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REGENERATION OF THE FEMORAL HEAD AFTER SUBCAPITAL OSTEOTOMY

An Experimental Study on Young Rabbits

By

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The changes occurring in the femoral head after severance of the femoral neck are still a subject of much investigation. The incidence of aseptic necrosis of the femoral head depends mainly on the damage to the nutritive vessels in the capsule, the ligamentum teres and the cancellous bone itself. Depletion of the arterial blood supply results in necrosis of the head, occurring in a high percentage of the cases both in man and in experimental animals (for ref., see *Rokkanen* 1962). The subsequent regeneration of the dead bone is a slow process taking place as a 'creeping substitution' (*Phemister* 1926). This regeneration of the necrotic head has frequently been confused with the healing process of the fracture in the femoral neck: these phenomena, although closely related, should be kept apart since they occur at different times and the fracture repair can take place despite vast necrosis of the femoral head (*Bessler & Müller* 1961, *Sevitt* 1964).

In young rabbits the main nutritive vessels to the femoral head are in the capsule. The importance of the ligamentum teres diminishes with increasing age (*Lemoine* 1957). In young animals the epiphyseal cartilage acts as a barrier between the metaphyseal and epiphyseal vessels (*Harris & Hobson* 1956). A subcapital osteotomy of the femoral neck will thus cleave the head into an upper, epiphyseal part and a lower, metaphyseal part leaving no communicating blood vessels be-

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tween these two areas. Experiments during such conditions were expected to give information on the route of regeneration of the avascular femoral head and will be reported below.

MATERIAL AND METHODS

On 25 rabbits, 8 weeks of age and of both sexes, the left hip joint was exposed through a posterolateral incision. The ligamentum teres was severed, the femoral head luxated and the femoral neck osteotomized with an electrical saw. The free femoral head was replaced in the acetabulum and the wound closed in layers. On an additional series of 14 rabbits the same osteotomy of the femoral neck was done, leaving the ligamentum teres intact and without luxation of the femoral head. No internal or external fixation was used and the animals were allowed to move freely in the cages.

The animals were killed 1, 2, 3, 6, 12, 16, 24 and 28 weeks after the operation, respectively. Both hip joints were dissected free and macroscopically examined. The femoral head was radiographed, sawed in halves in a frontal plane and embedded in paraffin and methyl metacrylate for further study.

Histological preparations were decalcified according to the EDTA method and stained by the hematoxylin-eosin and the P.A.S. oxidation methods.

Autoradiographs were made of 12 animals 1 and 3 weeks after the operation using radioactive phosphorus P^{32}, administered in a dose of 1 μc/g body weight intraperitoneally 24 hours prior to death. The autoradiographs were made on Kodak Autoradiographic Stripping Plates AR. 10, the exposure time being 3 weeks.

Oxytetracycline labelling of the bone was made by giving the animals oxytetracycline 50 mg/kg body weight on three consecutive days prior to death. The fluorescence technique of the metacrylate-embedded specimens has been described earlier (*Rokkanen & Slätis* 1965).

RESULTS

One to two weeks after osteotomy a fibrous sheath could be demonstrated in 4/6 specimens, arising from the capsule and growing around the femoral neck towards the femoral head, to which it adhered. Apart from this, the femoral head remained unattached to the surrounding tissue. Radiographically the head was unaltered. Histological signs of aseptic necrosis were, as a rule, minute and in no case could an undisputable total necrosis of the femoral head be demonstrated. The growth cartilage, however, was affected in all specimens as judged by defective staining and karyolysis. Autoradiographs lacked uptake of radioactive phosphorus in 2/3 animals. In one animal with a strong soft tissue cuff the metaphyseal part had a slight uptake of radioactive phosphorus. The same uptake could be demonstrated by the OTC labelling technique (Figure 1).

Three weeks after the osteotomy the fibrous sheath around the

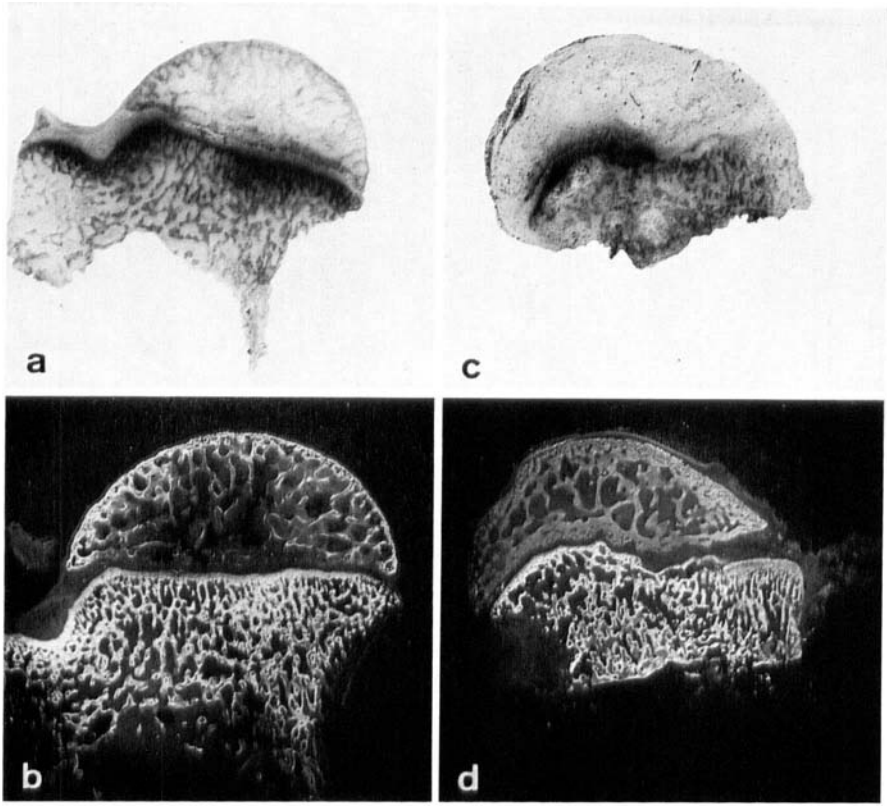

Figure 1. Autoradiograph (a) and fluorescence micrograph (b) of the right femoral head in a rabbit 8 weeks of age. Note the uptake of radioactive phosphorus and fluorescing oxytetracycline in the epiphysis and metaphysis, predominantly in the subchondral area. In c and d the left femoral neck of the same animal is depicted, 1 week after subcapital osteotomy of the femoral neck and severance of the ligamentum teres. The epiphysis is devoid of radioactive and fluorescing material. In the subchondral area, however, deposits of radioactive phosphorus and oxytetracycline can be seen.

femoral neck was in most cases encircling the site of fracture like a callous cuff, the upper edge adhering to the movable femoral head. Still no radiographic changes, apart from the fracture line, could be demonstrated. Histologically the degenerative changes in the metaphysis and to a lesser degree in the epiphysis, were now readily demonstrable. The first signs of regeneration could be demonstrated in 10/11 animals, fibrous tissue ivading the metaphyseal part of the femoral head and growing towards the growth plate. Autoradiographs revealed

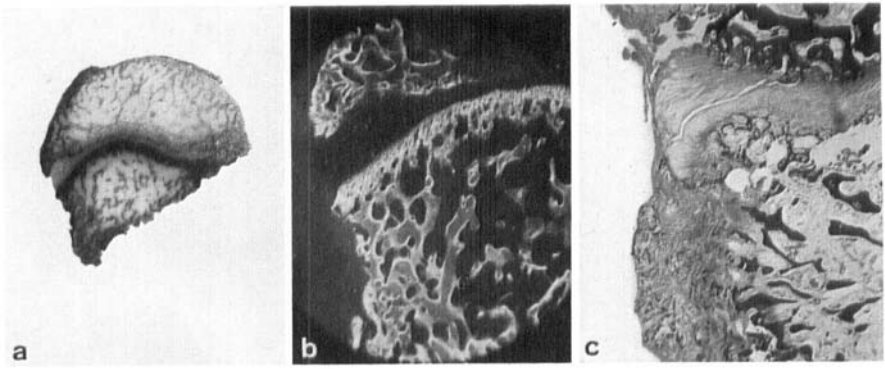

Figure 2. Autoradiograph (a), fluorescence micrograph (b) and micrograph (c) of the femoral head 3 weeks after subcapital osteotomy of the femoral neck and severance of the ligamentum teres. The uptake of radioactive phosphorus and fluorescing oxytetracycline in the metaphysis and the medial part of the epiphysis is clearly seen. Connective tissue invades the metaphysis and the corresponding medial part of the epiphysis, growing from below upwards. The rounded structure of the femoral head is still unaltered.

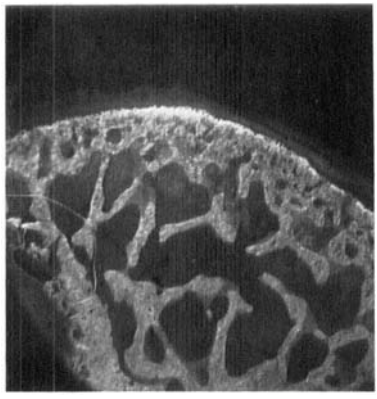

Figure 3. Fluorescence micrograph of the femoral head 1 week after subcapital osteotomy of the femoral neck and severance of the ligä teres. The epiphysis is devoid of fluorescing material except for a narrow zone beneath the articular cartilage.

uptake of radioactive material principally in the metaphyseal area but also in some cases in the medial part of the epiphysis. Labelling of the bone with oxytetracyclin gave a quite similar uptake pattern. The fluorescing tissue in the specimens corresponded closely to the tissue exerting radioactivity in the autoradiographs (Figure 2). In about half

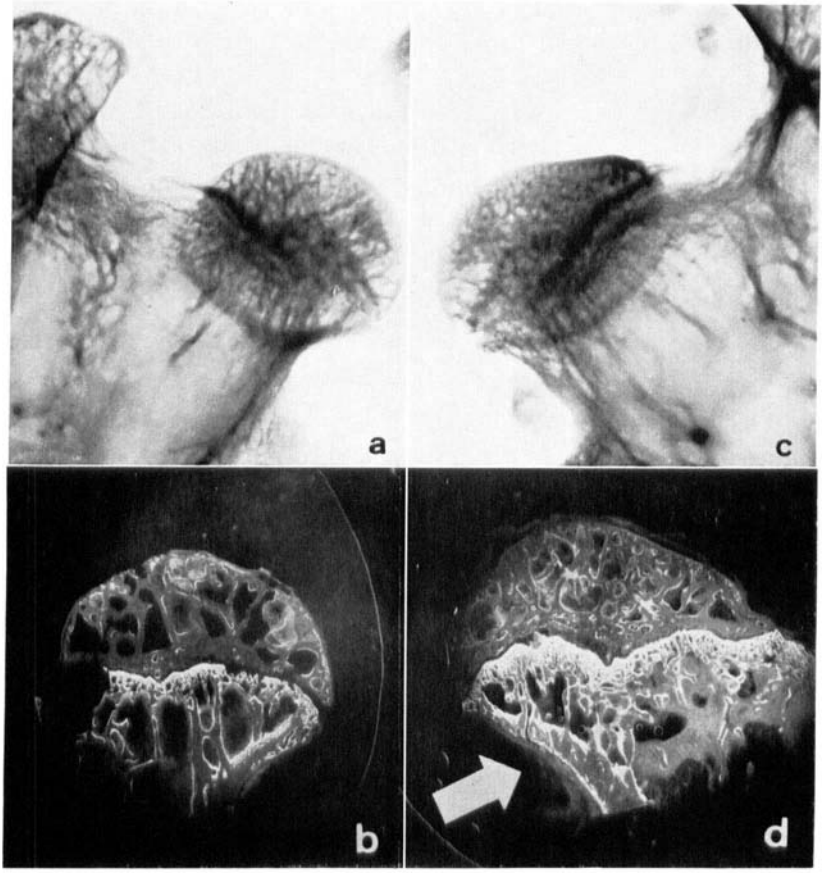

Figure 4. Radiograph (c) and fluorescence micrograph (d) of the femoral head and neck 20 weeks after subcapital osteotomy of the femoral neck and severance of the ligamentum teres. The osteotomy is healed (arrow), leaving a broad femoral neck and a flattened femoral head. Note the intense fluorescence in the fracture area, as compared with the unoperated side of the same animal (a, b).

of the cases during the first 3 weeks, a narrow zone of oxytetracyclin labelling could be demonstrated under the articular cartilage of the avascular femoral head (Figure 3).

At 6 weeks the first radiographic changes occurred. In 3/6 animals the femoral head was flattened. Histologically these specimens revealed derangement of the trabecular network with narrowing of the marrow spaces and collapse of the weight-bearing area of the epiphysis. Massive invasion of fibrous tissue in the metaphysis, partly extending to the epiphysis, and ossification of the growth plate were common observa-

tions. Oxytetracycline-labelling revealed fluorescing areas both in the metaphysis and epiphysis. The distribution and intensity of the fluorescence varied, however, considerably.

At 12 weeks the first healed osteotomy was recorded. In most specimens the femoral head was flattened, histologically the regeneration was now reaching the epiphysis, and in all but one specimen the ossification of the growth plate had proceeded further than on the healthy side. Fluorescing tissue was found in the femoral head in all cases and this fluorescence was constantly more intense than on the unoperated side. This was the case regardless of the degree of healing of the osteotomy.

Later, 16–28 weeks after the osteotomy 9/10 osteotomies had healed. Histologically the regenerative process was completed in 5/8 cases, although intense fluorescence revealed increased activity in several cases (Figure 4).

Throughout the experiment the degenerative changes and the subsequent route of regeneration was the same in the group of animals in which the ligamentum teres had been left intact.

DISCUSSION

Subcapital intra-articular osteotomy of the femoral neck severs the blood flow to the femoral head, and if severance of the ligamentum teres is added, the epiphysis and the adjacent metaphysis will be avascular. In this series the degenerative and regenerative changes following such a procedure proved to be fairly constant. The histological signs of vascular disturbances appeared in the growth plate, the metaphysis and the epiphysis, in this order. In agreement with earlier observations (*Wollenberg* 1928, *Rokkanen* 1962, *Rokkanen, Slätis & Laine* 1963) these histological changes appeared late and were not conclusive until 2–3 weeks after the operation.

Lack of radioactive phosphorus in the autoradiographs can be regarded as a sign of impaired vascularity, as was observed during the early stages of degeneration. Neither does oxytetracyclin bring about any fluorescence in avascular bone (*Rokkanen et al.* 1963, 1965) and these labelling techniques give in fact rise to a very similar uptake pattern both in the avascular and the regenerating bone. Thus, early detection of impending necrosis of the bone can be made by either method.

The route of regeneration of the necrotic femoral head was from the

metaphyseal area towards the epiphysis. The process of regeneration seemed to depend on the soft tissue bridge to the femoral head, growing like a callous cuff around the osteotomy. The role played by the ligamentum teres in the regeneration of the femoral head was negligible. The importance of this finding is not yet settled, but similar observations were previously made on older rabbits (*Rokkanen et al.* 1965). Further experiments on this subject, with special reference to fracture repair in the femoral neck, are in progress.

It has been claimed that the joint cartilage survives on the necrotic femoral head, owing to nutrition from the synovial fluid (*Ingelmark* 1950). The observation of oxytetracyclin labelling of the juxtachondral area in the avascular femoral head (Figure 2) is an argument in favor of independent nutrition of the cartilage.

Radiographic collapse of the femoral head was not observed until the regenerative process has proceeded to the weight-bearing area of the epiphysis, *i.e.* 6 weeks after the osteotomy. The collapse and, in some animals, an increased density of the femoral head thus coincides with the creeping substitution of the necrotic femoral head, and must be regarded as evidence of revascularization of the head. In this respect the series gives experimental support to the views expressed by *Bobechko & Harris* (1960) and *Bohr & Larsen* (1965).

SUMMARY

In order to investigate the regeneration of the avascular femoral head 39 young rabbits were operated. The left hip joint of 25 animals was opened, the ligamentum teres severed and the femoral neck divided by subcapital osteotomy; a similar osteotomy on 14 animals was made leaving the ligamentum teres untouched.

The animals were sacrified 1–28 weeks following the operation and the specimens were examined radiographically, histologically and by autoradiographic and oxytetracycline labelling techniques. The results can be summarized as follows:

1. Subcapital osteotomy of the femoral neck resulted in transient necrosis of the femoral head, regardless of the state of the ligamentum teres.
2. Histological signs of impaired vascularity were observed in the growth cartilage, the metaphysis and the epiphysis, in this order. Histological evidence of bone necrosis was not undisputable until

2–3 weeks after the operation. The avascular areas of the bone were easily demonstrated by the autoradiographic and oxytetracycline labelling techniques.

3. Regeneration of the femoral head began about 3 weeks after the osteotomy and progressed from the metaphyseal area below towards the growth plate and epiphysis above. A fibrous sheath surrounding the site of osteotomy and adhering to the femoral head seemed to be an important factor in the regenerative process. An intact ligamentum teres did not alter the route of regeneration.
4. Collapse of the weight-bearing area of the epiphysis started about 6 weeks after the osteotomy and coincided with the invasion of fibrous tissue in the necrotic femoral head.

RESUME

Afin d'examiner la régénération de la tête fémorale avasculaire, 39 jeunes lapins ont été opérés. L'articulation de la hanche gauche a été ouverte chez 25 animaux, le ligamentum teres blessé et le col fémoral divisé par ostéotomie subcapitale; une ostéotomie similaire a été pratiquée chez 14 animaux en laissant intact le ligamentum teres.

Les animaux ont été sacrifiés 1 à 2 semaines après l'operation et des spécimens ont été examinés radiographiquement, histologiquement et par des techniques autoradiographiques et à l'oxytétracycline.

Les résultats peuvent être résumés comme suit:

1. L'ostéotomie subcapitale du col fémoral provoque une nécrose passagère de la tête fémorale, quel que soit l'état du ligamentum teres.
2. Des signes histologiques de vascularité altérée ont été observés dans le cartilage de croissance, la métaphyse et l'épiphyse, dans l'ordre indiqué. Une évidence histologique de nécrose osseuse n'était pas indiscutable avant 2 à 3 semaines après l'opération. Les surfaces avasculaires de l'os étaient facilement démontrables au moyen des techniques autoradiographiques et à l'oxytétracycline.
3. La régénération de la tête fémorale commença environ 3 semaines après, progressant de la partie métaphysaire en-dessous, du côte de la plaque de croissance et de l'épiphyse au-dessus. Une gaîne fibrause entourant l'endroit de l'ostéotomie et adhérant à la tête fémorale semble être un facteur important du processus de régénération. Un ligamentum teres intact ne modifie pas la voie de la régénération.
4. Le collapsus de la partie de l'épiphyse supportant le poids commence

6 semaines après l'ostéotomie et coïncide avec l'invasion de tissu fibreux dans la tête fémorale nécrotique.

ZUSAMMENFASSUNG

Um die Regeneration des avaskulären Femurkopfes zu untersuchen wurden 39 junge Kaninchen operiert. Das linke Hüftgelenk von 25 Tieren wurde geöffnet, das ligamentum teres wurde durchschnitten und der Femurhals mittels subcapitaler Osteotomie durchtrennt. Eine gleiche Osteotomie unter Belassung des lig. teres wurde an 14 Tieren vorgenommen.

Die Tiere wurden 1–28 Wochen nach der Operation getötet und die Präparate wurden röntgenologisch, histologisch und mittels autoradiographischer und Oxytetracyklin Markierungstechniken untersucht. Die Ergebnisse können folgendermassen zusammegefasst werden.

1. Subkapitale Osteotomie des Femurhalses hatte eine vorübergehende Nekrose des Femurkopfes, gleichgültig in welchem Zustand sich das ligamentum teres befand, zur Folge.
2. Histologische Zeichen von verminderter Gefässversorgung wurden in der kartilaginären Wachtstumszone, der Metaphyse und Epiphyse, in dieser Reihenfolge beobachtet. Der histologische Beweis von Knochennekrose war nicht sicher vor der 2.–3. Woche nach der Operation. Die gefässlosen Gebiete wurden mühelos mittels autoradiographischer und Oxytetracyklin Markierungstechniken demonstriert.
3. Die Regeneration des Femurkopfes begann ungefähr 3 Wochen nach der Osteomtomie und schritt vom Metaphysengebiete von unten nach aufwärts gegen die Wachstumszone und die Epiphyse fort. Eine fibröse Scheide, die den Sitz der Osteotomie umgibt und am Femurkopf haftet, scheint ein wichtiger Faktor im regenerativen Prozess zu sein. Ein intaktes ligam. teres veränderte den Regenerationsweg nicht.
4. Kollaps der gewichttragenden Fläche der Epiphyse begann ungefähr 6 Wochen nach der Osteotomie und fiel mit dem Eindringen von fibrösem Gewebe in den nekrotischen Femurkopf zusammen.

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