The Role of Condylar Cartilage in the Development of the Temporomandibular Joint

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A review of studies on the development and functional adaptation of the mandibular condylar cartilage, presenting a comprehensive concept of condyle development and its adaptive response that may help elucidate the etiology of some temporomandibular disorders.

KEY WORDS: · CARTILAGE · FUNCTION · GROWTH · TEMPOROMANDIBULAR JOINT ·

Change is the essence of temporomandibular joint disorders. Like most other diseases and structural-functional disorders, they must have developed over a period of years in response to certain often undefined etiologic factors. It is therefore surprising that the majority of publications report only cross-sectional studies, primarily on adults, whereas only a few longitudinal studies are available (DIBBETS 1977; DIBBETS ET AL. 1985).

Especially when attempting to elucidate the etiology of temporomandibular joint (TMJ) disorders, thorough knowledge of the morphology, origin, growth, and development of the joint structures is essential. Although the articular eminence, mandibular fossa, articular disc and synovial tissues have also received much attention in this respect, the mandibular condyle itself is generally considered to be of primary importance.

The primordium of the mandibular condyle is cartilagenous, and growth of the mandibular condyle can be equated to growth of the mandibular condylar cartilage. Growth of this secondary cartilage, and especially its regulation, has been the subject of extensive discussions in the past. From these discussions, and particularly from experimental and clinical evidence obtained in our laboratories, we

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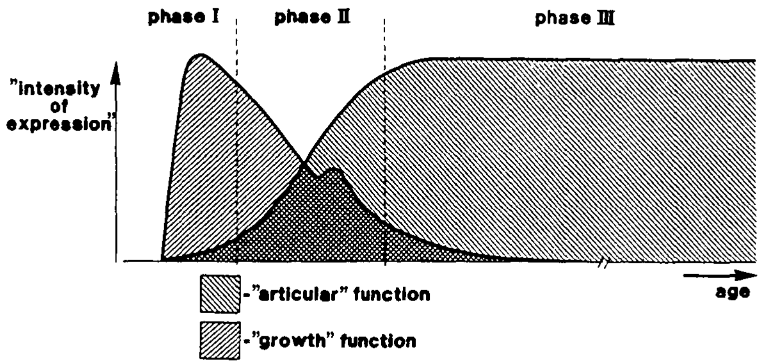

Figure 1. Graphic representation of the function of mandibular condylar cartilage during development, predominantly based on data obtained from the rat. Phase II runs from 5 days to approximately 30 days of age, with some growth activity continuing until about 150 days of age.

It should be stressed that the shape of the curves, the duration of the phases, their overlap, and the relative intensity of the two functions may vary among different animal species. For man, phase II starts before birth and runs until about 20 years of age, with growth activity continuing until approximately age 25. The morphological relationships between differently aged rat and human condylar cartilage have been documented by *Heeley et al. (1985).*

have crystallized a concept of the development of the condylar cartilage of the mandible.

This concept provides an insight into the adaptive response of the mandibular condyle to altered functional activity of the TMJ during development, and might help to elucidate the etiology of some temporomandibular joint disorders in young and adult patients.

Growth and Development of Mandibular Condylar Cartilage

A Concept

The characteristics of cartilage make it a most appropriate tissue for performing two very important functions in the body:

1. *The capacity of cartilage to produce a strong but flexible provisional supportive framework at a relatively high rate of growth fulfills a crucial function during embryonal and postnatal growth.*
2. *The chemical and physical properties of the matrix components give cartilage RESILIENCE, a property which is well suited to cushion compressive forces in loaded articular joints.*

Mandibular condylar cartilage fulfills both functions, though for the greater part, diachronously. These functions influence the development and determine the ultimate shape and composition of the mandibular condyle.

Figure 1 schematically illustrates the relative intensity of expression of the two functions during development. As units for the intensity of expression of the growth function one might think of growth velocity per day; for units of the articular function an index might be constituted to include the extent as well as the frequency of condyle loading. Grossly, three phases shading off into each other can be discerned.

- During phase I, the embryonal and the early postnatal stages, the mandibular condylar cartilage functions mainly as a growth cartilage. Although some intrauterine mandibular movements with functional activity in the TMJ have been observed, the articular function of the condylar cartilage still seems subordinate.
- In phase II, the functional activity increases, causing the mandibular condylar cartilage to function more as an articular cartilage. Increase of the articular functioning is accompanied by a decrease of the growth activity, despite the hormonally induced growth spurt occurring during this stage.
- In phase III, the orofacial muscular structure and activity reach their relatively stable adult stage and gradually the condylar cartilage functions almost entirely as an articular cartilage. The growth activity diminishes further, and some maintenance turnover activity might be considered as the last remnant of the "growth" function.

Experimental Findings

We have carried out a number of *in vitro* experiments with the mandibular condylar cartilage from rats. Figure 2 shows the morphology of the rat mandibular condyle at four different stages during development:

- at birth (phase I)
- at 4 days of age (the beginning of phase II)
- at 28 days of age (the end of phase II)
- at the adult stage (phase III).

Considerable differences can be are discerned in the relative amount of cartilage, the zonal structure (particularly the thickness of the articular layer), and in the condyle shape in these different stages. Each of these three structural aspects reflects the changing functions of the mandibular condyle during development.

PHASE I. In general, biomechanical (functional) stimuli seem to be essential for the chondrogenesis and maintenance of secondary cartilage on membrane bones (HALL 1975, 1979). However, the appearance of condylar cartilage before the actual formation of mandibular bone and before the occurrence of any functional activity in the TMJ region indicates that other factors must be involved in the initiation of this type of secondary cartilage (DUTERLOO AND JANSEN 1970).

GLASSTONE (1971) transferred the intact area of presumptive temporomandibular joint from 13-day-old mouse embryos into organ culture, and from the undifferentiated mesenchyme a normal temporomandibular joint developed during culture. This included normal mandibular condylar cartilage. These findings imply that factors promoting the formation of the condylar cartilage are intrinsic to this particular region, and that induction processes through factors from surrounding tissue may play an important role. Moreover, an appropriate nutritional supply, which might be influenced by the gradual starting of functional activity, must be considered essential for continuing chondrogenesis during phase I.

In phase I, the mandibular condylar cartilage functions mainly as a growth cartilage resembling other growth cartilages in that respect (e.g. the growth plates of long bones). A considerable growth potential can be attributed to it during this stage. The round-headed shape of the condyle (which consists mainly of cartilage) regularly elongates at a high rate, and the ossification front still lies at some distance from the articular surface.

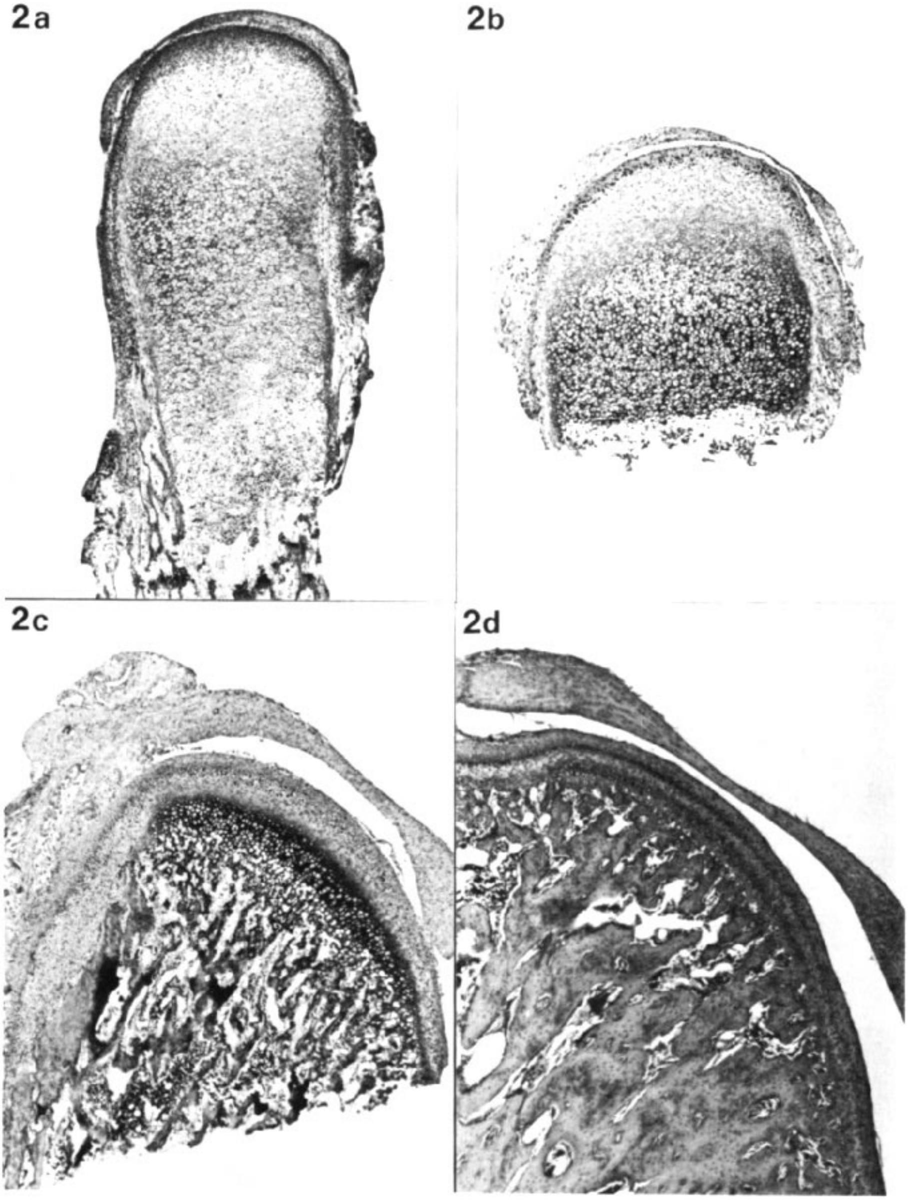

Figure 2
Midsagittal sections of the mandibular condyles of rats at ages 1 day (a), 4 days (b), 28 days (c), and adult (d).
Haematoxylin-eosin ×35

PHASE II. We have cultured condylar cartilage from 4-day-old rats, which might be considered to be at the transition period from phase I to phase II. The condylar cartilage still demonstrated a considerable autonomous growth potential and a "phase I-like" growth during a serum-free culture period of up to 28 days (COPRAY ET AL. 1983).

However, a recent comparative study in which the condylar cartilage from rats aged 0 to 30 days were cultured during a period of 10 days clearly demonstrates that the growth potential gradually diminishes during phase II (Figure 3) (COPRAY AND DUTERLOO 1986). Also, the in-vitro labeling experiments of KVINNSLAND AND KVINNSLAND (1979) in rats show a decrease of proliferative activity in this period, with a temporary rise around the age of 14 days.

The question arises whether this decrease in growth activity is merely genomically determined or partly induced by increasing hormonal and biomechanical stimuli. An indication for the role of biomechanical stimuli in this respect was provided by the experiments of MELANSON AND VAN DIJKEN (1972). They reduced the biomechanical stimuli generated by functional articular activity in the TMJ while leaving the hormone supply unimpaired by extirpating the entire glenoid fossa in 21-day-old rats. In the absence of functional loading, the mandibular condylar cartilage retained its growth activity, and growth in length was observed.

In past years we have performed an extensive basic study on the influence of biomechanical stimuli on mandibular condylar cartilage growth. A force application system was developed to enable us to apply a wide range of quantified continuous and intermittent compressive forces to the mandibular condylar cartilage of 4-day-old rats in a serum-free culture system (COPRAY ET AL. 1985A).

It became apparent that biomechanical stimuli could inhibit as well as stimulate proliferation and matrix synthesis in the

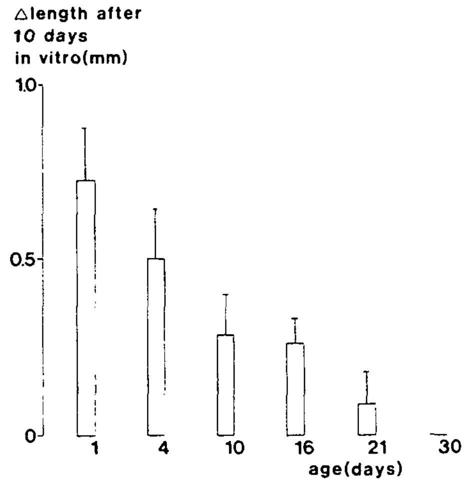

Figure 3. Increase in length of mandibular condyles derived from rats ages 1, 4, 10, 16, 21, and 30 days after 10 days of serum-free culture *(mean ±S.D.; N=6).*

mandibular condylar cartilage cells, dependent on the magnitude, exposure time, and mode (continuous or intermittent) of the applied force (COPRAY ET AL. 1985B).

Results indicate further that biomechanical stimuli could also influence the ossification process in the mandibular condylar cartilage (COPRAY ET AL. 1985C).

Moreover, we have demonstrated that intermittent biomechanical stimuli could alter condyle shape during the growth of the condylar cartilage. The experiments of MELANSON AND VAN DIJKEN (1972) have shown that, concomitant with the regaining of growth activity after glenoid fossa extirpation, the absence of functional loading resulted in a remodeling of the condylar cartilage from the mature functional mediolaterally-skewed appearance to the round-headed embryonal shape.

In our in-vitro system, we could initiate the opposite shape in the growing condylar cartilage by the sidelong application of bio-

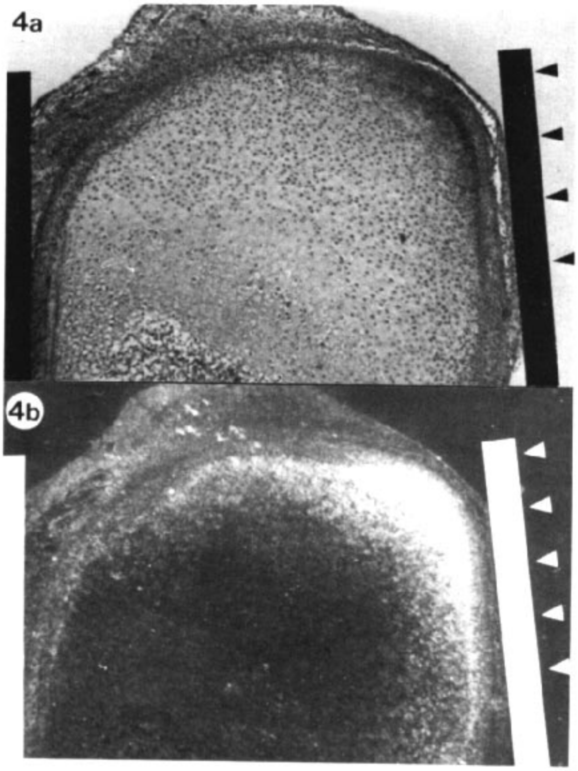

Figure 4
Autoradiograms of midsagittal sections of ^{35}S-sulphate labelled condyles after 72 hours of culture with sidelong application of an intermittent compressive force. Under the influence of these biomechanical stimuli the cartilage production increased at the glenoid side of the condyle.

mechanical stimuli (Fig. 4) (Copray et al. 1985d). In contrast to compressive forces, we could not mimic shearing forces in our in-vitro system. It is thought that shearing forces induce thickening of the fibrous articular layer, which is a most appropriate structure to resist and cushion such forces. As such, the shearing forces would have an indirect effect on the growth activity of the mandibular condylar cartilage, because the thicker, rigid, ill-permeable enveloping structure of the articular layer might hinder (e.g. by diffusion disturbances) the growth processes in the different condylar cell types.

It seems apparent that an important part of the observed changes in the relative amount, the structure, and the shape of the mandibular condylar cartilage of the rat during phase II (Fig. 2) can be ascribed to the increasing functional loading. These changes reflect the gradual shift of the behavior of the condylar cartilage from that of a pure growth cartilage (phase I) to a functional articular cartilage (phase III).

Features typical of a pure articular cartilage (small cell size and increased amount of intracellular matrix), for instance, can already be seen in the condylar cartilage when the rat is changing its diet from milk to whole pellets in association with weaning (Kantomaa 1986).

Phase III. The properties and reactions of more adult articular cartilage to altered functional loading is well documented due to the considerable amount of experimental work done on the articular cartilage of the femoral head and the knee joint in a wide variety of animals.

Articular cartilages become thinner as a response to diminished functional loading (Eichelberger et al. 1952; Akeson et al. 1958; Akeson et al. 1973; Palmoski et al. 1979 and 1980) or to overloading (Salter and Field 1960; Trias 1961), and even disappear at complete immobilization (Ginsberg et al. 1969).

Articular cartilage thickens in response to normal or slightly increased functional loading (Muir 1977; Radin et al. 1978) and reacts with an improvement of its structural mechanical properties (Van Kampen 1983). The reactions of the mandibular condylar cartilage during phase III to experimentally altered functional loading largely seems to confirm the similarities with articular cartilage (Stöckli and Willert 1971; McNamara 1980; Carlson et al. 1980; Bouvier and Hylander 1984; Kantomaa and Rönning 1982, among others).

Summarizing, it is important to consider the developmental phase of the condyles, when interpreting the results of altered loading experiments. The reaction to altered functional loading of condylar cartilage which still possesses a certain growth potential is different from that of adult cartilage. Immobilization of the mandibular joint in adult animals leads to a complete loss of the condylar cartilage (McNamara 1980), while reduction of functional loading on the mandibular condyle in young growing animals seems to revive its growth activity (Folke and Stallard 1966; Melanson and Van Dijken 1972; Fuller 1974; Lindsay 1977; Petrovic 1975 and 1979).

From medical and dental clinics the questions have been forwarded, whether altered functional loading as may result from occlusal malrelations, aberrant patterns of oral behavior, changes in composition of the dentition, etc., could affect the mandibular condyle in young patients, and whether this might lead to the development of some form of TMJ dysfunction.

Previous studies, especially the experiments of Kantomaa (1984), have demonstrated that an altered position of the condyle in the fossa and subsequent altered loading can change the shape of the condyle. Kantomaa displaced the glenoid fossa in young rabbits posteriorly with the use of artificial sutural synostoses. This caused the condyle to articulate more inferiorly and anteriorly in the fossa, against the zygomatic process. A subsequent shifting and thickening of the condylar cartilage to the new side of compression was observed (Fig. 5). Since the actual osseous mandibular condyle is formed by endochondral ossification of the condylar cartilage, the shape of the condyle was altered.

In other experiments, Kantomaa (1986) changed the functional loading in young rats by cutting incisors and by feeding them with a soft diet. This resulted in an increased growth in height of the condylar process, and in a more angular shape of the condyle (Fig. 6).

Our concept indicates that the time at which functional changes occur during phase II is a critical factor in the ultimate response of the condyle. For instance, condylar adaptation to a change in TMJ activity pattern occurring at the beginning of phase II might very well be followed by re-adaptation after re-establishment of the initial loading pattern, or even after new functional disturbances later during that phase.

As long as the end of phase II (the period of growth activity) has not been reached, appropriate adaptations to changing patterns of TMJ activity occur in the mandibular condyle. In fact, a direct relationship may exist between specific functional activity patterns and specific individual growth patterns, and this will ultimately be reflected in altered form of the mandibular condyle.

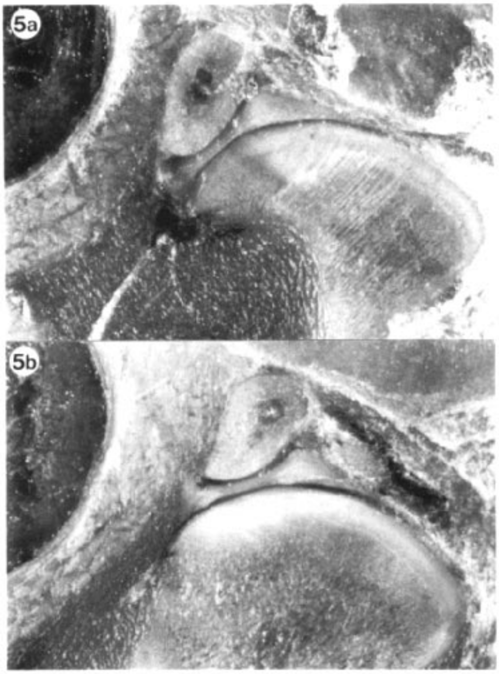

Figure 5
Temporomandibular joints of 25-day-old control (a) and experimental (b) rabbits. Fossa displacement in the experimental animal caused the condyle to be situated more inferiorly and anteriorly in the fossa. After an experimental period of 15 days, the cartilage layer is thickened in the anterior region.

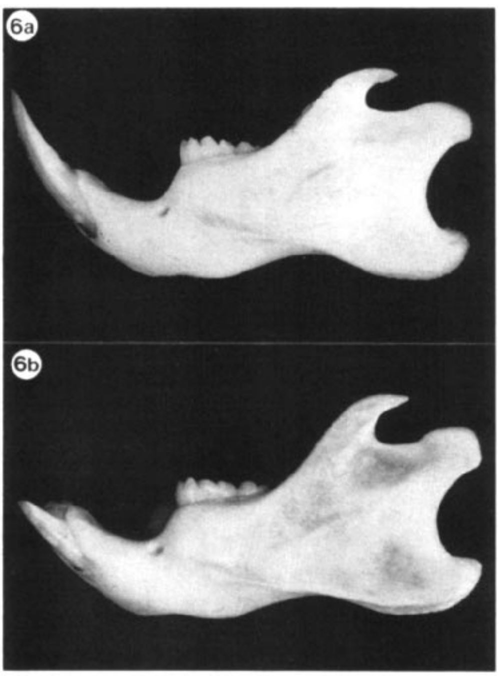

Figure 6
Mandibles from 40-day-old control (a) and experimental (b) rats. The experimental rat was fed a soft diet after the incisors were cut. This resulted in increased growth in length of the condylar process and a more angular shape of the condyle.

In phase III, the condyle lacks the capacity for adequate adaptation to severe functional alterations, so any imbalance between form and function might lead to TMJ disorders (MOFFETT ET AL. 1964; DE BONT 1985).

— Clinical Findings —

Longitudinal study of temporomandibular joint dysfunction in children in Gröningen found flattened condyles that were initially considered to be abnormal. The flattened contour of the condyles as observed radiographically were identified as symptoms of developing temporomandibular joint dysfunction.

During the course of the investigation, which has now run for over 15 years, it became evident that flattened condylar projections can also be considered as indicators of growth patterns. One of the observed phenomena on this flattening was that it did not always appear to be a permanent characteristic. For a number of children the condyle in one year appeared to be more or less rounded, and the next year the condylar projection was judged to be flattened.

In the foregoing conclusions from animal experiments a direct relationship was assumed between specific functional activity patterns and specific individual growth patterns, reflected in the altering form of the mandibular condyle. Extrapolating this assumption to a clinical situation in humans, a model might be postulated in which rounded and flattened condyles both represent stages of a characteristic growth pattern. The rounded contour in that situation may be considered a reflection of predominantly mechanical functional conditions like articulation. The flattened contour, on the other hand, could reflect the dynamic growing condition in which the condyle responds predominantly to mandibular displacement.

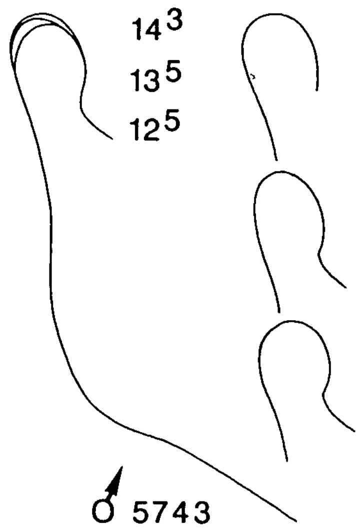

Figure 7 Superimposition of tracings of the condyle and ramus from one patient at ages 13yrs 5mo, 14yrs 3mo, and 12yrs 5mo, showing alternately rounded, flattened, and rounded contours.

If this model has actual significance, it may be recognized in a longitudinal study in which the appropriate growth parameters were registered. Careful analysis of the longitudinal data for participants with observed alternating rounded and flattened contours suggests the existence of the hypothesized growth pattern. Figure 7 shows the structural superposition of both mandibles. The suggestion may be put forward that alternating rounded and flattened contours reflect the ultimate competition of at least two functions for dominance (DIBBETS AND VAN DER WEELE 1986).

— Concluding Remarks —

Complex influences on the growth of the mandibular condyle during phase II make it almost inevitable that imbalances in the delicate condyle-fossa relationship will occur without directly loading to so called "dysfunction."

In general, these are temporary phenomena, since the condylar cartilage appears quite capable during this phase to react very adequately to the altering functional loading patterns. Adaptations occur until the condyle has reached a "stable" "adult" position in the mandibular fossa and a regular functional loading pattern has developed. Only in the few cases that basic growth processes are disturbed, or excessively aberrant oral behavior distresses the TMJ beyond its adaptive potential, will these growth phenomena lead to some kind of TMJ disorder. It is of utmost importance to separate such cases from mere physiologic imbalances.

WHAT WE HAVE TRIED TO MAKE CLEAR IS:

- that one momentary picture of an "aberrant" contour of a mandibular condyle in young patients should never be used as in indicator for TMJ dysfunction, let alone for therapeutic intervention, since the picture might be altered once again during further development.
- That one momentary picture of an "aberrant" contour of a mandibular condyle in young patients should never be considered as a predisposition sign for later development of TMJ disorders in the adult stage.
- The development of abnormal condyles as seen in some TMJ disorders in adults (phase III) seems to correspond to similar anomalies in other joints subjected to trauma or abnormal functional loading; the behavior of the mandibular condylar cartilage in these pathologic conditions is essentially the same as that of articular cartilage in other joints.

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