Condylar Adaptation to Muscle Alteration in the Rat

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Unilateral surgery is used to alter the functional forces of the lateral pterygoid muscle of the rat. Early changes in condyle structure and form gradually disappear as adaptation to the new functional environment is consummated in this animal model.

The concept that condylar cartilage is embryonic in structure and exhibits an adaptive growth potential is an outgrowth of studies of the histomorphology, histochemistry, growth pattern and response to nutritional upsets (Durkin, Heeley and Irving, 1973). Many others also consider growth in the mandibular condyle to be adaptive or compensatory (Moss, 1959, Koski and Mäkinen 1963, Koski, 1968; Gianelly and Moorrees, 1965; Pimenidis and Gianelly, 1972).

Durkin, Heeley and Irving (1979) observed that the condylar cartilage changes during maturation from a hypertrophic to a nonhypertrophic form, and postulated that this reflects a change from an adaptive to a non-adaptive type. In the rat, this transformation is complete by 220 days, after which the condyle is considered to be no longer capable of adaptive growth (Fig. 1).

An adaptive response has also been reported as an effect of alteration in temporomandibular joint (TMJ) function (McNamara, Connelly and McBride 1975; Petrovic, Stutzmann and

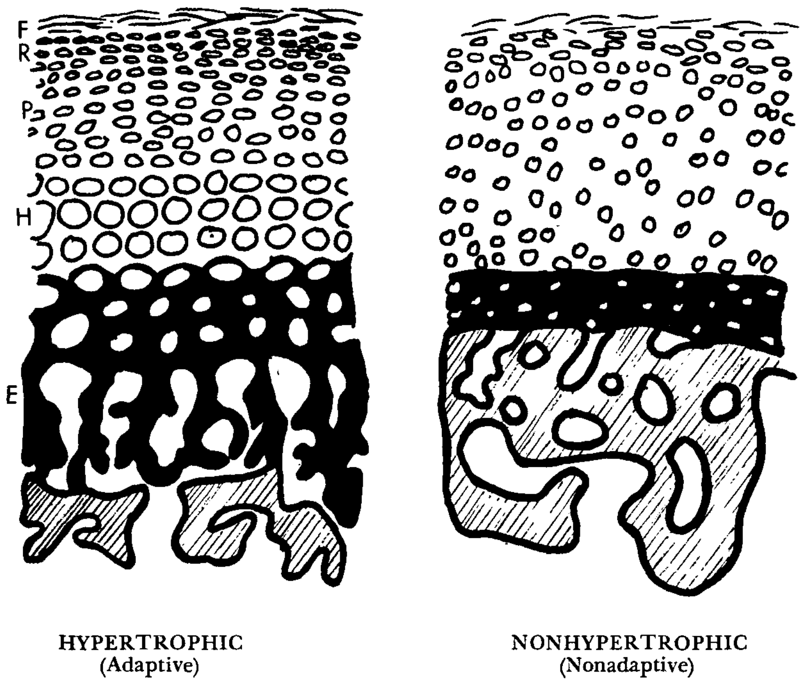


Fig. 1 Condylar cartilage before (hypertrophic) and after (nonhypertrophic) maturation (Adapted from Durkin *et al.*, 1972).
F = Fibrous capsule
R = Resting (embryonic, prechondroblastic, progenitor) zone
P = Proliferative (intermediate, functional chondroblastic) zone
H = Hypertrophic (vesicular, chondroblastic mineralized and nonmineralized) zone
E = Erosion front

Oudet, 1975). Clinically, orthopedic remodeling of the TMJ has been postulated to occur following orthodontic therapy (Graber, Chung and Aoba, 1967; Graber, L., 1975) or surgery (Hollender and Ridell, 1974).

Baume and Derichsweiller (1961) reported an increase in growth of the posterior part of the condyle following anterior displacement of the mandible in two *Macaca Mulatta* monkeys 44-50 months old. The change after 4½ months of treatment was greater than after 2½ months.

Following a constant retracting force applied to the mandible of young (age 14-23 months) macaques for 140 days, Janzen and Bluher (1965) reported alteration of growth and remodeling of the condyles. Resorption occurred at the posterior surface of the condyle and the posterior wall of the glenoid fossa, and apposition at the anterior surface of the condyle.

McNamara, *et al.* (1975) reported *functional and skeletal changes following* anterior and vertical displacement of the mandible of rhesus monkeys for 3 to 15 months. These studies covered infant, juvenile, adolescent and adult levels of maturation.

No significant alteration was noted in the adolescent and adult animals, but marked changes were observed in the rapidly growing infants and juveniles. Those changes included alteration in the direction and an increase in the rate of condyle growth corresponding to the concurrent responses in other skeletal structures and in the lateral pterygoid muscle.

These authors maintain that such structural modifications in the condyle are transient adaptive responses that terminate with normalization in a remodeled form. They conclude that the condyle responds to changes in neuromuscular activity, particularly the function of the lateral pterygoid muscle, dependent on the level of maturation of the tissues.

Research in the Rat

Petrovic et al. (1975) reported finding that growth at the condylar cartilage results via a mechanism which depends on "messages of local origin," and that the "coordination of the masticatory apparatus" depends on a "regional, structural homeostasis." They found an increase in thickness of the articular disc and the prechondroblastic (resting) and chondroblastic (proliferative and hypertrophic) zones following anterior displacement of the mandible in young rats. The increased activity of the lateral pterygoid muscle is reflected in its decreased length and hypertrophied fibers.

Displacing the mandible backward by means of a chin cup is followed by a decrease in the thickness of the prechondroblastic and chondroblastic zones and an increase in the length of the lateral pterygoid muscle. In these experiments, force was applied 8 to 12 hours a day for 1, 2 and 4 weeks, simulating the force application of orthodontic treatment.

Folke and Stallard (1966) used a permanently cemented inclined plane on the lower incisors to displace the mandibles of rats posteriorly. Contrary to the findings of Petrovic *et al.* (1975), they observed increased formation of cells in the condylar cartilage and marked apposition of bone at the insertion of the lateral pterygoid muscle after four weeks. These differences suggest a need for further study to evaluate the effects of differences in experimental design and the direction and magnitude of the applied forces.

Ingervall *et al.* (1972) conducted a histochemical study of the condyle following a similar experiment. Posterior displacement of the mandible resulted in increased metabolic activity in the posterior parts of the condyle, indicating increased cartilage formation. The most marked reactions were seen in the embryonic (prechondroblastic or resting) and intermediate (proliferative) zones. Anteriorly, at the insertion of the lateral pterygoid muscle, marked remodeling and bone deposition was observed. The glenoid fossa showed replacement of cartilage by bone anteriorly, and cartilage formation posteriorly.

Young animals showed more pronounced tissue reactions than older ones, but the authors concluded that the capacity for articular remodeling was still present in old (365 day) animals. On the other hand, Durkin and co-workers (1973, 1979) showed the condylar cartilage in the same animal model system to be nonhypertrophic at 220 days.

The previous studies underline the fact that the condyle is responsive to functional changes. It seems, as Durkin *et al.* (1973, 1979) suggested, that the maturational stage of the condylar cartilage is a key factor in its ability to adapt.

The importance of condylar response in both growth and therapy is emphasized by Durkin (1972), who considered the condylar cartilage to provide an adjustment mechanism essential to maintaining the health and integrity of the TMJ.

This hypothesis was tested in the present study using unilateral alteration of mandibular function in rats. While previous experiments have looked at the condylar response to externally activated deviations of posture and function, this study attempts to relate the response to intrinsic alterations in muscular balance.

Methods and Materials

The right masseter muscle in 25- and 60-day old male Holtzman rats was detached surgically. In one group, the muscle was reattached as far anteriorly on the body of the mandible as possible (experimental group). In the other group, the muscle was left to reattach sponaneously (sham-operated group). Four animals were unoperated. The animals were sacrificed 20, 50, 80 and 110 days postoperatively.

The sample analyzed histologically included 24 operated, 8 sham operated, and four unoperated animals. In each group, additional animals were studied using morphological measurements of various sections of the mandible.

Serial histologic sections were evaluated after staining with hematoxylin and eosin, Van Geison's reaction for collagen (as cited by Lillie, 1954), and Sudan Black B for lipids at sites of calcfication (Irving, 1959).

Results

The condylar head on the operated side of both surgical groups was higher and narrower than on the unoperated side, giving the condyle a more conical appearance (Fig. 2). This difference was most marked at the earlier time intervals and in the surgically reattached animals.

An especially marked morphological change was found in the condylar head on the *unoperated* side of animals operated at 25 days of age and examined 50 days postoperatively. The condylar cartilage was shifted medially, giving it an overall skewed appearance (Fig. 3). A lesser degree of skewing was seen on the operated side, and none at all was found at later postoperative periods or in animals operated at 60 days.

The cellular morphology of the condylar cartilage in younger (45-day) animals was similar to that reported in previous studies. The resting, proliferative and hypertrophic zones were normal in appearance, and chondroclastic erosion was taking place at the lower border. At this stage, the cartilage was a hypertrophic (adaptive) type on both operated and unoperated sides (Fig. 4).

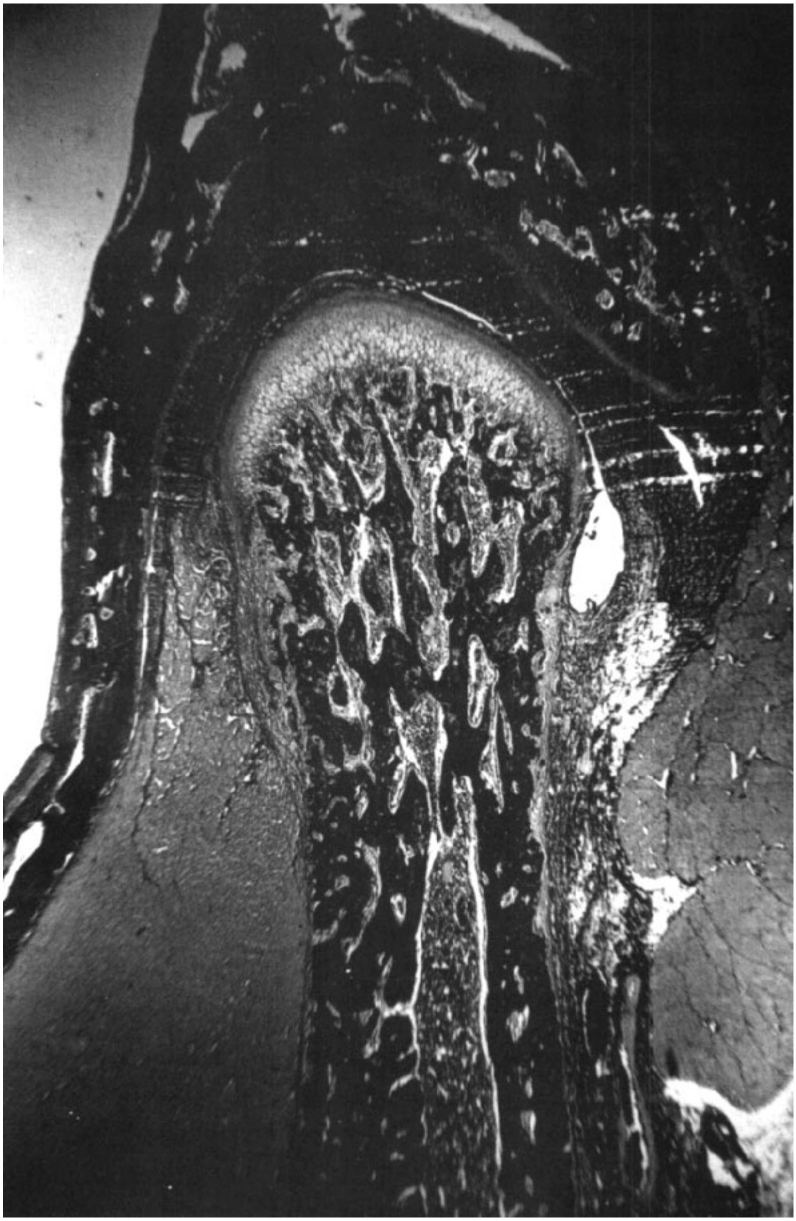
In older animals, the cartilage was narrower and less hypertrophic, showing maturational progression toward the nonhypertrophic (nonadaptive) form, but it was not yet completely sealed off with subchondral bone at this age of 140 days (Fig. 5).

Sudan black, which reacts with lipids at mineralization sites (Irving, 1959), was positive in the calcifying cartilage matrix on both sides of both operated and unoperated specimens, indicating active calcification in all condylar cartilages.

Discussion

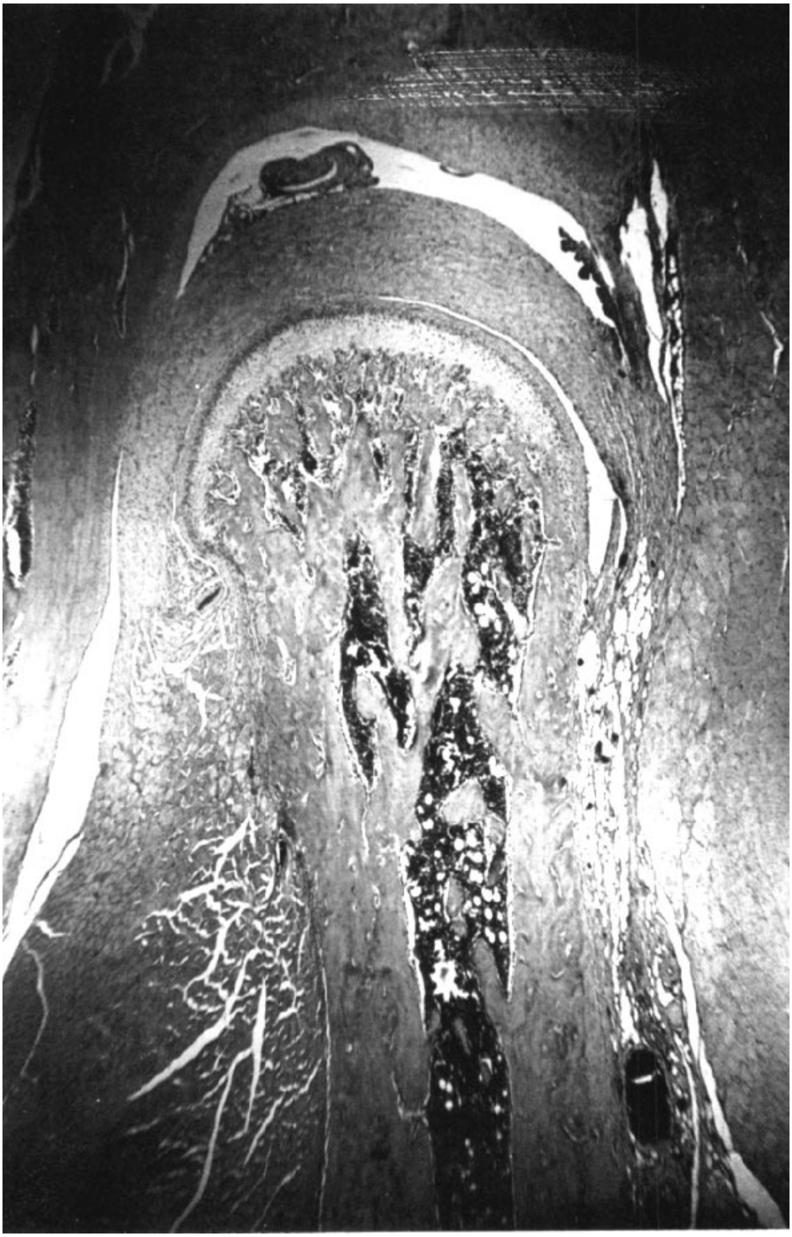
The adaptability observed in the condylar cartilage supports the findings of other investigators (Petrovic *et al.,* 1975; McNamara, 1975; Durkin *et al.,* 1979; Moss, 1959; Gianelly and Moorrees, 1965; Koski and Mäkinen, 1963). It is also in agreement with the conclusion of Durkin (1972) that the condylar cartilage is an adjustment mechanism maintaining the normal anatomic integrity of the TMJ.

Fig. 2 Coronal section through central part of the condyle from unoperated (left) and operated (right) side in a 25-day-old experimental rat at postoperative day 20. Condylar head on operated side is higher and narrower, giving it a more conical appearance compared to the flatter surface on the unoperated side (Van Gieson ×28).



(Fig. 2 continued)

Fig. 3 Coronal section through central part of the condyle 50 days postoperatively in a rat operated at 25 days of age. The condylar cartilage on the unoperated side (left) is skewed compared to the operated side (right). (Hematoxylin and eosin, ×28.)



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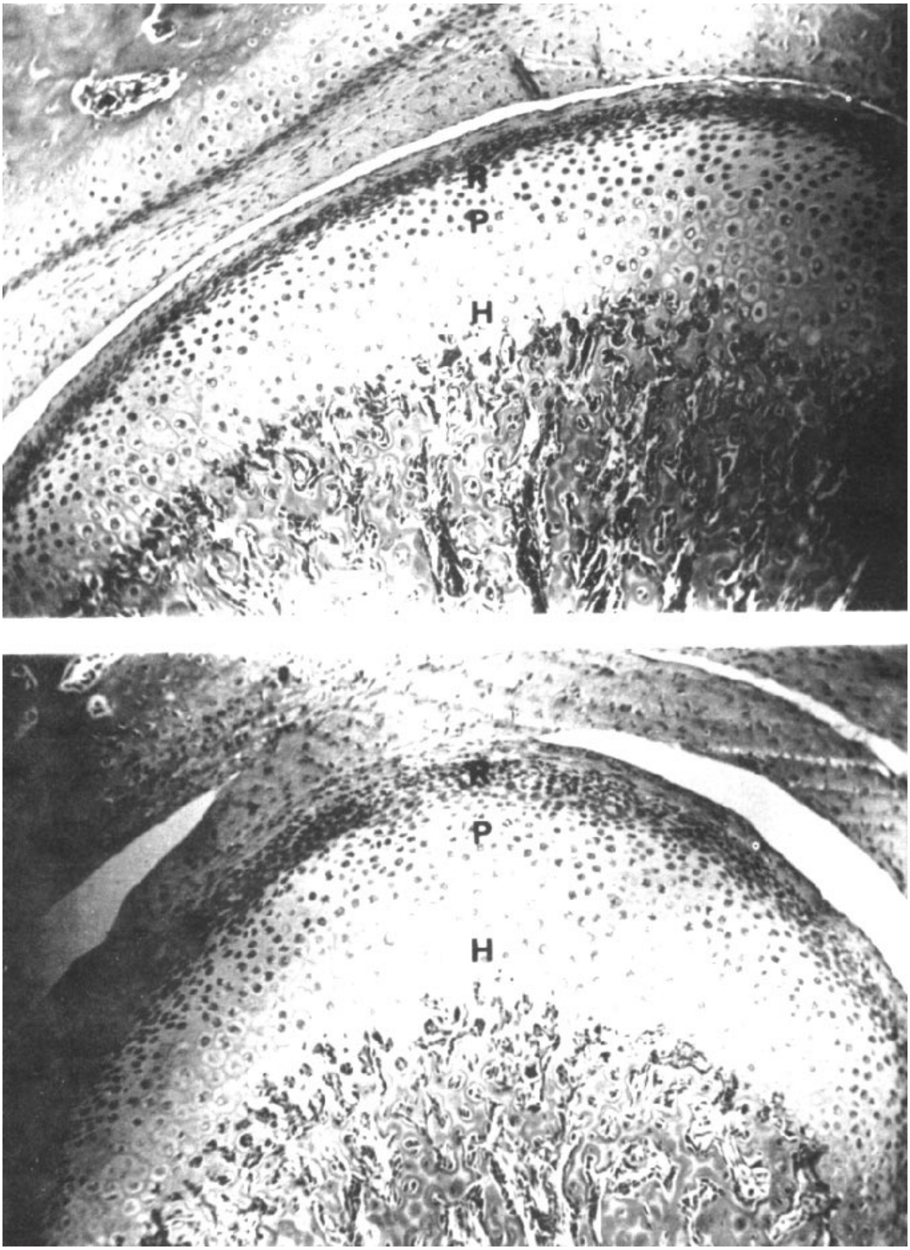

Fig. 4 Coronal sections through central part of the condyle 20 days postoperatively in an experimental rat operated at 25 days of age. The unoperated side (above) is uniformly flatter than the more conical shape of the condyle on the operated side (below), which is relatively thick in the central area. The various zones, resting (R), proliferative (P), and hypertrophic (H) appear normal on both sides. Chondroclastic erosion is occurring in an approximately normal fashion at the lower border of cartilage in both sites (Hematoxylin and eosin ×110.)

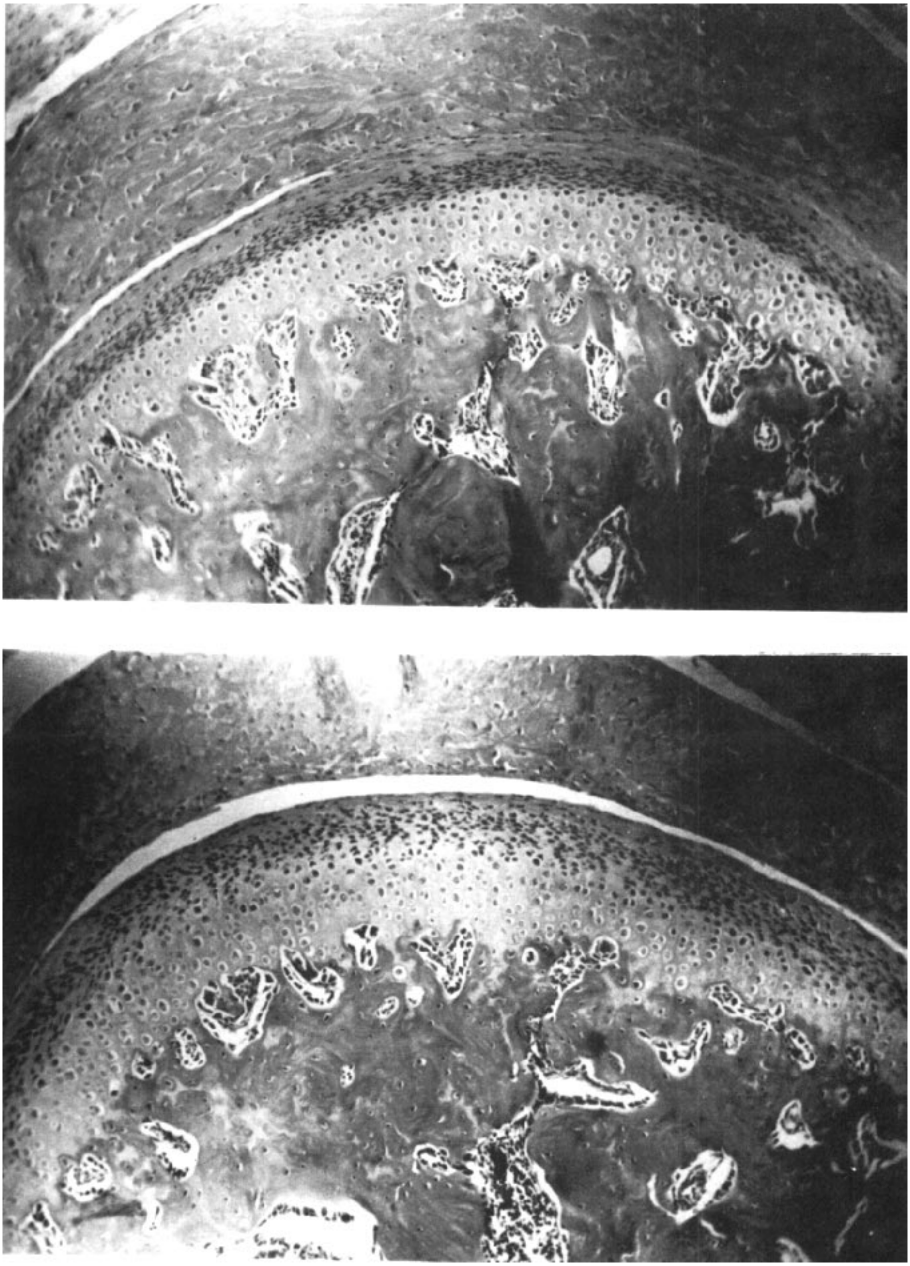

Fig. 5 Coronal sections through central part of the condyle 80 days postoperatively in an experimental rat operated at 60 days of age. The morphological difference between unoperated (above) and operated (below) sides show less than at earlier postoperative periods. Cartilage in both sides appears normal, narrower and less hypertrophic than in Fig. 4, showing maturational progression toward the nonhypertrophic form. (Hematoxylin and eosin ×110.)

Such an adjustment mechanism seemed to be operating in the transitional morphological changes in the condylar heads on the operated sides. In the 25-day-old experimental group, a marked skewing of the condylar head on the unoperated side was observed 50 days postoperatively. This modification could be related to the 75-day age of the animals, or to the functional demands on the condyle 50 days after surgery. However, other animals of comparable age did not show this phenomenon, nor was it seen in later postoperative periods in any experimental group.

The fact that differences in the appearance of right and left condyle heads were less marked after 50 postoperative days may indicate that homeostasis had been reached by that time. This is consistent with the findings of McNamara *et al.* (1975), where normal remodeling followed the initial peak response of the condyle to mandibular displacement. These authors concluded that structural modifications within the condyle are transient in nature, appearing only with changes in the functional environment and disappearing with the attainment of a new functional balance.

The morphological patern of the condylar cartilage at the cellular level was similar to the controls in both operated groups at all ages. The maturational changes reported by Durkin *et al.* (1979) were also evident in the present study. In the younger groups, the cartilage was in the hypertrophic form, while in the older animals it began to show typical maturational changes. Although neither control nor experimental animals reached the age when a completely nonhypertrophic form of condylar cartilage would be expected, they did show narrowing of the cartilage, an increase in matrix, and early stages of sealing off by subchondral bone.

Durkin *et al.* (1979) indicated that progression toward the nonhypertrophic form does occur at this site, which implies that the cartilage in the present study was in an adaptive state for the entire experimental period. It is therefore not surprising to find the condylar cartilage adapting to functional demands, whether stemming from normal or from altered relationships. The similarity between the morphological pattern of condylar cartilage in controls and operated animals was emphasized by the finding that calcification patterns were also similar in all groups of corresponding age.

Summary

Unilateral detachment, with and without anterior positioning of the masseter muscle, was performed in 25- and 60-day old rats. This alteration in muscle function led to a change in morphology of the mandibular condyle, and demonstrated the adaptive nature of the condylar cartilage to functional demands.

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