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Altered mandibular function and prevention of skeletal asymmetries after unilateral condylectomy in rats

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SUMMARY Unilateral condylar injury is known to be a frequent cause of mandibular asymmetry. Whether this is due to the trauma itself or to the disturbed function that follows the injury is a very important question with ramifications for clinical complications related to facial asymmetries.

The aim of this study was to test the hypothesis that mandibular function in a protruded position can compensate for the absence of one condyle and prevent potential growth asymmetries.

Forty-eight 4-week-old rats were divided into two experimental and two control groups consisting of 12 animals each, as follows: (A) unilateral condylectomy was performed on the right side and the mandible was left to function normally; (B) after unilateral condylectomy on the right side, the mandible was forced to function in a protruded position; (C) a sham operation was performed in the condylar area of the right side but no appliance was used; and (D) 12 animals were used as controls without any operation or appliance.

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 per day. The experimental period was 30 days. Dorsoventral radiographs were taken and vital dyes were administered at three time intervals, i.e. on days 1, 15 and 30, for all animals. Cephalometric analysis included 14 measurements.

Findings resulting from statistical analysis and comparisons of measurements obtained in the four groups can be summarized as follows: (i) when comparing group A with groups C and D, less growth was found in the right mandibular sides in group A; (ii) when comparing group B and groups C and D, less growth was found in the right mandibular sides in group B; (iii) when comparing groups A and B, more growth was found in the right mandibular sides in group B; (iv) when comparing the right and left mandibular sides in group A, less growth was found in the right side; and (v) when comparing the right and left mandibular sides in group B, no significant growth differences were found.

These findings support the hypothesis that altered mandibular function in a protruded position can compensate for the effects of unilateral condylectomy and prevent the appearance of skeletal mandibular asymmetries in growing rats.

Introduction

Asymmetry of the mandible may result from developmental abnormalities such as condylar agenesis, hypo- or hyperplasia, or from acquired conditions such as trauma, tumours, infections, functional mandibular displacement and other local factors (Rushton, 1944; Speculand, 1982; Melnik, 1992).

Unilateral chewing patterns that are due to idiopathic situations or to asymmetric functions of the muscles of mastication may also lead to mandibular asymmetries (Vig and Hewitt, 1975; Blakenship and Ramfjord, 1976; Shah and Joshi, 1978; Curtis *et al.*, 1991; Schmid *et al.*, 1991; Isotupa *et al.*, 1992). Mandibular asymmetry may be an effect of parafunctional habits, such as thumb sucking and mouth breathing (Linder-Aronson, 1970). Several condylectomy experiments have been carried out in the past (Jarabak *et al.*, 1949; Sarnat, 1957; Das *et al.*, 1965; Gianelly and Moorrees, 1965; Sarnat and Muchnic, 1971; Pimenidis and Gianelly, 1972; Bernabei and Johnston, 1978) in order to prove or disprove the regulatory role of the condylar cartilage in mandibular growth.

Older concepts have described the condylar cartilage as the pacemaker and organizer of mandibular growth (Sicher, 1947; Sarnat, 1957), but nowadays the condylar cartilage is considered as a site that contributes to the overall mandibular growth and its function is to provide regional adaptive growth in response to orofacial functional demands (Moss, 1972; Enlow, 1980). A more detailed analysis of its role supports the concept that the condyle behaves as if it were a growth centre, without, however, being capable of generating the force usually attributed to an epiphysis (Johnston, 1986).

On the other hand, several investigations have proved that induced functional or passive forward positioning of the mandible leads to adaptive growth responses in the craniofacial skeleton (McNamara, 1972; Petrovic *et al.*, 1975). The role of function in the expression of mandibular growth can be traced in mandibular asymmetries induced by early functional crossbites; however, condylar anomalies such as the ones found in hemifacial microsomia and other syndromes are also associated with mandibular asymmetries.

Contemporary treatment for such cases includes the use of appliances that affect the functional position of the mandible, in order to enhance bone growth and remodelling (Harvold, 1983; Vargervik, 1983).

This experimental study was designed in order to test the hypothesis that the absence of one condyle can be compensated for by altered mandibular function that harmonizes growth and minimizes potential asymmetry.

Materials and methods

Forty-eight 4-week-old Wistar rats were used in this study. The animals used were obtained from the Greek Pasteur Center. The initial weight of the animals ranged from 41 to 48 g. The animals were divided into two experimental and two control groups, consisting of 12 animals each, as follows: group A, unilateral condylectomy was performed on the right side and the mandible was left to function normally; group B, after unilateral condylectomy on the right side, the mandible was forced to function in a protruded position, by means of an appliance; group C: a sham operation was performed in the condylar area of the animal's right side, but no appliance was used; and group D, the animals were used as controls without any operation or appliance.

Condylectomy was performed in the way described by Tsolakis *et al.* (1997).

The appliance used to achieve mandibular protraction has been described earlier (Tsolakis and Spyropoulos, 1997), and was also used in a previous study (Tsolakis *et al.*, 1997). The experimental period was 30 days. Dorsoventral radiographs were taken on days 1 and 30 as only on those specific radiographs can the condyle be defined (Hiiemae and Ardran, 1968). A special cephalostat was used in order to provide reliable and reproducible cephalometric radiographs (Tsolakis *et al.*, 1997) The radiographs were enlarged ×9 to reduce tracing errors.

Cephalometric landmarks

The ×9 enlarged radiographs were traced and the following landmarks were identified on each dorsoventral cephalometric radiograph to be used in the analysis of the skeletal changes (Figure 1).

- T1 the most anterior point of the alveolar bone on the concavity of the lower right incisor
- T2 the most anterior point of the alveolar bone on the concavity of the lower left incisor
- Co the most superior and posterior point of the right condyle
- Co′ the most superior and posterior point of the left condyle

Cephalometric measurements

Co–T1, Co′–T2 and Co–Co′ were the cephalometric measurements that were performed on each initial (before) and final (after) dorsoventral radiograph in order to evaluate mandibular size and form.

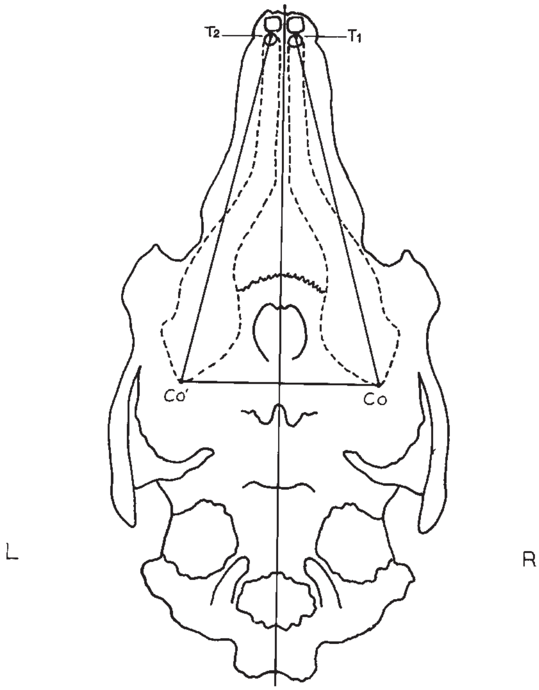

Figure 1 Cephalometric landmarks.

Results

Weight gain

There were individual differences in animal weight gain throughout the experimental period (Table 1). The analysis of variance (Table 2) did show 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 Bonferroni's *t*-test between groups A and B did not show significant differences (Table 3). Since there was no statistically significant weight gain difference between groups A and B, it can be concluded that the animals' strain due to the bilateral condylectomy was equal to the animals' strain due to the wear of the hyperpropulsion appliance. Furthermore, animals subjected to mandibular protrusion after condylectomy did not show any significant weight gain difference when compared with animals that were subjected only to mandibular protrusion. It is worth noting that all the animals grew and functioned normally and the weights of all experimental groups were within the normal range for their age (Donta, 1981).

Table 1 Changes in animal weight gain (g) throughout the experimental period.

Group	Initial		Final		Difference	
	Mean	SD	Mean	SD	Mean	SD
A	44.00	2.22	122.08	2.02	78.08	2.43
B	43.83	1.53	120.25	1.76	76.42	1.56
C	43.42	1.51	125.25	1.71	81.83	1.99
D	43.33	1.97	125.08	1.31	81.75	1.91

Group A: right unilateral condylectomy; group B: right unilateral condylectomy plus protrusion; group C: sham-operated; and group D: controls.

Table 2 Statistical analysis: changes in animal weight gain (g) throughout the experimental period shown by analysis of variance.

Source of variation	Sum of squares	df	Mean square	*F* value	*P*
Between groups	264.229	3	88.08	22.05	10^{-4}***
Within groups	175.750	44	3.99		
Total	439.979	47			

Table 3 Statistical analysis: changes in animal weight gain (g) throughout the experimental period shown by *t*-tests.

Group	B	C	D
A	$t = 2.00$, $P = 0.06$	$t = -4.13$, $P < 10^{-3}$***	$t = -4.11$, $P < 10^{-3}$***
B		$t = -7.41$, $P < 10^{-4}$***	$t = -7.48$, $P < 10^{-4}$***
C			$t = -0.10$, $P = 0.92$

***$P < 0.001$.

Table 4 Comparison of mean values (mm) of measurements of dorsoventral cephalograms between controls and group A (right unilateral condylectomy).

Measurements	Controls			Group A			*P*
	Mean	SD	SE	Mean	SD	SE	
CoT_1 be	20.62	0.27	0.07	20.43	0.24	0.06	NS
CoT_1 af	28.40	0.27	0.07	23.76	0.23	0.06	***
$Co'T_2$ be	20.60	0.26	0.07	20.45	0.23	0.06	NS
$Co'T_2$ af	28.39	0.27	0.07	27.35	0.32	0.09	***
CoT_1 af – CoT_1 be	7.78	0.27	0.07	3.33	0.23	0.06	***
$Co'T_2$ af – $Co'T_2$ be	7.79	0.26	0.07	6.90	0.28	0.08	***
CoCo′ af	3.12	0.32	0.09	2.32	0.45	0.12	***

***$P < 0.001$.
be (before): initial cephalometric measurement; af (after): final cephalometric measurement; Co: the most superior and posterior point of the right condyle; Co′: the most superior and posterior point of the left condyle.

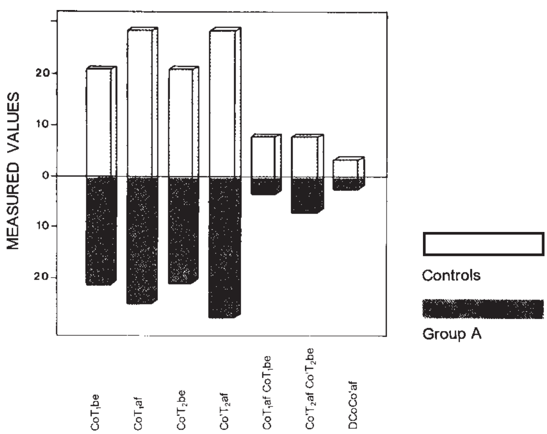

Figure 2 Mean values of measurements from dorsoventral cephalograms in controls and group A.

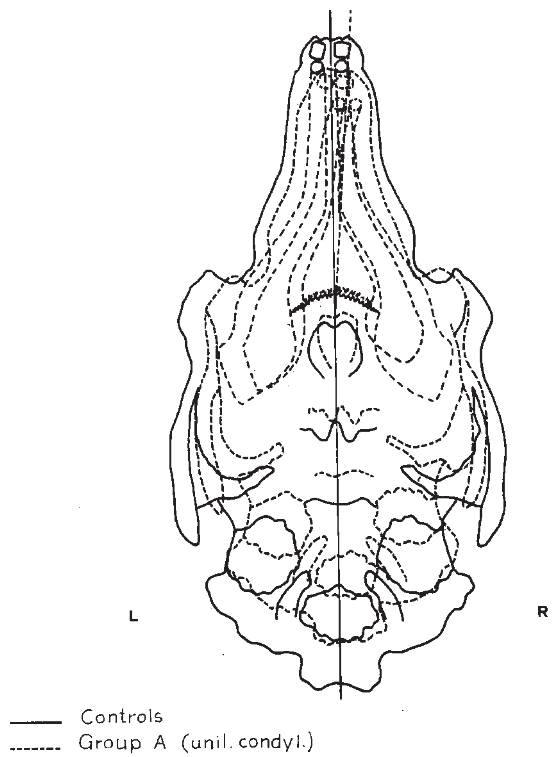

Figure 3 Superimposition of the mean tracings of the dorsoventral radiographs of group A and controls.

Cephalometric results

The findings are based on statistical analysis according to Wilcoxon's test and superimposition of mean tracings for each group of animals.

Since no statistically significant differences were found between groups C and D, both groups were used as controls. Comparison of mean values of measurements on dorsoventral cephalograms between group A (unilateral condylectomy and normal mandibular function) and groups C and D (control) revealed less growth in the right mandibular sides in group A at the end of the experiment (Table 4 and Figure 2).

Table 5 Comparison of mean values (mm) of measurements of dorsoventral cephalograms between controls and group B (right unilateral condylectomy plus protrusion).

Measurements	Controls			Group B			*P*
	Mean	SD	SE	Mean	SD	SE	
CoT_1 be	20.62	0.27	0.07	20.54	0.19	0.05	NS
CoT_1 af	28.40	0.27	0.07	26.17	0.28	0.08	***
$Co'T_2$ be	20.60	0.26	0.07	20.57	0.19	0.05	NS
$Co'T_2$ af	28.39	0.27	0.07	28.38	0.27	0.07	NS
CoT_1 af – CoT_1 be	7.78	0.27	0.07	5.63	0.24	0.06	***
$Co'T_2$ af – $Co'T_2$ be	7.79	0.26	0.07	7.81	0.23	0.06	NS
CoCo′ af	3.12	0.32	0.09	1.94	0.36	0.10	***

***$P < 0.001$.
be (before): initial cephalometric measurement; af (after): final cephalometric measurement; Co: the most superior and posterior point of the right condyle; Co′: the most superior and posterior point of the left condyle.

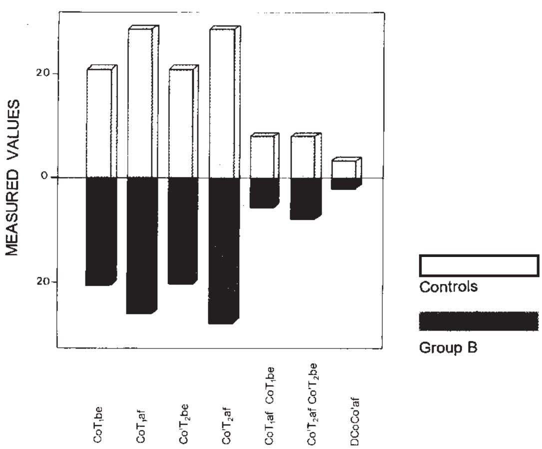

Figure 4 Mean values of measurements from dorsoventral cephalograms in controls and group B.

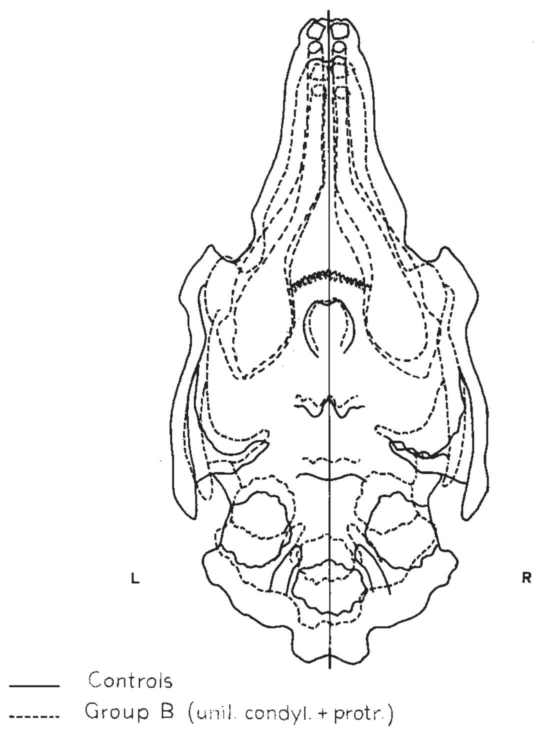

Figure 5 Superimposition of the mean tracings of the dorsoventral radiographs of group B and controls.

The mandible in the unilaterally condylectomized group was deviated at the end of the experiment towards the side of the condylectomy and this can be observed with the superimposition of the mean tracings of the dorsoventral radiographs of group A and groups C and D (Figure 3). Comparison of mean values of measurements on dorsoventral cephalograms between group B (unilateral condylectomy and mandibular protraction) and controls revealed less growth in the right mandibular sides in group B at the end of the experiment (Table 5 and Figure 4). The mandible in group B was not deviated at the end of the experiment towards the side of the condylectomy, and this can be observed from the superimposition of the mean

Table 6 Comparison of mean values (mm) of measurements of dorsoventral cephalograms between group A (unilateral condylectomy) and group B (right unilateral condylectomy plus protrusion).

Measurements	Group A			Group B			*P*
	Mean	SD	SE	Mean	SD	SE	
CoT_1 be	20.43	0.24	0.06	20.54	0.19	0.05	NS
CoT_1 af	23.76	0.23	0.06	26.17	0.28	0.08	***
$Co'T_2$ be	20.45	0.23	0.06	20.57	0.19	0.05	NS
$Co'T_2$ af	27.35	0.32	0.09	28.38	0.27	0.07	***
CoT_1 af – CoT_1 be	3.33	0.23	0.06	5.63	0.24	0.06	***
$Co'T_2$ af – $Co'T_2$ be	6.90	0.28	0.08	7.81	0.23	0.06	***
$CoCo'$ af	2.32	0.45	0.12	1.94	0.36	0.10	NS

***$P < 0.001$.
be (before): initial cephalometric measurement; af (after): final cephalometric measurement; Co: the most superior and posterior point of the right condyle; Co′: the most superior and posterior point of the left condyle.

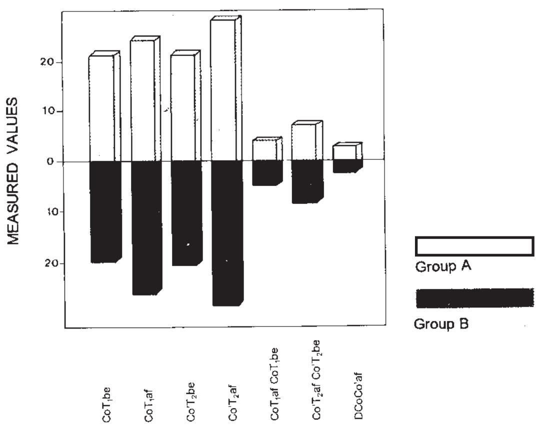

Figure 6 Mean values of measurements from dorsoventral cephalograms in group A and group B.

tracings of the dorsoventral radiographs of group B and controls (Figure 5).

Comparison of mean values of measurements on the dorsoventral cephalograms between group A and group B revealed more growth in the right mandibular sides in group B at the end of the experiment (Table 6 and Figure 6).

The superimposition of the mean tracings of the dorsoventral radiographs of group A and of group B also reveal the lack of mandibular deviation as well as more mandibular growth in animals belonging to group B (Figure 7).

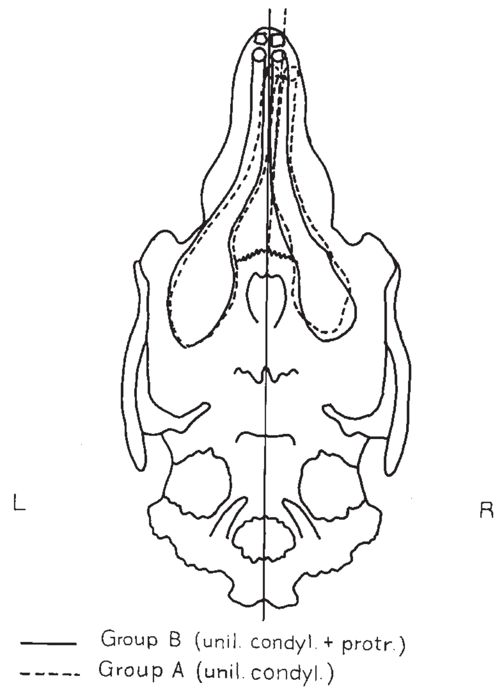

Figure 7 Superimposition of the mean tracings of the dorsoventral radiographs of group A and group B.

Discussion

The purpose of this study was to test the effect of altered mandibular function in a protruded position on the mandibular growth of unilaterally condylectomized rats. As has been reported elsewhere (Tsolakis *et al.*, 1997), 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 during a growing period. However, the findings of this investigation support the view that the absence of the condyle has a substantial effect on the amount of mandibular growth, since the condylectomized sides of the mandible in group A were significantly smaller than the unoperated mandibular sides.

A marked asymmetry was observed in the mandible of the unilaterally condylectomized group and this finding is in accordance with the results of Jarabak *et al.* (1946), Sarnat (1957) and Sarnat and Muchnic (1971).

The right mandibular sides of the group that were subjected to mandibular protrusion immediately after condylectomy were smaller in size at the end of the experiment than the reciprocal unoperated mandibular sides of the control group. They were, nevertheless, bigger insize at the end of the experiment than thereciprocal mandibular sides of the animal group subjected only to condylectomy. However, disturbed function due to unilateral condylectomy without a protruding appliance seems to affect growth of the non-condylectomized side as well since it grew less in these animals than in controls and in condylectomized animals that had protruded mandibular function.

Whilst an obvious mandibular asymmetry and a midline deviation existed in the animal group subjected only to unilateral condylectomy, no such asymmetry or deviation could be seen in the animal group subjected to unilateral condylectomy followed by mandibular protrusion.

It should be stressed that the appliance used in this study differs from previous similar appliances (Petrovic *et al.*, 1975; Tonge *et al.*, 1982; Ghafari and Degroote, 1986; Tewson *et al.*, 1988) in that it produces true protrusion of the mandible without any side effects or deviations (Tsolakis and Spyropoulos 1997). Therefore our findings are not influenced by other parameters such as mandibular postures and shifts. According to Blankenship and Ramfjord (1976) and Curtis *et al.* (1991), an adaptability of the craniofacial complex to asymmetrically exerted lateral forces exists. The exerted protrusive forces in the animal group that had been previously subjected to unilateral condylectomy were isometric on both sides for 12 hours per day. Whenever the appliances were removed the exerted forces during the feeding period were asymmetrical due to the musculoskeletal differentiation following unilateral condylectomy. However, functional intervention to a protruded mandibular position for a further 12 hours seems to compensate for the negative effects of unilateral condylectomy to a significant extent. This is consistent with previous findings (Tsolakis *et al.*, 1997) that the condyle contributes to the development of the lower jaw but is not the dominant element that controls and directs the growth of the mandible. This investigation proves that functional stimuli may compensate for the effects of unilateral condylar absence overcoming the mechanical implications of lack of condylar support unilaterally by harmonizing growth of both sides of the mandible. This is in accordance with Harvold's rule No. 1 concerning muscle–bone interaction (Harvold, 1983).

Extrapolating from these experimental observations to clinical practice, it is important to establish balanced function early in cases of mandibular asymmetry caused by various pathological conditions of the condyle.

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