Condylar Cartilage Response to Continuous Mandibular Displacement In the Rat

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Continuous anterior and vertical displacement of the rat mandible produces an increase in area of the resting zone and accelerated ossification of the hypertrophic zone. These responses differ greatly from those reported with intermittent displacement. They may be transient, or they may be an expression of accelerated maturation.

KEY WORDS: • CARTILAGE • CONDYLE • MANDIBLE, DISPLACEMENT •

Numerous studies of mandibular propulsion have focused on adaptive changes of the condylar cartilage, with varying results. Ingervall, Freden and Hyden (1972) reviewed many early studies and attributed discrepancies between reported results to differences in species and age of the animals used in the various investigations.

Baume and Derichsweiler (1961) found an increase in growth of the posterior part of the condyle following anterior displacement of the mandible in two *Macaca mulatta* monkeys.

Following similar mandibular movement in infant, juvenile, adolescent and adult rhesus monkeys *(Macaca mulatta)* for experimental periods of 3 to 15 months, McNamara, Connelly and McBride (1975) reported alteration in amount and direction of growth of the mandibular condyle only in the rapidly-growing animals, corresponding to muscular (lateral pterygoid) and skeletal responses.

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The initial changes involved hypertrophy and hyperplasia of the prechondroblastic (resting) and chondroblastic (proliferative and hypertrophic) zones of the articular cartilage, particularly along the posterior border of the condyle. This response was maximal after six weeks. It then abated, so that by 10 weeks only "normally occurring remodeling" was seen. Continued cartilage proliferation at 12 weeks in one case was interpreted as indicating differences in rate of adaptation among animals.

Petrovic, Stutzmann and Oudet (1975) reported an increase in thickness of the prechondroblastic and chondroblastic zones following propulsion of the mandible in young rats 28 days old. Concomitant decrease in length of the lateral pterygoid muscle and hypertrophy of its fibers indicated the increased activity of this muscle. While McNamara et al. (1975) used continuous forces in the rhesus monkeys, Petrovic et al. (1975) applied intermittent forces for 8-12 hours a day for periods of 1, 2 and 4 weeks.

The present investigation was undertaken as a preliminary study of the nature of condylar response to continuous (24 hours a day) propulsion of the rat mandible.

— Materials and Methods —

Eight 30-day-old male Sprague Dawley rats were divided among control (n=4) and experimental (n=4) groups. An inclined plane, made of stainless steel orthodontic band material 0.1mm× 3.2mm, supported by acrylic, was bonded to the upper incisors of the experimental animals with composite resin to cause continuous forward and inferior displacement of the mandible (Fig. 1).

The animals were maintained on a regular diet. Twenty-four days following the insertion of the appliance, the animals were decapitated and their heads skinned and fixed in 10% neutral buffered formalin. The tissues were decalcified in equal parts of 7% sodium citrate and 33% formic acid and processed for routine histology.

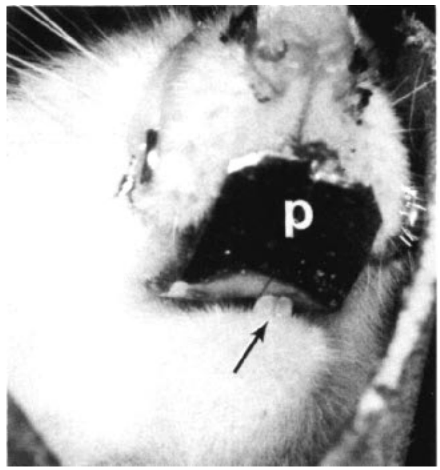

Fig. 1

Inclined plane (P) cemented to the upper incisors causes mandibular downward and forward movement. Arrow → mandibular incisors.

Serial sections of 6μm each were cut through the mandibular condyle in the coronal plane, stained with hematoxylin and eosin, and examined for cell and tissue morphology. Representative sections were examined to locate the central area of the condylar cartilage, which was selected on the basis of its shape and uniformity compared with more peripheral areas, and on its position in the glenoid fossa.

The total surface and thickness of the condylar cartilage, as well as the areas and thicknesses of resting, proliferative and hypertrophic zones, were measured on a total of 20 sections covering 1.2mm in the central area of the condylar cartilage. Color slides were made of each tenth histological section in a reproducible manner, using the Leitz Wetzlar Orthoplan and Orthomat camera, at a magnification of 10×. The slides were then projected on a grid to give a total magnification of 120×, and the cartilaginous zones traced. The limits of each zone were defined on the basis of cell morphology and matrix staining (Figs. 2,3).

The area of each cartilaginous zone was measured with a planimeter and expressed as a percentage of the total cartilage area. The means of these percentages in control and experimental condyles were compared statistically with Student's t-test.

The axis of the condyle was constructed as a line parallel to the condylar neck, and equidistant from the parallel tangents to the medial and lateral borders of the condyle. The thickness of each of the layers was then calculated as the mean thickness of the respective layer in an area of 250µm (30mm on the tracing) around the central axis of the condyle (Fig. 2). Student's t-test was also applied to total thickness, thickness of the individual zones, and their percentages of total thickness in control and experimental condyles.

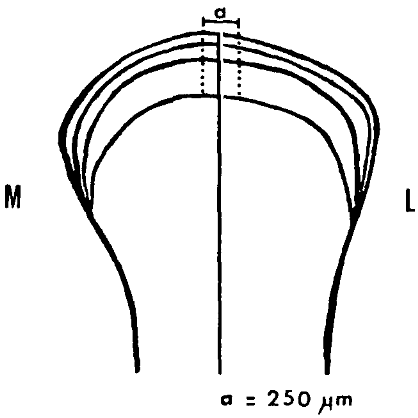

Fig. 2

The central axis is parallel to the condyle neck, and equidistant from the medial (M) and lateral (L) borders of the condyle. The thickness of each layer is calculated as the mean thickness of the respective layer in an area 250µm wide around the central axis.

— Results —

Weight increase was observed in experimental as well as control animals. However, at the time the experiment was terminated, the experimental animals had gained less weight than the control animals (average gain 180 gm), demonstrating that the normal function of the experimental animals was impaired by the oral device.

Histologically, the overall thickness of the condylar cartilage was less in the treated animals (222±25.0µm (SEM)) than in the controls (285.5±25.9µm (SEM)), although this difference is not statistically significant.

The area of the hypertrophic zone, relative to the total cartilaginous area, was smaller in the experimental animals than in the controls ($p < 0.01$) (Fig. 3). The hypertrophic zone was also significantly narrower in both relative ($p < 0.01$) and direct ($p < 0.02$) measurements (Figs. 3, 4, 5).

While no statistically significant difference was observed between the different proliferative zones, the resting zone area in experimental animals was larger than in the controls ($p < 0.01$). Likewise, the thickness of this zone was greater, but not at a statistically significant level.

When expressed in percentages of total thickness, both resting ($p < 0.01$) and proliferative ($p < 0.05$) zones were larger in the experimental than in the controls.

Fig. 3 Frontal sections through the central part of the mandibular condyle in a control rat (A) and an experimental rat (B)

Resting (R) and proliferative (P) zones appear comparable in thickness, while the hypertrophic (H) layer is thinner in the experimental animal (B) than in the control (A).

E: erosion front *(Hematoxylin and eosin ×110).*

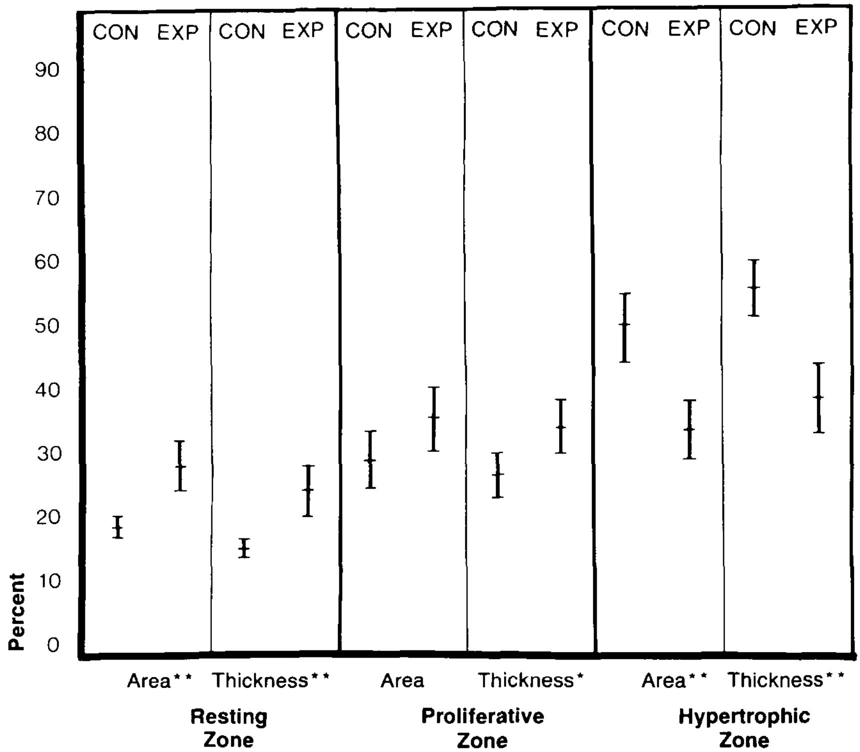

Fig. 4 Means and standard deviations for area and thickness of resting, proliferative and hypertrophic zones, expressed as percentage of total area and thickness of the condylar cartilage.
Con = Control Exp = Experimental *P < .05 **P < .01

— Discussion —

In rats developing normally, hypertrophic condylar cartilage matures to a nonhypertrophic stage (Durkin 1972, Durkin et al. 1973 and 1979).

The sequence begins with chondroblasts from the resting zone which produce cartilage matrix to become chondrocytes in the proliferative zone. They then hypertrophy (hypertrophic zone), and the matrix calcifies circumferentially.

The calcified matrix around the lowest level of hypertrophic chondrocytes is next resorbed by chondroclasts in the zone of erosion. Subsequently, subcondylar bone is formed beneath this zone (Fig. 3).

Between 200 and 250 days of age, a nonhypertrophic stage is attained, where the hypertrophic zone and active erosion are absent; the lower border of the cartilage merges directly with the subcondylar bone.

The findings of this study demonstrate an earlier ossification of the hypertrophic cartilage in rats subjected to derangement of the condylar environment by mandibular propulsion. This conclusion is supported by the decrease in area and

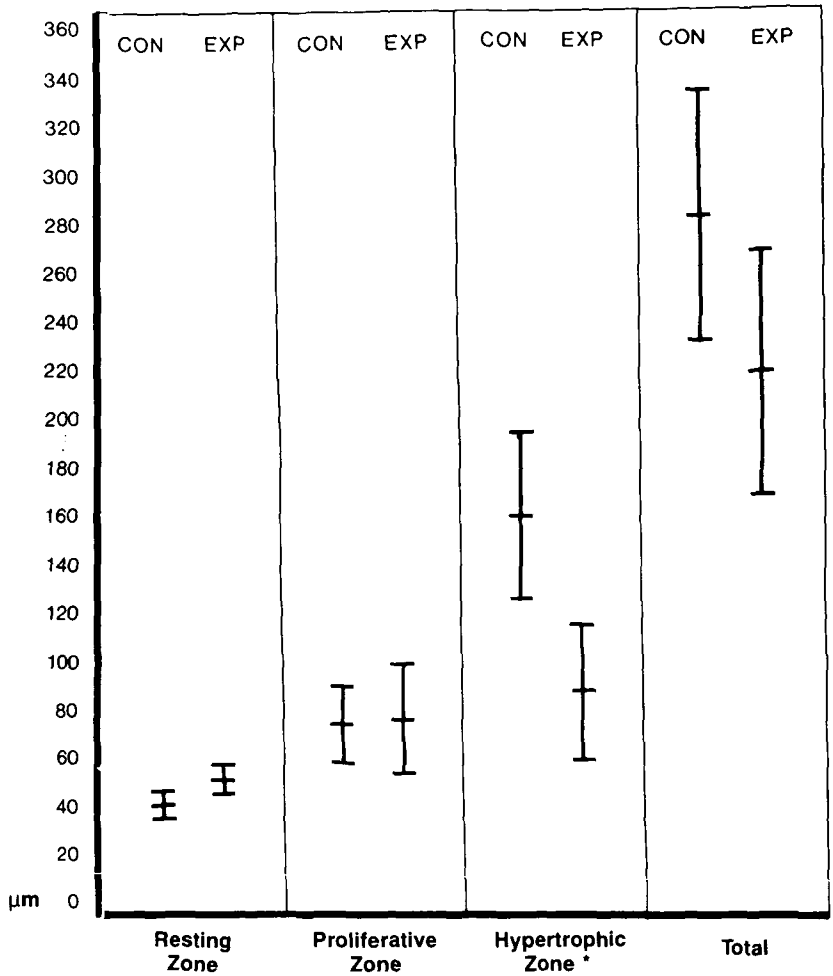

Fig. 5 Mean thicknesses and standard deviations (µm) of resting, proliferative and hypertrophic zones, and total thickness of the condylar cartilage. * P<.02

thickness of the hypertrophic zone in the experimental animals. This phenomenon perhaps reflects a static period in a dynamic process.

Following mandibular displacement, an initial increase in proliferation may have been neutralized by a concurrent increase in the rate of erosion of the hypertrophic cartilage. This explanation may account for the proportional increase in the thickness and area of the resting zone, and the thickness of the proliferative zone.

It may be postulated that some of the observed changes were induced by alteration of normal growth, since increases in body weight of experimental animals did not reach those of control animals. However, condylar cartilage response to some nutritional deficiencies results in changes different from those observed in this investigation; both ascorbic acid deficiency and vitamin D deficiency lead to increased cartilage thickness and disturbed erosive activities (DURKIN 1972, DURKIN ET AL. 1973 AND 1979). Nonetheless, future studies should consider the nutritional aspect to identify its effects and then avoid them by dietary control.

The concept of adaptability of condylar cartilage is supported by the present findings as well as by Moss (1959), KOSKI AND MÄKINEN (1963), GIANELLY AND MOORREES (1965), KOSKI (1968), PIMENIDIS AND GIANELLY (1972), DURKIN (1972), DURKIN ET AL. (1973 AND 1979), AND GHAFARI AND HEELEY (1982). Condylar cartilage responds to systemic hormonal or dietary disturbances (DURKIN 1973 AND DURKIN ET AL. 1979), as well as to local changes like modification of mechanical stress (INGERVALL ET AL. 1972, PETROVIC ET AL. 1975, MCNAMARA ET AL. 1975, AND GHAFARI AND HEELEY 1982, TONGE ET AL. 1982).

Response of secondary cartilage to pressure has been recognized in cartilaginous areas other than the mandibular condyle (PRITCHARD, SCOTT AND GIRGIS 1956, VIGNON ET AL. 1973, AND BERESFORD 1981). Earlier ossification of the sutural cartilage of rats has been reported following alteration of pressure on the midpalatal suture by displacement of the buccal musculature away from the maxillary dental arch (GHAFARI 1984).

In accordance with those findings, the present investigation suggests that the adaptive capability and/or growth potential of condylar cartilage may be regulated and thus limited by the forces exerted on it. Further investigation of mandibular propulsion over longer periods than those used in this study, as well as measurements of ramal and condylar thicknesses, are required to support this hypothesis.

Such an investigation would help to determine whether the findings observed after the interval studied are —

- Transient in nature, followed by a slowdown in proliferation to ultimately return to a normal histomorphological picture relative to age.
- An expression of early maturation, therefore an expression of the growth potential already inherent in the cartilage
- Fluctuate in response to altered force levels transmitted to the cartilage as a result of different functional positions.

At present, it may be concluded from this study that the adaptive response of the condylar cartilage reflects accelerated ossification of the hypertrophic zone. This was not observed following the application of intermittent propulsion with an advancement device inserted in the rat's mouth for 8-12 hours a day (PETROVIC ET AL. 1975 AND STUTZMANN AND PETROVIC 1979).

The difference between the findings in these experiments may be attributed to the different cyclical nature of the forces at the condyle. While intermittent propulsion may allow for a rebound of the condylar response, continuous propulsion apparently does not.

BOUVIER AND HYLANDER (1982) reported a decrease in the proliferative and hypertrophic layers of the posterosuperior region of macaque condyles with a soft diet, and thinning of the superior condylar region of rats on a soft diet. While they found differences in adaptive locations in rat and macaque condyles, they suggested that a lowering of loads on the condyle may have accounted for their results. Similar morphologic changes have been reported in rats whose incisors had been clipped or removed (SIMON 1977), in rabbits whose mandibles were subjected to retrusive forces (Tsolakis 1981), and in monkeys placed in intermaxillary fixation (McNamara 1981).

Those studies tend to support the findings and hypothesis enunciated in the present study regarding regulation of condylar adaptation by force loading. A decrease in force levels through forward and downward shift of the mandible, with subsequent reduction of biting forces and dietary alteration, could account for the smaller condylar cartilage thickness and area in the displaced mandibles observed in this study.

The repositioning of the mandible with a "hyperpropulsor" in the experiments of Petrovic et al. (1975), would have also led to decreased occlusal forces. However, since the daily removal of the "hyperpropulsor" resulted in intermittent displacement of the mandible, the increased thickness of the prechondroblastic and chondroblastic zones could have been a result of the higher bite forces during the periods of normal function.

This same hypothesis may explain the discrepancy between the present findings and those following continuous propulsive forces in monkeys, where McNamara et al. (1975) reported hypertrophy and hyperplasia of prechondroblastic and chondroblastic condylar layers. In their model, they forced the macaque mandible forward with a fixed splint which could have maintained increased biting forces and condylar loads.

On the other hand, intermaxillary fixation which resulted in morphologic change similar to the present findings would have decreased the biting force and condylar load in the macaque monkeys (McNamara 1981).

Finally, differences observed in rat and monkey studies may also be attributed to the relative magnitude of mandibular displacement due to appliance design, to species differences in the adaptive potential of the condylar cartilage (Ingervall et al. 1972), and /or the different genetic growth programs in rats (vertical condylar growth direction) and macaques (upward and backward condylar growth direction) (Bouvier and Hylander 1982).

Mechanical stress may indeed dictate proliferation or decrease of condylar cartilage, but the nature and limitation of such adaptation are not yet known.

As already mentioned, future studies attempting to further clarify condylar response to mechanical changes must look into the actual pressure levels generated through optimal or altered occlusal forces, and their effect on condylar response. Various types of forces with controlled magnitude, direction, duration and continuity must be evaluated.

— Summary —

An inclined plane bonded to the upper incisors of rats is used to produce continuous forward and downward mandibular displacement, with the following effects —

- Histologically, the area of the resting zone was increased and ossification of the hypertrophic zone of the condylar cartilage accelerated, demonstrating the capability of this cartilage to adapt to a functional alteration.
- The changes observed may be transient in nature, may be an expression of early maturation, or may fluctuate with various alterations in force levels transmitted to the cartilage by different functional positions of the mandible.
- These observations differ greatly from those reported following intermittent displacement, which led to increased thickness of the prechondroblastic and chondroblastic zones.

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