.71	0.34	0.09	***
E-Mf	5.71	0.35	0.10	4.60	0.29	0.08	***
Z-Me	5.84	0.87	0.25	4.40	0.29	0.08	***
Go-Me	4.08	0.64	0.18	3.34	0.29	0.08	***
E-GoMe	3.11	0.44	0.12	2.12	0.27	0.07	***

0.001 < *P* < 0.01, **P* < 0.001.

**Figure 7** Comparison of growth changes between controls and group C (bilateral condylectomy plus protrusion).

(1978) and Haas (1984) that the condyles are active growth centres that develop and translate to a forward and downward direction, in contrast to the rest of the mandible, which does not grow and develops normally when the condyle is absent.

Our findings prove that the condyle is an essential factor for normal growth, but that the lower jaw is able to grow and translate to a downward and forward direction even without the presence of the condyle. A difference exists, of course, in the amount of growth between the condylectomized and the control mandibles. This finding supports the view that the condyle does not reproduce all the force needed for the

**Figure 8** Superimposition of average lateral radiographs of the control group and group C (bilateral condylectomy plus protrusion).

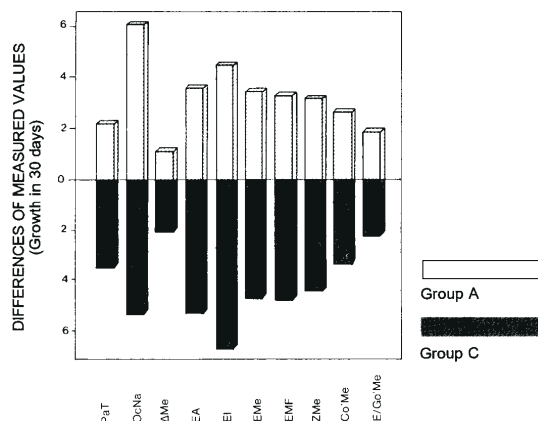
translatory mandibular movement downwards and forwards, but contributes to a certain extent to the normal translation and growth of the lower jaw. This hypothesis is in accordance with the findings of Yozwiak (1979), supporting the view that the condyle is not able to produce the amount of force observed in the long bone epiphysis.

In the mandibular protrusion group, an anterior crossbite was produced and a Class III molar relationship established. At the same time, the rat mandibles that were forced to hyperpropulsion were of a larger size than the

Table 7 Differences (mm) between growth changes in group A (bilateral condylectomy) and group C (bilateral condylectomy plus protrusion).

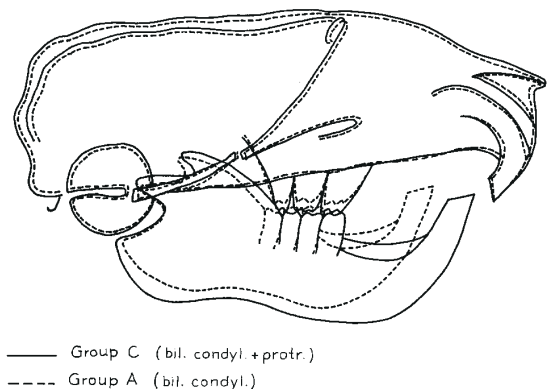
Measurements (differences)	Controls			Group B			P
	Mean	SD	SE	Mean	SD	SE	
Pa-T	2.19	0.29	0.08	3.49	0.49	0.14	***
Oc-Na	3.94	0.38	0.10	5.33	0.72	0.20	***
A-Me	1.05	0.40	0.11	3.97	0.20	0.05	***
F-A	3.47	0.27	0.07	5.20	0.36	0.10	***
F-I	4.37	0.42	0.12	6.70	0.52	0.15	***
F-Me	3.35	0.37	0.10	4.71	0.34	0.09	***
E-Mf	3.21	0.43	0.12	4.60	0.29	0.08	***
Z-Me	3.21	0.43	0.12	4.40	0.29	0.08	***
Go-Me	2.54	0.24	0.06	3.34	0.29	0.08	***
E-GoMe	1.88	0.27	0.07	2.12	0.27	0.07	NS

0.001 < P < 0.01. *P < 0.001.

**Figure 9** Comparison of growth changes between group A (bilateral condylectomy) and group C (bilateral condylectomy plus protrusion).

controls. These findings are in agreement with those of other investigators (Joho, 1968; Stöckli and Willert, 1971; Elgoyen *et al.*, 1972; McNamara, 1972, 1973, 1974; Petrovic *et al.*, 1975; McNamara and Carlson, 1979).

As a result of the findings of this study one can support the view that the growth of the lower jaw is affected to a certain extent by functional and environmental factors. Moreover, they show the close interrelationship between form and function. However, although in our experiments as well as in previous investigations it was found

**Figure 10** Superimposition of average lateral radiographs of group A (bilateral condylectomy) and group C (bilateral condylectomy plus protrusion).

that the size of the mandibles forced to hyperpropulsion is larger than the control mandibles, one cannot conclude that the amount of change in growth is due to the increase in the width of the hypertrophy zone of the condylar cartilage as reported by Petrovic *et al.* (1975). It is also undocumented whether this increase in growth is due primarily to the surrounding mandibular functional matrix. According to Killiany (1984), condylar loading results in decreased vertical condylar growth, while unloading results in an increase in vertical growth of the condyle. Yozwiak (1979) and

Tsolakis (1981) also proved that it is possible to retard mandibular growth by loading.

In contrast to the findings observed by McNamara (1972) and Petrovic *et al.* (1975), Tonge *et al.* (1982) as well as Ghafari and Degroote (1986) could not find more condylar growth in hyperpropulsion experiments. This difference could be due to the fact that the appliances used by Tonge *et al.* (1982), Ghafari and Degroote (1986) and Tewson *et al.* (1988) were not able to produce a definite and secure forward shift of the mandible, as explained by Tsolakis and Spyropoulos (1997).

Our finding of an anterior crossbite in the rat may be explained by the fact that, while wearing a hyperpropulsion appliance, the animal is unable to produce any gnawing or tooth sharpening movements on the lower incisors for a period of 12 hours per day. Taking into account that the gnawing as well as the tooth sharpening capacity of rodents are of basic specialization in this order (Hiiamae and Ardran, 1968), any absence of these functions may result in different antero-posterior relationships of the anterior teeth, especially in cases where the mandible is protracted forwards by means of an appliance, thus creating an anterior crossbite. It can therefore be stated that the condyle is a necessary element for normal growth and development of the lower jaw.

On the other hand, whenever the condyle was absent, the lower jaw of the experimental animals could grow and translate downwards and forwards. However, these were smaller in size than the lower jaws of the control animals. In contrast, the lower jaws of the experimental group of animals in which the mandible was protracted without any previous condylectomy grew more than the mandibles of the control group. Overall, the results of the experimental combination of condylectomy and mandibular protrusion in the same experimental animals reinforce the theory supporting the role of the condyle as a functional rectifier (Johnston, 1986).

Conclusions

Taking into consideration the above findings, the following conclusions can be drawn.

1. The lack of the condyle significantly affects the amount of mandibular growth.
2. The condyle is an essential factor for normal growth and development because it contributes to a percentage of the normal translation and growth of the lower jaw.
3. The growth and development of the lower jaw is affected, to a certain extent, by functional and environmental factors.
4. Absence of the condyles can be compensated for, to a certain extent, by hyperpropulsion of the lower jaw in growing rats.
5. The results of the experimental combination of condylectomy and mandibular protrusion in the same experimental animals reinforce the theory that the condyle acts as a functional rectifier (Johnston, 1986).

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