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**EFFECT OF COMPRESSION ON THE HEALING OF  
SUBCAPITAL OSTEOTOMIES OF THE FEMORAL NECK  
AND ON THE AVASCULARIZED FEMORAL HEAD**

*An Experimental Study on Adult Rabbits*

*By*

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Fractures in cancellous bone unite without any intermediate formation of cartilaginous callus and without any marked degree of periosteal reaction. Healing is accelerated if the bony surfaces are pressed against each other by some appropriate device. This principle has been successfully applied in arthrodesis and in the treatment of fractures (*Charnley & Baker 1952, Charnley 1953, Gasser 1965*). The results are mostly good when both cancellous bone fragments are adequately vascularized. The prospects are poorer when the blood supply of one of the fragments is disturbed, as is the case in subcapital fractures of the femoral neck. In these cases, aseptic necrosis of the femoral head and pseudarthrosis of the neck are of common occurrence. In order to improve the prognosis, a compression technique has been used (*Charnley, Blockey & Purser 1957, Charnley 1961*) apart from various types of sliding nails. The results have been promising.

There are few data concerning the effect of compression on the healing of osteotomies in the presence of one avascular fragment. Better knowledge concerning this problem would clarify the possible usefulness of compression in the treatment of fractures of the femoral neck.

In continuation of previous experiments on osteotomies of the femoral neck (*Rokkanen, Slätis & Laine 1965, Slätis & Rokkanen 1966*), the

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*Figure 1.*

*Figure 2.*

*Figure 1. Roentgenogram taken one week after osteotomy of the femoral neck. The compressing device is in place. The line of osteotomy is visible.*

*Figure 2. Roentgenogram taken 12 weeks after osteotomy of the femoral neck. The femoral head is flattened and its density is increased. The osteotomy has united.*

aim of this study was to investigate the effect of compression on the healing of osteotomy of the femoral neck and on the changes in the head.

#### MATERIAL AND METHODS

In the experiments 47 adult rabbits of both sexes were used. The left hip joint was exposed by a posterolateral incision, the ligamentum teres was severed, the femoral head was dislocated and the trochanteric muscles were detached. The femoral neck was osteotomized with an electrical saw so as to become completely free. The femoral head was replaced and fixed with a transcervical bolt. In the experimental group, which comprised 24 animals, continuous compression was produced by the application of a spring between the head of the bolt and the trochanter (Figure 1). When maximally compressed, the spring yielded a pressure on the osteotomized bone of 35 g per square millimetre. In the control group, consisting of 23 animals, only fixation with a bolt was used.

The animals were killed 1, 3, 6 and 12 weeks after the operation. The femoral heads on both the operated and the unoperated side were dissected out and roentgenographed. The proximal parts of the femora were split into two halves in the

frontal plane; one half was taken for histological investigation and the other half was fixed in methyl metacrylate for oxytetracycline (OTC) fluorescence microscopy.

The animals were given 50 mg of oxytetracycline per kg body weight for three consecutive days before being killed.

After EDTA decalcination the histological specimens were stained by Weigert-van Gieson's haematoxylin and the Alcian blue methods.

The methyl metacrylate specimens were sawed and ground to sections 100  $\mu$  in thickness for the purpose of microscopic fluorescence studies.

## RESULTS

In the compression group one infection and two bolt breaks occurred, in the control group three infections and five bolt breaks. In the analysis of the results the infected animals are omitted, but the cases with bolt breaks are assessed.

The following observations were made on the healing of the osteotomies and the changes of the femoral heads:

*One week after operation* 4/6 osteotomies in the *compression group* were firm. In one case roentgenography revealed that the spring was not maximally compressed.

Histologically, granulation tissue and formation of new bone were observed principally in the area of cancellous bone in the femoral neck.<sup>1</sup> The cancellous bone of the femoral head was mainly nuclear, whilst the cancellous spaces were poor in cells.

The OTC fluorescence was strongest in the internal callus of the femoral neck. In the femoral head a slight uptake was observed laterally, close to the osteotomy, and in one specimen in the whole area of the osteotomy but not in any other site (Figure 3 a).

In the *control group* 1/6 osteotomies were firm. Roentgenologically the contact was found to be poor in three animals.

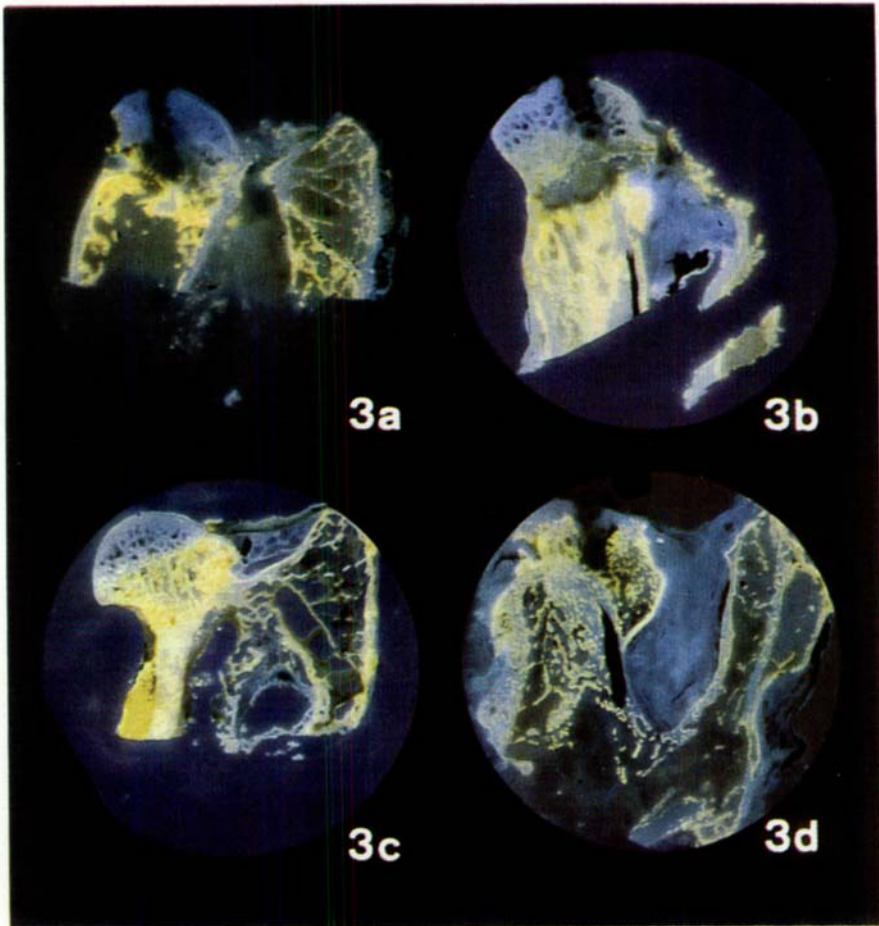
Histologically, the external callus formation was more exuberant than in the compression group. In contrast to the compression group, no regeneration was observed in the femoral head.

The OTC uptake in the femoral neck was equally strong in both groups.

*Three weeks after operation*, the osteotomy was firm in 2/6 animals

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<sup>1</sup> In what follows, regeneration (granulation tissue and formation of new bone) in the area of cancellous bone are called internal callus. External callus is used to designate the callus growing on the outer surface of the femoral neck towards the femoral head, ensheathing the osteotomy.



*Figure 3 a. Fluorescence micrograph taken one week after osteotomy of the femoral neck and application of compression. The strongest OTC uptake is seen in the femoral neck in the internal callus. Slight uptake is discernible in the femoral head in the vicinity of the osteotomy.*

*Figure 3 b. Three weeks after the osteotomy. The strongest OTC uptake is still observed in the femoral neck. Close to the osteotomy a weaker fluorescence is seen in the femoral head.*

*Figure 3 c. Six weeks after the osteotomy. The OTC uptake is strong in the femoral neck and of the same strength over an area extending into the middle of the femoral head.*

*Figure 3 d. Twelve weeks after the osteotomy. The OTC uptake is weaker in the femoral head and neck than in the previous group. Note the derangement and flattening of the femoral head.*

in the *compression group*. Roentgenologically, two bolt breaks were detected.

Histologically, two cases showed bony union of the lateral part of the femoral head and the neck. Regeneration proceeded from the neck into the head, mainly by the internal route. Animals with movable femoral heads had a more abundant external callus. The femoral head was more clearly ischaemic than in the foregoing group. Granulation tissue was observed in the head in the vicinity of the osteotomy.

The OTC fluorescence was still strongest in the femoral neck. After union of the osteotomy the uptake began to extend to the femoral head (Figure 3 b).

In the *control group* all femoral heads were movable. One bolt break was observed roentgenologically.

Histologically, the internal bone formation was found to have remained stationary at the level of the osteotomy, and the external callus was more conspicuous than in the compression group. On the other hand, the femoral heads with their enlarging necrotic areas resembled those in the animals of the compression group.

The OTC fluorescence revealed a more exuberant external callus formation than in the compression group. In two cases weak OTC uptake was observed in the femoral head adjacent to the osteotomy, but in the remainder no uptake was noted in the head.

*Six weeks after operation* the osteotomy was firm in 5/6 animals in the *compression group*. A roentgenological increase in density was observed in the femoral neck.

Histologically, bony union of the fragments could be observed. An area of uniform regeneration extended to the middle of the femoral head. In the latter, the cancellous spaces were empty and the subchondral cancellous bone was entirely anuclear. In the articular cartilage clusters of abnormal cells were seen, and fibrocartilage grew like a sheath from the sides over the articular surface, signifying degeneration.

The uptake of fluorescing material was brisk in the femoral neck and extended as far as the middle of the head, only the dome of the head being still devoid of fluorescence (Figure 3 c).

In the *control group* the osteotomy was firm in 3/5 cases. Two bolt breaks were detected roentgenologically.

Histologically, vigorous internal callus formation was observed in the femoral neck, and a more abundant external callus than in the compression group extended to the femoral head. The degeneration of

the femoral head and the articular cartilage corresponded to what was observed in the compression group.

The OTC uptake was strong in the femoral neck in both the internal and external callus, but extended into the femoral head only in two animals.

*Twelve weeks after operation* all five osteotomies in the *compression group* were firm. Roentgenologically, the femoral head was flattened in four and showed increased density in three animals (Figure 2). The osteotomy had united in all cases.

Histologically, marked invasion of granulation tissue extended to the articular cartilage. The original cancellous bone in the femoral head was completely necrotic. The articular cartilage was covered with fibrocartilage and in part completely destroyed.

The OTC fluorescence in the femoral neck was weaker than in the foregoing group. A strong uptake was observed in the whole of the femoral head (Figure 3 d).

In the *control group* the osteotomies were firm in 2/4 animals. In two cases a bolt break had occurred. Roentgenologically, no obvious flattening or increased density was observed.

Histologically, marked regeneration of the femoral neck extended to the subchondral area of the femoral head in two cases. In two animals bony union had occurred. The cancellous bone in the femoral head was anuclear, and the articular cartilage was completely degenerated as in the compression group.

The OTC uptake was still strongest in the neck. It extended into the subchondral area of the femoral head only in two cases.

#### DISCUSSION

In the rabbit, capsulectomy of the hip joint causes only slight degeneration of the femoral head. Partial osteotomy of the femoral neck produces greater changes. As a result of total osteotomy necrosis of the head invariably develops, and in these cases the ligamentum teres does not contribute to the regeneration of the femoral head (*Rokkanen 1962, Rokkanen, Slätis & Laine 1965, Slätis & Rokkanen 1966*). Hence, it seems obvious that the femoral head of the rabbit is principally vascularized through the cancellous bone.

In the rabbit, healing of an unfixed osteotomy of the femoral neck is brought about by direct bone formation in the osteogenic tissue growing from the neck into the devascularized head. In addition to

this principal route of healing, an external callous cuff develops round the osteotomy, growing from the soft parts of the femoral neck to the necrotic head (*Slätis & Rokkanen 1966*). This external callus leads to fixation of the osteotomy and also participates in the revascularization of the head. The present study disclosed that the poorer the fixation of the osteotomy, the more important was the part played by the external callus in the process of healing. In cases where internal fixation was adequate, only slight external callus was observed, as healing occurred directly through the cancellous bone.

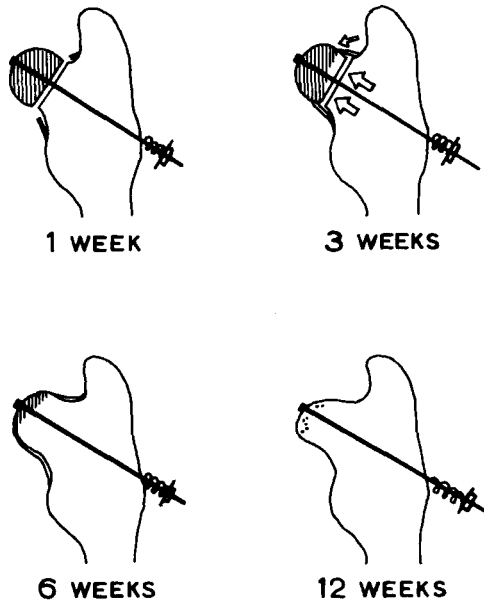
The fixation of the femoral head with a compressing device increased the stability of the osteotomy and led to a better rate and frequency of union. After omission of the compression bolt breaks occurring during the experiment (7/43) and the animals killed after one week, the frequency of union was 12/15 during 3–12 weeks in the compression group against 5/10 in the control group. The compressive force and the frequency of union in the compression group correspond to the data reported by Charnley in human subjects. *Forgon & Bornemisza (1963)* also demonstrated a favourable influence of compression on the healing of experimental osteotomies of the femoral neck in dogs.

The femoral head collapsed 6–12 weeks after osteotomy had been performed. At that time the osteotomy had united and the ingrowth of connective tissue had partly reached the dome of the head. The collapse was marked in the compression group, and it seems obvious that continuous compression easily leads to derangement of the femoral head. The shape of the head remained unchanged as long as it was entirely necrotic, and the subsequent collapse coincided with the regenerative process. The results are consistent with Charnley's observation that compression leads to an increased degree of collapse of the femoral head and neck.

The articular cartilage remained histologically unchanged during the first three weeks, but then degenerated. Obviously, the cartilage remains sound for quite a long time, nourished by the synovial fluid, but degenerates as the process of regeneration reaches the subchondral area. In this connection it is interesting to recall a comment by *Sevitt (1964)* to the effect that after a fracture of the femoral neck has healed in a human subject it would often be advantageous if the head remained necrotic.

The results of these experiments are depicted in Figure 4.

Compression obviously has to be used with good judgement in cases in which one of the cancellous bone fragments is necrotic; it tends to



*Figure 4. The healing of a subcapital osteotomy of the femoral neck and the changes occurring in the femoral head after application of a compressive device. The femoral head is rendered completely devoid of vascular supply.—One week after the osteotomy no uptake of fluorescing material can be detected as a sign of seriously impaired vascularity.—Three weeks after the osteotomy ingrowth of fibrous tissue and formation of new bone are clearly seen in the femoral head adjacent to the osteotomy. The main route of regeneration is through the cancellous bone (arrows). In addition, external callus is adhering to the margin of the head. Through this a minor degree of regeneration takes place.—At six weeks most osteotomies have healed. The zone of new bone formation extends to the middle of the femoral head. At the time the breakdown of the trabecular structure starts. Derangement of the femoral head proceeds as granulation tissue grows towards the subchondral area.—At twelve weeks the osteotomy usually is united. Regeneration has reached the dome of the head, which frequently is flattened and, like the femoral neck, increased in density. The articular cartilage has largely been replaced by fibrocartilage.*

lead to collapse of the necrotic fragment and structural derangement in the last stages of repair. Since, on the other hand, compression clearly accelerates the healing of the osteotomy and since collapse occurs only after the osteotomy has healed, the theoretically best method would be to remove the compressing device after healing has occurred but before collapse has taken place. The adequate operative technique and the optimal moment for removal of the compressing device are, however, questions which still have to be settled.

## SUMMARY

The effect of compression on the healing of osteotomies of the femoral neck and on the changes in the femoral head was studied in 47 adult rabbits. The left femoral neck was osteotomized. In 24 animals the osteotomy was fixed with a transcervical bolt in order to produce compression with the aid of a spring. In 23 animals used as controls only bolts were applied without compression. The animals were killed 1-12 weeks after the operation. Specimens were examined roentgenologically, histologically and by the oxytetracycline labelling technique.

Compression was found to yield better fixation of the osteotomy, leading to more favourable results as regards the rate and frequency of union. Healing started from the femoral neck and proceeded principally by internal callus formation across the osteotomy to the femoral head. On the other hand, in the poorly fixed osteotomies the external callus played a relatively greater part.

The shape of the femoral head remained unaltered as long as it was necrotic. Subsequent collapse of the head started 6-12 weeks after osteotomy as a result of revascularization and the resorption of bone associated with regeneration. The collapse was more complete in the compression group.

It is concluded that compression osteosynthesis of a fracture of cancellous bone in which one fragment is necrotic promotes union but easily leads to derangement of the necrotic fragment in the late stages of repair.

## RESUME

L'effet de la compression sur la guérison des ostéotomies du col fémoral et sur les modifications de la tête fémorale a été étudié chez 47 lapins adultes. Le col fémoral gauche a été sectionné. Chez 24 animaux l'ostéotomie a été fixée par une vis transcervicale afin de produire un effet de compression à l'aide d'un ressort. Chez 23 animaux de contrôle on posa seulement la vis, mais sans compression. Les animaux furent sacrifiés entre 1 et 12 semaines après l'opération. Les spécimens ont été examinés radiologiquement, histologiquement et au moyen de la technique du label à l'oxytétracycline.

On a constaté que la compression donne une meilleure fixation de l'ostéotomie et conduit à des résultats plus favorables par rapport au taux et à la fréquence de la soudure. La guérison a commencé du col fémoral en progressant principalement par la formation de cal interne à travers l'ostéotomie jusqu'à la tête fémorale. D'un autre côté, dans

les ostéotomies où la fixation n'est pas très bonne, le cal externe joue un rôle relativement plus important.

La forme de la tête fémorale est restée inchangés aussi longtemps qu'elle était nécrotique. Un collapsus subséquent de la tête est intervenu 6 à 12 semaines après l'ostéotomie comme un résultat de la revascularisation et de la résorption de l'os, associées à la régénération. Le collapsus était plus complet dans le groupe à compression.

Il est conclu que l'ostéosynthèse de compression d'une fracture d'os spongieux dans laquelle l'un des fragments est nécrotique favorise la soudure mais peut facilement conduire à une altération du fragment nécrotique dans le dernier stade de la restauration.

#### ZUSAMMENFASSUNG

Die Kompressionswirkung auf die Heilung einer Osteotomie des Schenkelhalses und auf die Veränderungen des Schenkelkopfes wurde bei 47 erwachsenen Kaninchen studiert. Der linke Schenkelhals wurde osteotomiert. Bei 24 Tieren wurden die Osteotomieflächen durch einen transcervikalen Bolzen fixiert, um eine Kompression durch eine Feder zustandezubringen. Bei 23 Tieren, die zur Kontrolle verwendet wurden, wurde nur ein Bolzen ohne Kompression angebracht. Die Tiere wurden 1–12 Wochen nach der Operation getötet. Proben wurden röntgenologisch, histologisch und durch „oxytetracyclin-labelling“ untersucht.

Es wurde gefunden, dass die Kompression eine bessere Fixation mit sich führte und dass dadurch bessere Resultate im Hinblick auf die Schnelligkeit und die Häufigkeit der Heilung erhalten wurden. Die Heilung begann im Schenkelhals und schritt durch innere Kallusbildung über die Osteotomiestelle zum Femurkopf weiter fort. Andererseits spielte die äussere Kallusbildung eine relativ grössere Rolle bei Fällen, bei denen die Knochenenden schlecht gegen einander fixiert worden waren.

Die Form des Schenkelkopfes blieb unverändert so lange er noch nekrotisch war. Der allmähliche Kollaps des Kopfes begann 6–12 Wochen nach der Osteotomie als Resultat der Revaskularisierung und der Knochenresorption, die mit der Regeneration verbunden war. Der Kollaps war in der Kompressionsgruppe mehr ausgeprägt.

Die Schlussfolgerung ist, dass Kompressionsosteosynthese eines Bruches im spongiösen Knochengewebe die Heilung fördert, wenn eines der Knochenfragmente nekrotisch ist, in der späteren Phase der Hei-

lung aber, eine strukturelle Unordnung des nekrotischen Knochenfragmentes mit sich bringt.

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