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# EFFECTS OF COMPRESSION ON GROWTH PLATES IN THE RABBIT

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Compression was applied to the distal femoral growth plate in rabbits. Measurements of bone length and microscopic studies of the physis showed that the axial growth rate decreased proportionally with the compression force; forces greater than 30 N caused cartilage cell damage and rapid cessation of physeal growth.

*Key words:* bone growth; epiphysis; physis

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The mechanical aspect of the bone growth process is poorly understood at present. A precise knowledge of several dynamic parameters is necessary to approach the problem of controlling the growth rate. Evaluating the force which develops in the human growth plate during the growth phase would also allow us to define the mechanical specifications of materials and devices used for internal fixation. Blount & Clarke (1945) stated that the force exerted is sufficient to break one steel staple of 3/32 inch diameter on each side; the force was about 900 pounds. Various devices to limit the longitudinal bone growth have been used in different experimental animals. Hass (1948), Gelbke (1951) and Düben (1956) anchored wires on both sides of the growth plate. Strobino et al. (1952), Sijbrandij (1963) and Trueta & Trias (1961) tied calibrated springs between transfixation pins. Amako & Honda (1957), Sijbrandij (1963) and Christensen (1973) used rigid metallic staples. An external device exerting variable compression force on the growth plate was designed with which precise measuring of the longitudinal force driving the entire growth phase was possible. The purpose of the study was to provide preliminary answers to the following questions: what is the minimum force which can stop the growth quickly? What is the effect of a controlled compression force on the growth rate? What is the histological behaviour of the growth plate when it is subjected to a known compressive force?

## MATERIALS AND METHODS

In 6-week-old white male New Zealand rabbits two parallel centrally threaded pins were transfixed in the right femur, proximal and distal to the distal growth plate. Two force transducers were fixed to both ends of the distal pin. The electrical strain gauge transducers used gave a precise analogue evaluation of the compressive force (Figure 1). Two series of experiments were carried out on 24 rabbits:

*The "locked method":* for the determination of the minimum force which would quickly check the longitudinal growth process.

*The "regulated method":* in which a constantly controlled compression force was applied to analyze the variations of growth rate as a function of force. The increase of bone length was periodically measured (every 3 days).

After a maximum duration of 2 month's experiment, the femur was dissected clean. The left unloaded femur being used as a reference, direct measurements with a slide caliper showed:

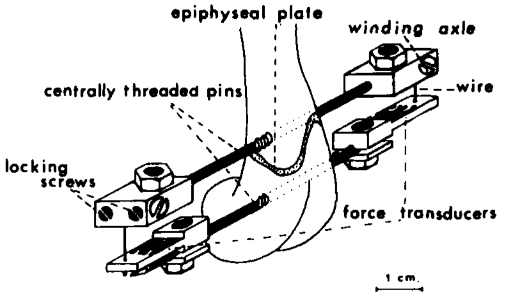


*Figure 1. The external measuring unit, fixed on the distal extremity of the femur.*

1) A difference in length in both femurs from the top of the head to the horizontal plane of the condyle.
2) A difference in the intercondylar distance.

The bones were then prepared for a histological study. On each histological specimen, five determinations were made for evaluating the changes which had occurred in the columnar organization: total growth rate of the growth plate, growth rate of the germinative zone, the growth rate of the proliferation zone, the growth rate of the hypertrophic zone, and the rate of the hypertrophic cell.

## RESULTS

Experiments have been carried out on two series of 24 animals, for the "locked" and "regulated" compression. Daily variations of the compression force and the physeal lengthening have been measured. Otherwise, at the end of the experiments, morphological comparisons between the loaded and unloaded femur (right and left) were performed, leading to an estimate of the daily growth difference. The results are presented in Tables 1 and 2.

### *Growth of unloaded growth plate*

The measurement of the distance between the pins enabled the physeal growth to be obtained. The calculated mean value was 390 μm per day. This result has already been reported by Compere & Adams (1937), Strobino et al. (1952) and Weissman (1974). Thus, we could verify that the implantation of pins had no perceptible effect on the growth rate.

*Table 1. Variations of physeal growth rate*

| Compression Force (N) | No. of animals | Growth rate (mean values), μm/day | Standard deviation, μm/day |
|---|---|---|---|
| 0 | 6 | 390 | 84 |
| 10 | 5 | 144 | 35 |
| 20 | 5 | 95 | 18 |
| 25 | 3 | 79 | 13 |
| 30 | 4 | <40 | – |

### *Growth rate of loaded growth plate*

The "locked" method: different initial compression forces were applied, and the system locked in position. Increasing forces, due to axial growth, were periodically recorded until their variations reached nonsignificant values. The graphic representations (Figure 2) show that, whatever the amplitude of the initial force may be, all the curves point in an asymptotic direction, Fd = 38N. This value would correspond to the maximum compression force to be exerted on the growth plate, producing a quick inhibition of the longitudinal bone growth.

The "regulated" method: several amplitudes of compression forces (up to 30 N) have been applied to the growth plate, and maintained at a constant value during the whole experiment. The variations of lower physeal elongation depending on time are represented in Figure 3. The following observations can be made from the Figure:

– The longitudinal growth rate is inversely proportional to the applied compressive force.

*Table 2. Variations of the daily difference of lengthening of loaded and unloaded femurs*

| Compression Force (N) deviation | No. of animals | Δ (Lr-Lf), μm/day | Standard deviation μm/day |
|---|---|---|---|
| 10 | 5 | 110 | 60 |
| 20 | 5 | 180 | 120 |
| 25 | 3 | 240 | 100 |
| 30 | 4 | 350 | 150 |

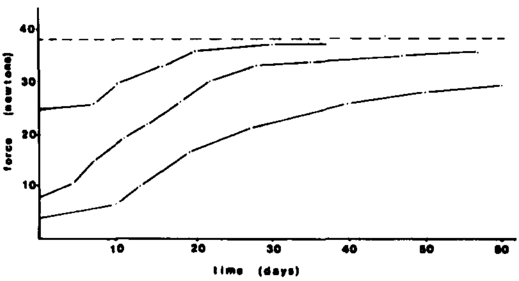


*Figure 2. Locked mode. Variations of compression force as a function of time for three given initial values 4, 8 and 24 N.*

– During the first month of the experiment, and for a given constant compression force, the bone elongation curve, plotted in relation to the time, is linear (Table 1).

*Variations of bone dimensions*

The mean values of daily variations of the difference in length Lr-Ll of the loaded and unloaded femur were calculated for several amplitudes of the compression force applied to the growth plate. Table 2 and Figure 4 give a rough estimate of the compression force effect on the bone growth. Comparative measurements on the right and left femur of the condylar antero-posterior diameter D, and the width of the fossa intercondylaris E, showed that there was no linear relation between condyle alterations and the applied force. Nevertheless, the mean values of the daily variations of the differences Dr-Dl and Er-El were always positive and ranged between certain extreme values:

$$50\ \mu m < Dr\text{-}Dl < 150\ \mu m$$
$$25\ \mu m < Er\text{-}El < 50\ \mu m$$

*Histological aspects*

*Variable force ("locked" method).* No major deformation of bone occurs, aside from a slight inward curve in the posterior concavity.

The following observations were made:

– An universal cartilaginous atrophy with the weakest average forces, which explains the decrease in length noted macroscopically.

– An increase in thickness of the cartilage, for the largest forces, resulting from a cellular hypertrophy concerning all the columns. It appears to be a question of a degenerative phenomenon and not of increased stimulation, since the osteogenesis of the metaphysis is diminished in all the bones and a shortening of the paw operated on occurs.

– In the cases where the cartilage thickens, the lesions are clearly more intense in the plane of the pins. At this level one observes a localized oedema with fibrillation of the matrix and disassociation of the columns, a fracture with chondrocyte necrosis, and a bony bridge.

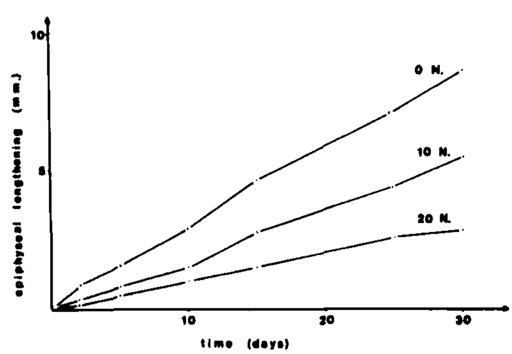


*Figure 3. Regulated mode. Physeal growth as a function of time for three constant compression forces of 0, 10 and 20 N.*

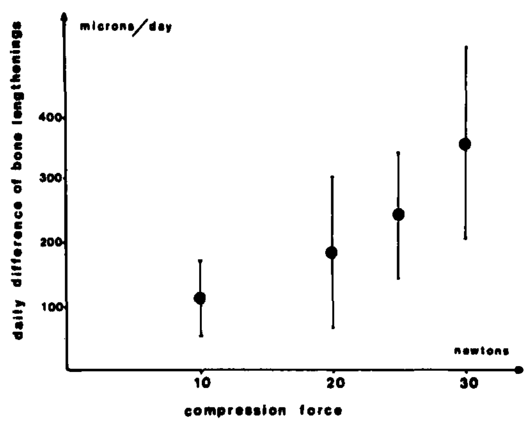


*Figure 4. Daily difference of lengthening of loaded and unloaded femur, for several compression forces applied to the growth plate.*

*Constant force ("regulated" method).* For constant forces, in most of the bones one observes an atrophy of the cartilage with a decrease of the multiplication of the cells in the germinative layer, but, in contrast, an increase in the volume of the hypertrophic cells. Osteogenesis of the metaphysis is slightly diminished as compared to the healthy side. On the force line which joins the implantation points of the two pins, one again finds more severe lesions, fissuration, and chondrocyte necrosis. It is to be noted that this mode of compression can cause considerable bending of the bony pieces.

## DISCUSSION

From the biomechanical aspect, two principal remarks become apparent after the study of the dynamic behaviour of the growth plate, subjected to a compression stress.

First, it appears that it is possible to control the decrease of the axial growth rate by externally regulating the compression force, axially applied to the growth plate. During the initial phase of the compression (first month), the growth rate remains constant for a given constant amplitude of the applied axial force. Secondly, measurements in the "locked method" indicate that the maximum value of the "static" force developed by the growth phenomenon itself is about 38 N. The resulting stress at the surface of the growth plate inhibits almost entirely the axial growth activity.

From the histological point of view, the problem is to determine the range of compression force amplitude which it is possible to exert on the growth plate without damage to the cells. The compression time is also an important parameter which it would be necessary to analyse separately.

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