Acta orthop. Scandinav. 38, 1–22, 1967.

From the Orthopaedic Department of Tel-Hashomer Hospital/Rechorot/Israel.
Tel-Aviv Med. School.

THE VASCULAR SUPPLY TO THE EPIPHYSEAL PLATE UNDER NORMAL AND PATHOLOGICAL CONDITIONS

By

E. Spira & I. Farin

Received 10.I,66

INTRODUCTION

There are four main sources for the bloodsupply to the growing long bones:

1. The epiphyseal vessels enter the area through the capsule and the periochondrium and anastomose very freely among themselves.
2. The periosteal vessels supply the outer side of the cortex and anastomose with the arterioles of the endosteum.
3. The nutrient artery has an ascending and descending branch supplying the metaphyses and the endosteum.
4. The metaphyseal vessels enter the bone from the periosteum next to the metaphysis and supply the outer parts of the metaphysis. They anastomose with the branches of the nutrient artery (Figure 1).

Purpose of this study

The vascular supply to the epiphyseal plate in particular is the purpose of this paper. We felt that our knowledge in this field will contribute to its better understanding.

Our studies were performed on rabbits aged 4 weeks (400–500 g weight) with older or younger animals being used when age was the decisive factor.

The epiphyseal plate chosen for our study was the distal ulnar epiphysis. The changes were recorded both under normal and pathological conditions.

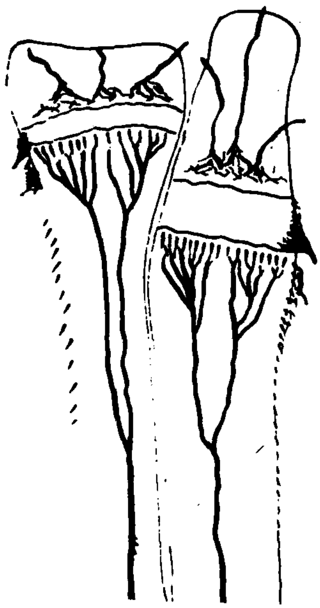


Figure 1. The main sources for the bloodsupply to the epiphyseal plate.

I. NORMAL CONDITIONS

a) *Vascular Channels*

At the age of 4 weeks, every microscopic section revealed bloodvessel conducting channels invading the epiphyseal plate from the epiphysis

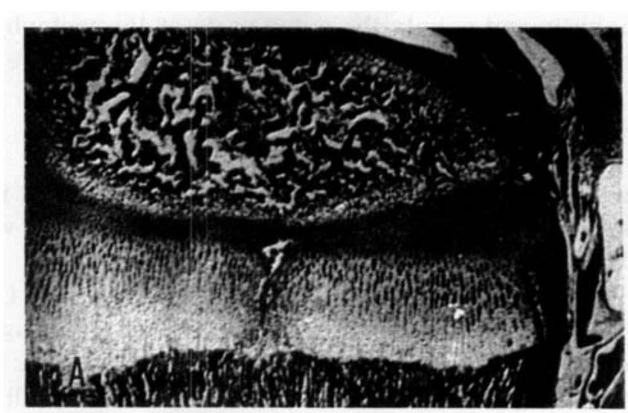
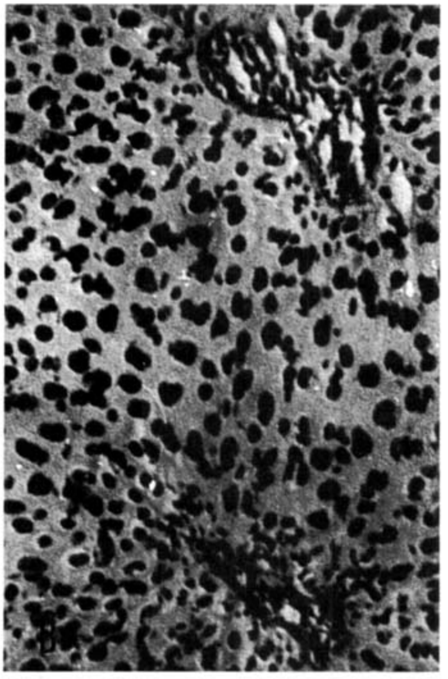
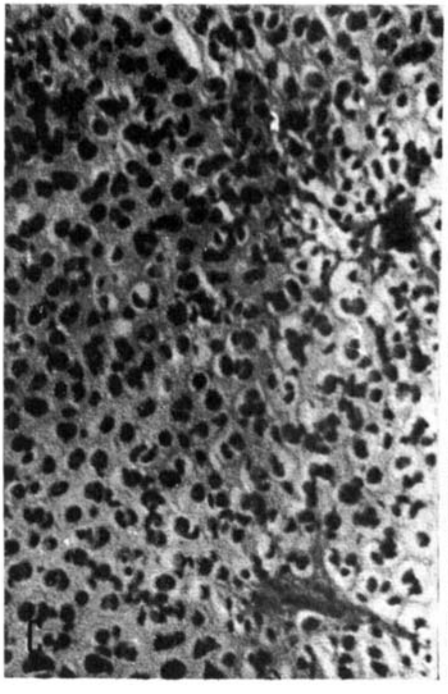
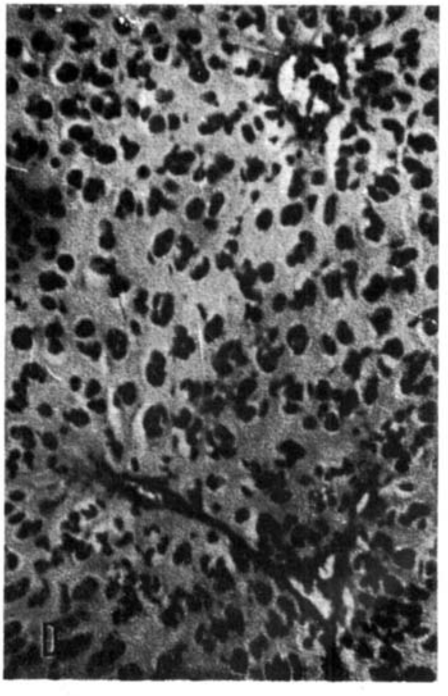


Figure 2. A. Longitudinal section of radial epiphyseal ossification centre of a rabbit (age 14 days) illustrating a cartilage channel leaving the centre in the direction of the metaphysis (× 12).

Figure 2. B, C. and D. Transverse sections through the epiphyseal cartilage of a rabbit (14 days old). Gradual diminution in size of the channel as it reaches the depth of the cartilage plate. (× 200).







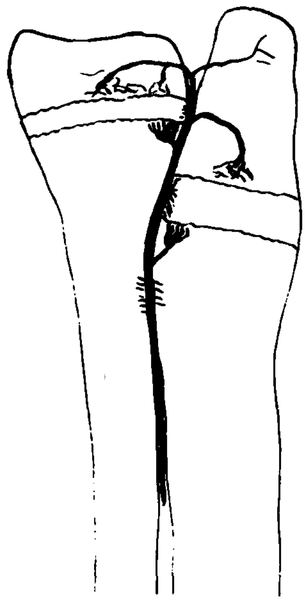


Figure 3. Distribution of "interosseous artery", with branches to the epi- and metaphyseal sides of the epiphyseal plate of radius und ulna.

toward the metaphysis. These vessels ended in the hypertrophic zone of the plate. At the age of 8 weeks, the number of these vessels dropped to 27 per cent and at the age of 10 weeks only remnants could be seen.

The depth to which these vascular channels invaded the plate diminished too and at 6 weeks they could be seen only in the germinative zone.

These vessel-conducting channels have a characteristic appearance. They are lined with flat cells most probably derived from the perichondrial layers. They enter the area of the developing epiphyseal plate

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Figure 4. Disturbance of metaphyseal bloodsupply by a drilled hole of 3 mm size in different relations to the plate 2 days after experiment.
A.–C. Micropaque angiographs (× 10).

A. Drilled hole in the middle and near the plate, completely disturbing the metaphyseal bloodsupply.
B. Drilled hole, far from the plate, with mild disturbance.
C. Closely drilled hole, excentrically placed, disturbing 2/3 of the bloodsupply.
D. Histological section (7 μ × 12). Enlargement of hypertrophic zone tn the disturbed area of the metaphysis, leaving the other part normal.

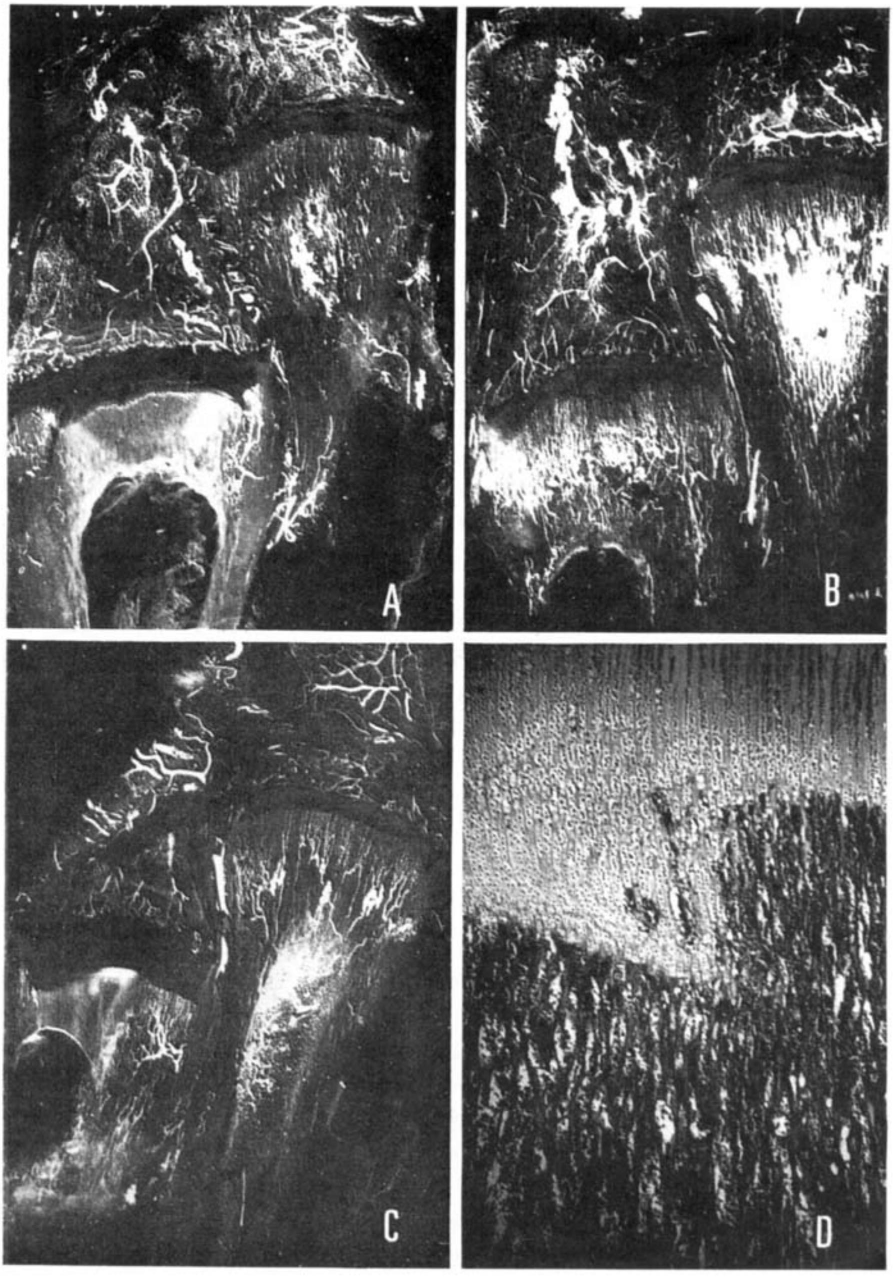


Figure 4.

from the epiphysis and the perichondrium. The vessels inside the channels appear together in bundles of arterial and venous capillaries. These channels themselves lie buried in the growing cartilage masses like in a rising dough. Only the collapsed tracts of these channels can be seen in the developed plate (*Spira, Farin & Karplus*) (Figure 2).

b) *Interosseous Artery*

We observed a large vessel, a branch of the ulnar artery, lying between the distal thirds of the radius and ulna. We named it the interosseous artery. From this vessel, many branches of various sizes enter the metaphysis and the epiphysis of both bones.

Their final branching is in the form of the typical "umbrella" on the epiphyseal side and as the erect "loops" on the metaphyseal side. In very young animals, these branches enter the epiphyseal ossification centre from the epiphyseal side and continue into the epiphyseal plate.

The participation of this vessel in the bloodsupply to the epiphyseal plate is varying. Our experiments have shown, however, that the metaphyseal branches may supply a third of the plate. On the epiphyseal side, the supply is less well defined, because of the rich anastomoses in this area. But here, too, this vessel contributes considerably to the normal vascular supply (Figure 3).

II. PATHOLOGICAL CONDITIONS

a) *Disturbance of the Metaphyseal Bloodsupply*

1) *Drilling.* A hole was drilled with a 3 mm dental drill into the metaphysis (54 rabbits).

Depending on the location, different extents of disturbances in the enchondral ossification were observed. The disturbance on this side was complete only when the drillhole was near the plate. The hypertrophic zone was enlarged on this site, while the rest of the plate grew in the normal way. In every experiment, a complete restoration of the normal enchondral ossification was established after 7 days (Figure 4).

2) *Osteotomy.* An osteotomy through the metaphyseal area was done, 3–4 mm proximal to the plate (70 rabbits).

The immediate effect was a haemorrhage between the fragments. As a consequence of this, the enchondral ossification was interrupted and the hypertrophic zone was enlarged (Figure 5). If contact between the fragments was close, the enchondral ossification started again after 4

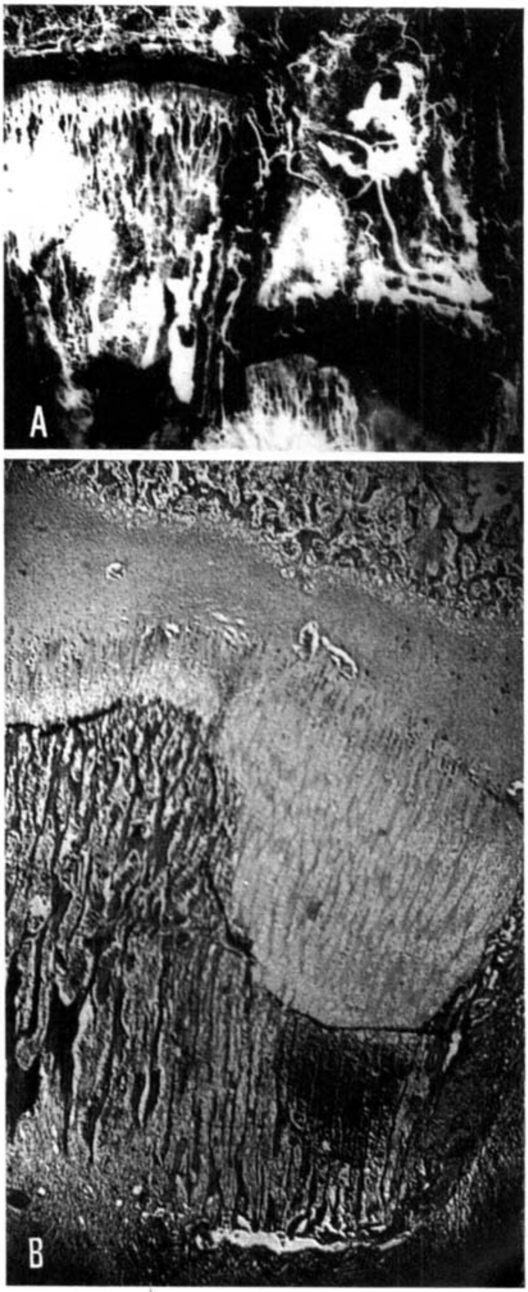
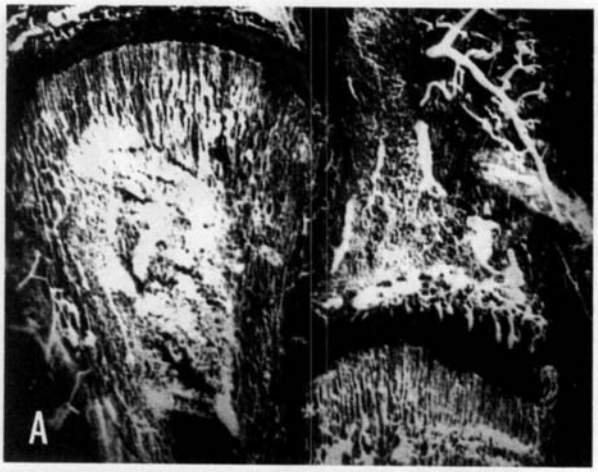


Figure 5. Disturbance of metaphyseal bloodsupply by osteotomy 24 hours after experiment. A. Micropaque angiograph. (× 10). No filling of bloodvessels in ulnar half of metaphysis. B. Longitudinal histological section (7 μ × 12). Haemorrhage and engorgement distally from the lesion. Enlargement of hypertrophic zone in the same area.



A. Micropaque angiograph (× 10), line of osteotomy on the ulnar half of bone, area filled with contrast material. Distally—fine new vessels reaching nearly to the normal height. From the epiphyseal side, opposite the lesion, epiphyseal vessels intrude the epiphyseal plate.

B. Histological section of the same area (7 μ × 12). Remnants of line of osteotomy. Progress of enchondral ossification with new trabeculae, leaving an area of enlarged hypertrophic zone, where revascularisation is still disturbed.

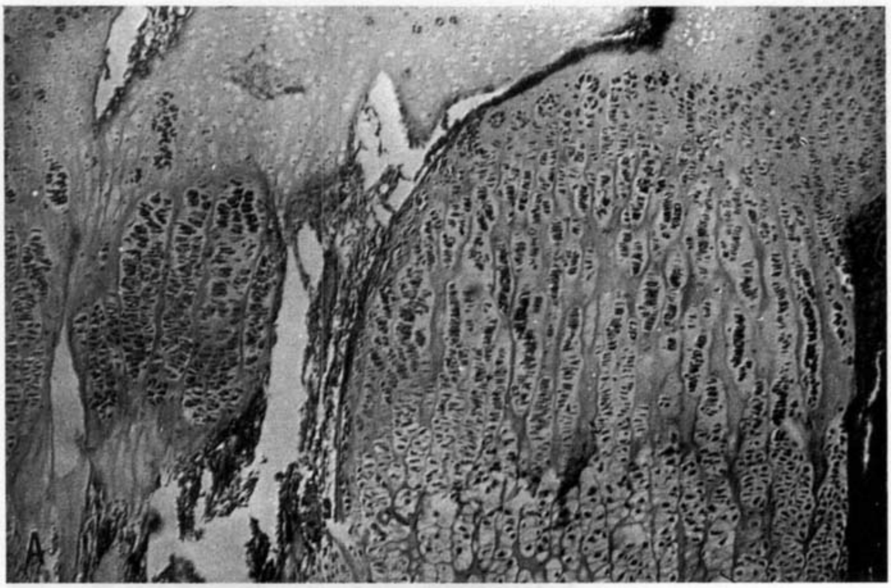
Figure 6. Disturbance of metaphyseal bloodsupply by osteotomy. 4 days after experiment.

Figure 7. Histological detail of the revascularised area (7 μ × 200) of Fig. 6. Direct vascular invasion of vessels into the hypertrophic zone and formation of sinuses with contrast material.

days. After 7 days, the previous line of interruption can be recognized by the thinner bone trabeculae beyond it, marking the formation of new spongy bone (Figure 6).

If the clot between the fragments was large, the enchondral ossification was considerably delayed, even for a few days. The masses of hypertrophic cells were invaded from the sides by metaphyseal vessels, leaving behind them remnants of hypertrophic cells. Where the revascularisation was delayed for more than 4–5 days, vessels from the epiphyseal side were observed invading the epiphyseal plate.

The metaphyseal vascularisation was observed as a direct invasion of vessels into the hypertrophic zone or the formation of sinuses from which vessels developed (Figure 7). In areas where revascularisation of the enchondral ossification was somewhat impaired, a fibrosis of the



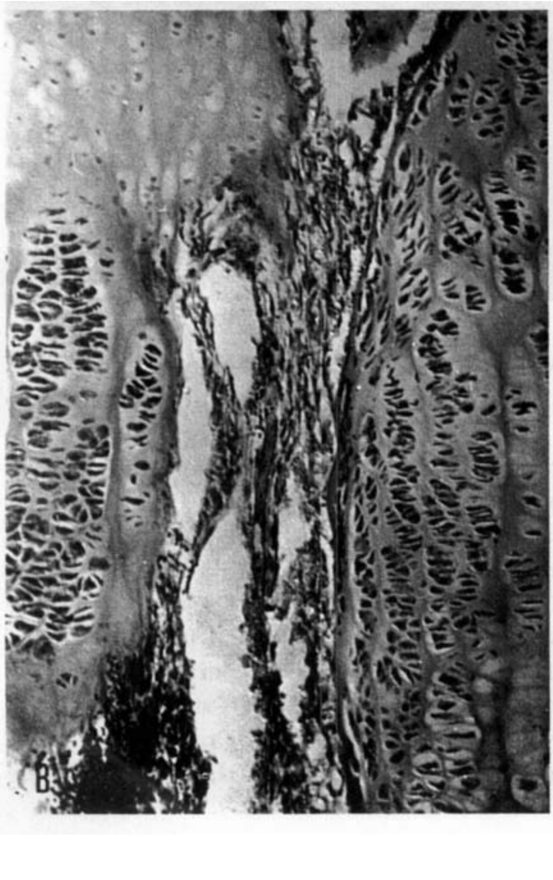


Figure 8. Traumatic epiphysiolysis with displacement. Longitudinal histological sections. A. 5 days after experiment (7 μ × 12), vessel conducting channel protrudes through the epiphyseal plate. B. Detail of the previous section (× 80), contrast material in the arterial capillaries, flat cells lining the channel walls.

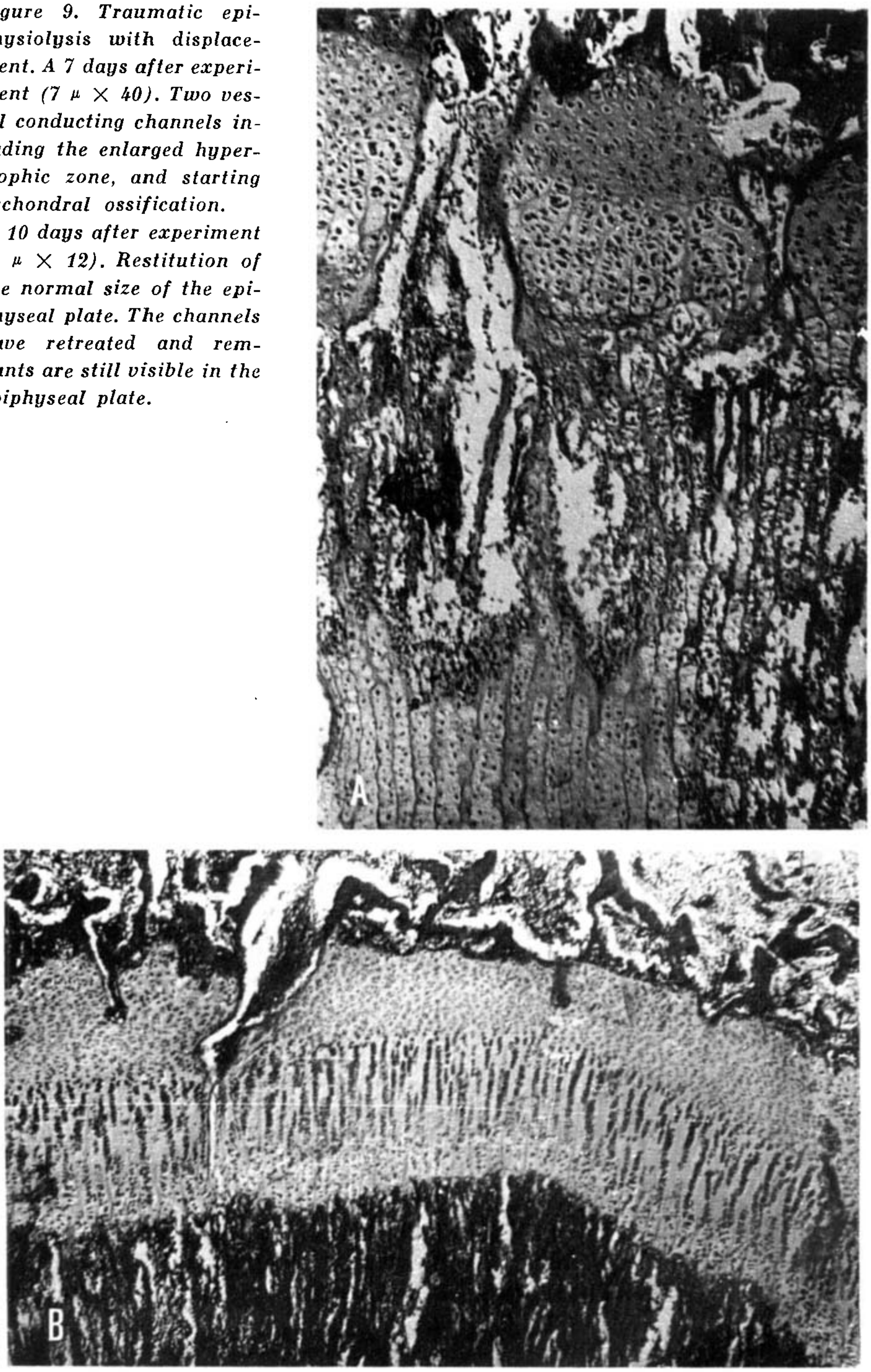


Figure 9. Traumatic epiphysiolysis with displacement. A 7 days after experiment (7 μ × 40). Two vessel conducting channels invading the enlarged hypertrophic zone, and starting enchondral ossification.
B. 10 days after experiment (7 μ × 12). Restitution of the normal size of the epiphyseal plate. The channels have retreated and remnants are still visible in the epiphyseal plate.

bone marrow together with an unusual early bone maturation were observed.

No definite disturbance was observed in this series.

3) *Traumatic Epiphysiolysis.* A traumatic epiphysiolysis with dislocation to 90° of the distal fragment was performed (100 rabbits). No reposition was attempted.

A large haematoma was separating the fragments. Enchondral ossification was disturbed and the hypertrophic zone enlarged. After 5 days, vessel conducting channels appeared from the epiphyseal side of the plate and protruded deeply into the epiphyseal plate. They can be observed to reach into the metaphyseal area, starting there by enchondral ossification. These channels have the same appearance as described before (Figure 8) (*Spira, Farin & Karplus*). After 7 days, multiple epiphyseal vascular channels are entering the epiphyseal plate in several places. The vessels invade the enlarged hypertrophic zone (Figure 9 a). After 10 days from the beginning of the experiment, the enchondral ossification, caused partly by the epiphyseal vessels, was restored to normal conditions. At the same time, the vessel-conducting channels retreated into the germinative zone and the channels collapsed again (Figure 9 b).

In 4 experiments, this regeneration did not occur. Instead, the channel conducting vessels enlarged their invasion of the metaphyseal area and finally a fibrous or bony gap divided the epiphyseal plate into separate parts.

b) *Disturbance of the Epiphyseal Bloodsupply*

1) An osteotomy was performed at a distance of 8–10 mm from the plate (25 rabbits).

No impairment of circulation to the epiphyseal plate could be observed.

2) An osteotomy was performed very near to the plate (25 rabbits).

When the osteotomy did not directly injure the bony plate or the germinative zone, no injury to the plate occurred, due to the enormous vascular branching and anastomosing in the area. But if the injury to the plate was direct, this area lost its staining and the adjacent columns did not form. The development of the plate in this area was definitely disturbed. But no consequences toward the further development of the plate could be observed (Figure 10).

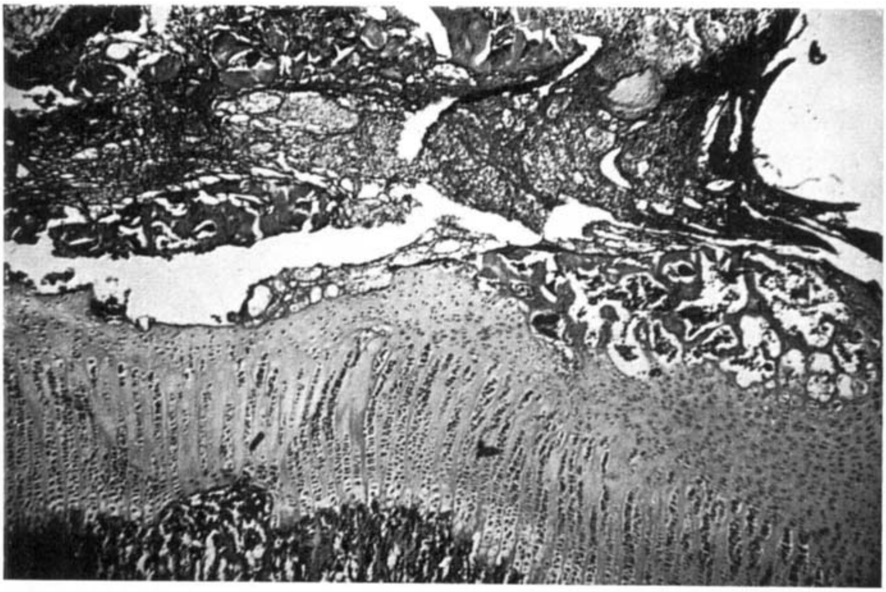


Figure 10. Disturbance of the epiphyseal bloodsupply by osteotomy, near to the plate (7 μ × 12). A big clot fills the gap of the site of the osteotomy, injuring the germinative zone of the plate in the centre.

c) *Disturbances of the Epiphyseal and Metaphyseal Blood Supply*

This disturbance was performed by means of a double rotating dental saw, performing the two osteotomies in one stage on either side of the plate.

1) Both osteotomies were placed at a distance of 3–4 mm from the plate (30 rabbits).

If the contact between the fragments was close, revascularisation occurred rapidly, like in the separate previous experiments. At the latest, after 14 days, the structure and growth of the plate were restored.

2) The osteotomies were placed very close to the plate (30 rabbits).

Due to the technical difficulties the cuts were sometimes nearer to the metaphyseal or epiphyseal side of the plate.

Again, the events of the separate injuries of the sides of the plate were repeated. Only if a great haematoma hampered the revascularisation from the metaphyseal side, epiphyseal vessels entered the area of the epiphyseal plate (Figure 11 a). If the epiphyseal bloodsupply is disturbed, metaphyseal vessels extend towards the epiphyseal side of

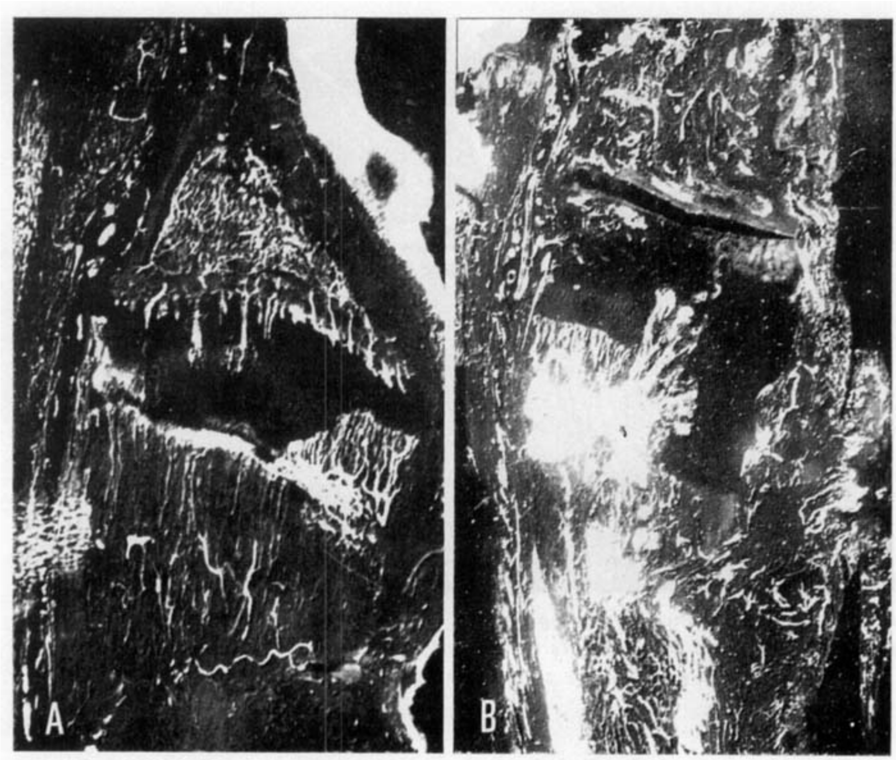


Figure 11. Disturbance of epiphyseal and metaphyseal bloodsupply near the epiphyseal plate. Micropaque angiographs (150 μ × 10); 7 days after experiment.

A. *Metaphyseal bloodsupply hampered by the haematoma-epiphyseal vessels enter the area of the epiphyseal plate.*

B. Epiphyseal bloodsupply hampered by the osteotomy-metaphyseal vessels extend towards the epiphseal plate. The metaphyseal blood supply itself is delayed on the ulnar third of the metaphysis.

the plate (Figure 11 b). In spite of the severe injury, however, the function of the plate was restored after a month. In severe injuries, a similar observation like in traumatic epiphysiolysis was recorded, causing fibrous or bony bridges in the epiphyseal plate (Figure 12).

3) Similar observations were made on autotransplantations of the plate (30 rabbits).

d) *Identity of the Epiphyseal and Metaphyseal Vessels*

In the series of autotransplantations, two plates with adjacent bone were accidentally turned round 180° to their axis. This offered a chance

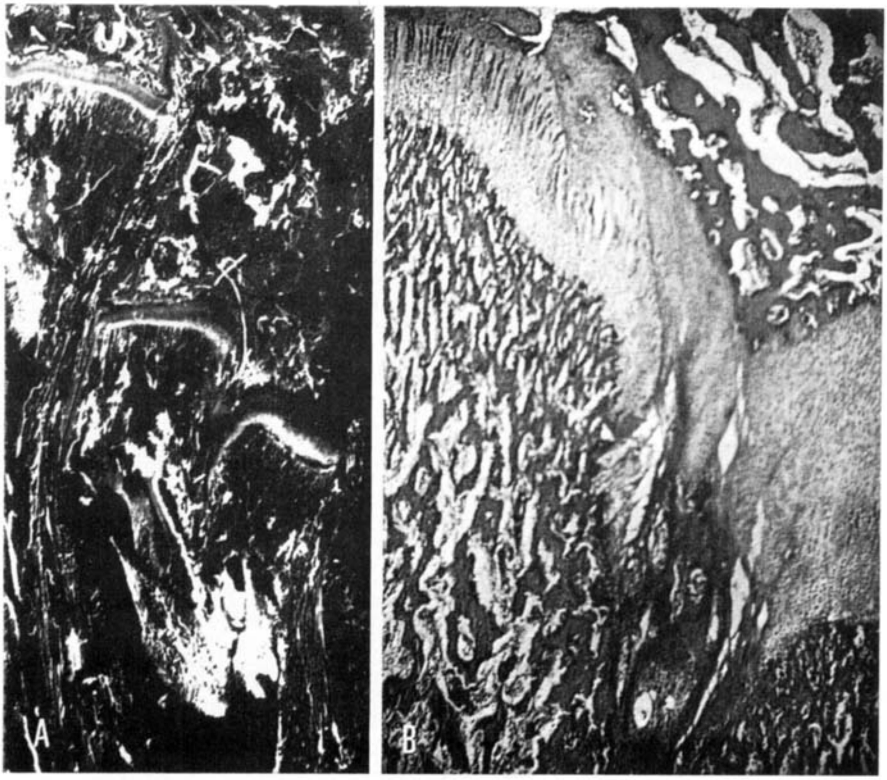


Figure 12. Disturbance of epiphyseal and metaphyseal bloodsupply, near the epiphyseal plate. 30 days after experiment.

A. *A fibrous bridge divides the two halves of the epiphyseal plate, delaying the ulnar half.*

B. *Histological section (7 μ × 40) from A., showing the fibrous bridge.*

to study the bloodsupply under these conditions. In both instances, the vessels preserved their original form as "loops" and "umbrellas". In both cases the contact between the fragments was very close and therefore revascularisation occurred very quickly (Figure 13).

e) *Disturbance of the Nutrient Artery*

Resection of part of the diaphysis of the ulna showed enlargement of the hypertrophic zone in the ulna due to a disturbance of the metaphyseal bloodsupply. To our surprise this enlargement did not occur in the distal ulnar epiphysis only, but also in the epiphyseal plate of the radius (Figure 14).

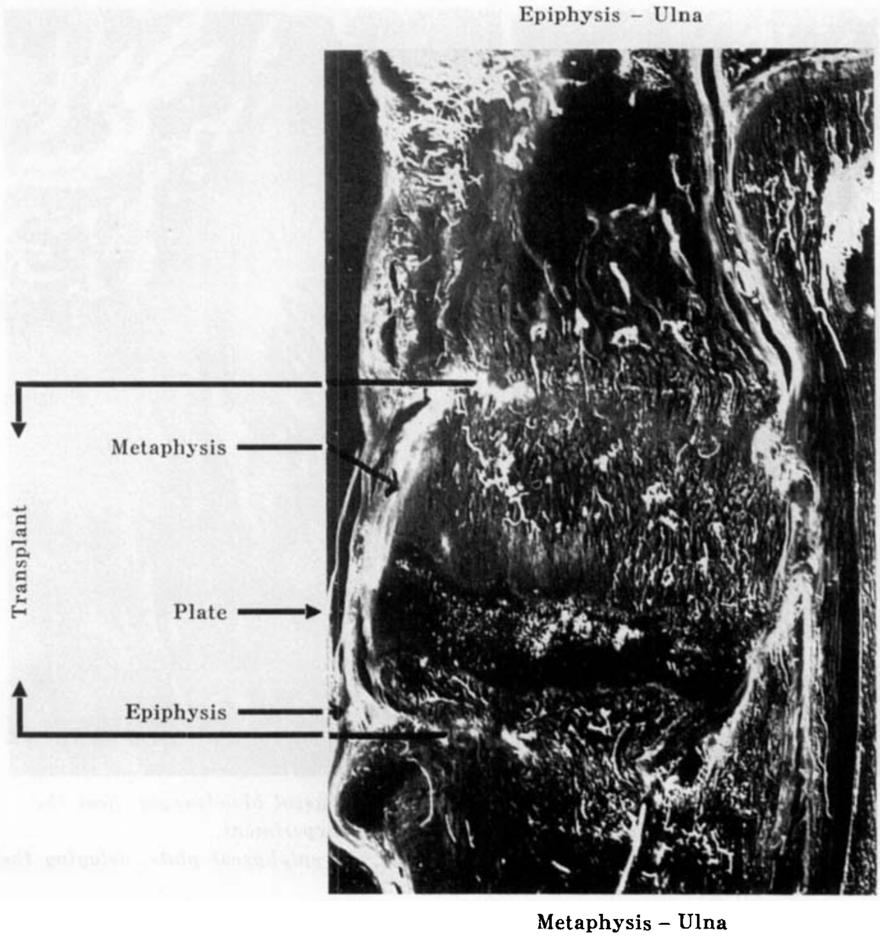


Figure 13. Epiphyseal plate with adjacent bone turned round 180° to its axis (7 days after experiment). Preservation of the characteristic original form of "loops" on the metaphyseal side and of "umbrellas" on the epiphyseal side is shown.

This was a chance observation in 16 experiments, while studying bone formation after resection of the diaphysis.

DISCUSSION

This study on the bloodsupply to the epiphyseal plate has produced some interesting observations.

The existence of vascular channels in the epiphyseal plate were observed already by *Langer* (1876). A similar observation was re-

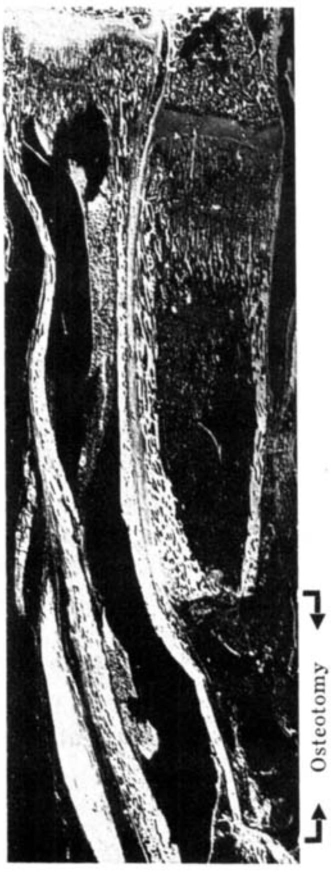


Figure 14. Disturbance of the nutrient artery in the diaphysis of the ulna caused enlargement of the hypertrophic zone of the distal plate in the ulna and the radius.
A. Total view.
B. Distal ulnar and radial epiphyses.

ported by *Bidder* (1906). He described connections with diaphyseal vessels. In this opinion, these vessels play a significant part in the nutrition of the cartilage and in the ossification of the epiphysis. *Tilling* (1958) surveyed the literature and described vascular channels perforating the epiphyseal plate in calves of 2 weeks of age. He made similar observations on the human foetus in the upper tibia and lower femur epiphysis. In his observations on calves and cows he saw vessels anastomosing with metaphyseal vessels, after perforating the epiphyseal plate from the epiphysis. He considers three sources for the metaphyseal vessels: 1. the nutrient; 2. the metaphyseal vessels joining the nutritia, and 3. the epiphyseal vessels which reach the area from the epiphysis through the epiphyseal plate.

Besides these observations, most of the students of this problem deny the existence of such vascular channels in the epiphyseal plate. The plate is considered a barrier for vascular connections between the epi- and metaphysis. Only in the perichondrium are vessels which pass longitudinally to the metaphysis from the epiphysis and supply both superficial areas of the bone (*De Marneffe, Harris* and Co-workers, *Trueta* a. o.).

In previous studies on growing rabbits (*Spira, Farin, Karplus*) we could demonstrate vascular channels containing arterioles and venules in all histological sections till the age of 4 weeks. Thereafter, the vessels gradually decreased in number and in depth of penetration, until, at the age of 10 weeks, no channels were seen in the plate; only the tracts of the collapsed channels remaining. Under pathological conditions, however, when the metaphyseal bloodsupply is severely disturbed for a few days, these vascular channels do reappear. These channels are lined with flat cells and again contain arterioles and venules, like under normal developing conditions.

But this time, the channels penetrate the epiphyseal plate to its full depth, even reaching the metaphysis. We observed them functioning in the metaphysis like metaphyseal vessels, starting enchondral ossification in areas where gross enlargement of the hypertrophic zone had occurred. This means that these epiphyseal vessels undertake functions which have been considered the main task of metaphyseal vessels. These vascular channels can, however, disappear again and collapse again to tracts, if the revascularisation of the plate has started again from the metaphyseal side. But they can expand to fibrous and bony bridges dividing the plate into different parts, if the metaphyseal blood supply has been severely interrupted. This, of course, means the complete disorganisation of the epiphyseal plate. Similar observations were also made under other experimental conditions (*Troupp, Brashear*).

The question remains whether these vascular channels are the old, collapsed channels or new ones. *Harris* a.o. (1965) maintain that these vascular channels lie in the cartilage anlage of the epiphyseal bone plate. But after the bone plate of the epiphysis has formed in mature animals, these vessels lie in bony channels, so that only the vascular tufts are in contact with the cartilage cells. Our observations were made on animals 6 weeks of age, at a time at which under normal conditions such channels can be seen only in a small number in the germinative zone. This means that this mechanism of penetration of vascular channels exists only in growing animals and not in mature ones. This question will be studied separately. The fact does exist, however, that the epiphyseal vessels protrude into the area of the epiphyseal plate; they may even invade the metaphysis. They are capable of recollapse when the revascularisation has started, and they can also develop into bony bridges.

We have not observed a similar behaviour on the side of the metaphyseal vessels, if a vascular impairment exists on the epiphyseal side of the plate. We saw metaphyseal vessels invading the area of the plate in some doublesided interruptions of the bloodsupply. They never reached the area of the germinative zone. This difference in behaviour could be explained by the difference of the anatomical character of both vessel groups. While the epiphyseal vessels anastomose very richly amongst themselves, even in the area of the endbranches in the "umbrella", the metaphyseal "loops" are arranged more in segmental form, supplying their specific area only.

The vessels on both sides of the plate do preserve their anatomical characteristics, even if they are turned round 180°, provided that the contact between the fragments is very close and revascularisation of the area takes place very quickly. Additional studies have to show the further behaviour of these vessels.

According to *Trueta* and co-workers, the epiphyseal vessels function as vascular supply to the germinative zone of the plate, while the metaphyseal vessels function as enchondral ossification. In our observations on growing animals, these epiphyseal vessels function for the supply of the growing cartilage anlage of the plate, and only after the epiphyseal plate is fully developed, they function in the known form. Under pathological conditions, these vascular channels of the epiphysis are capable of substituting for the metaphyseal vessels in their function. The interosseal artery described by us as a vessel, supplying both the metaphyseal and the epiphyseal side of both bones in the rabbit is also an example that the function of both vascular supplies are not purely specific to one side of the plate. At present, we have no evidence for a mechanism functioning in this area and permitting interchange of functions between both vascular supplies. But such a mechanism seems very probable.

We observed neural influence on the growth of the epiphyseal plate when diaphyseal bone was resected. One could expect that the epiphyseal plate of the same bone would react, as was observed by *Heikel & Troupp*, but that the epiphyseal plate of the neighbouring bone also reacts by reflex was so far unknown, and has to be studied in further detail.

It appears from our study that every experimental disturbance of the blood supply to the epiphyseal plate in the growing animal can be overcome, if the contact between the fragments is close and the clot formation is kept to a minimum. Only direct disturbance of the germinative zone causes a localised distraction of the normal plate formation. This observation is of especial interest for experimental transplantations, which are to our knowledge completely dependent on quick revascularisation. This observation has been made repeatedly by *Haas, Brashear, Harris, Ring* a.o.

SUMMARY

The vascular supply to the distal epiphyseal plate of the ulna in rabbits was studied under normal and experimental conditions.

The existence and behaviour of blood vessel conducting channels, crossing the epiphyseal plate from the epiphyseal to the metaphyseal side were described under different conditions. There is no similar behaviour of the vessels on the metaphyseal side of the plate. The difference in behaviour seems to lie in the anatomical character of the vessels.

The vessels on both sides of the plate preserved their characteristics, even if the plate was turned round 180°.

Under pathological conditions, the epiphyseal vessels can substitute the function of the metaphyseal vessels.

A vessel, supplying both sides of the plate of both forearmbones is described.

Every experimental disturbance of the blood supply to the epiphyseal plate in the growing animal can be overcome under certain conditions.

RESUME

La vascularisation de la plaque épiphysaire distale de l'articulation du coude chez les lapins a été étudiée dans des conditions normales et expérimentales.

La présence et le comportement des canaux conducteurs du vaisseau sanguin traversant la plaque épiphysaire du côte de l'épiphyse au côté de la métaphyse, sont décrits en partant de conditions variées. Il n'y a pas de comportement similaire des vaisseaux du côté métaphy-

saire de la plaque. La différence de comportement semble être liée au caractère anatomique des vaisseaux.

Les vaisseaux des deux côtés de la plaque conservent leurs caractéristiques même si la plaque est retournée 180°.

Dans des conditions pathologiques, les vaisseaux épiphysaires peuvent se substituer dans leur fonction aux vaisseaux métaphysaires.

Il est donné une description d'un vaisseau approvisionnant les deux côtés de la plaque des deux os de l'avant-bras.

Toute perturbation expérimentale de l'apport sanguin à la plaque épiphysaire chez l'animal en croissance peut être redressée dans certaines conditions.

ZUSAMMENFASSUNG

Die Gefässversorgung der distalen Epiphysenplatte der Ulna von Kaninchen wurde unter normalen und experimentellen Bedingungen studiert.

Das Vorhandensein und das Verhalten von Blutgefässen, welche in Kanälen die Epiphysenplatte in Richtung der Metaphyse Kreuzen wurden unter verschiedenen Bedingungen beschrieben. Ein ähnliches Verhalten der Gefässe an der Metaphysenseite der Platte besteht nicht. Die Verschiedenheit des Verhaltens scheint im anatomischen Charakter der Gefässe zu liegen.

Die Gefässe zu beiden Seiten der Platte bewahrten ihre charakteristischen Eigenschaften, selbst wenn die Platte um 180° gedreht wurde.

Unter pathologischen Verhältnissen können die Gefässe der Epiphyse die Funktion der Metaphysengefässe übernehmen.

Ein Gefäss, das beide Seiten der Epiphysenplatte beider Unterarmknochen versorgt, wird beschrieben.

Jede experimentelle Störung der Blutversorgung der Epiphysenplatte des wachsenden Tieres kann unter gewissen Bedingungen überwunden werden.

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