FROM THE ORTHOPAEDIC CLINIC OF THE KAROLINSKA INSTITUT, STOCKHOLM (PROFESSOR PATRIK HAGLUND†)
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ON DEFECTS AND PSEUDARTHROSES OF THE BONY BRIDGE FOLLOWING PARASPINAL BONE TRANSPLANTATION IN GROWING RABBITS

BY

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In an earlier work, "On defects in the bone-graft after Albee's operation for tuberculous spondylitis", the author has described defects of the autoplastic bone-graft fixed in the spinous processes or of the new-formed bony bridge that has replaced it. These defects are situated either at the level of the tuberculous destruction of the vertebral body—in some cases they are level with the axis of inflexion—or at the level of an uninjured intervertebral connection peripheral to the affected vertebral body. The author considered these bone defects to be produced by strains from bending and tension thrown at the level of the axes of spinal motion upon the bony bridge formed by the graft and callus. The defects are described as "acute or insiduous fractures arisen as a result of stress on the graft beyond its strength, whether momentary, prolonged or steadily repeated."

Five cases of graft-defects were histologically studied 2 weeks, 6 months, 6 months, 12 months and 15 months respectively after the defect had arisen. In the 2-weeks case the defect appeared on the sections as a crack through the bony bridge, which here consists of nucleus-stained bone. The crack is filled with a blood clot, enclosing small bony fragments. Nearest the crack, bone-corpuscles are absent within a narrow area, the lacunae being empty. The bone also exhibits signs of active lacunar absorption, the fibrous bone marrow has begun to grow

from the medullary spaces into the blood clot of the defects. In the 6 to 15 months' defects the diastasis between the bone fragments is filled with cartilage or cartilaginoid tissue, a couple of cases presenting the picture of a typical pseudarthrosis.

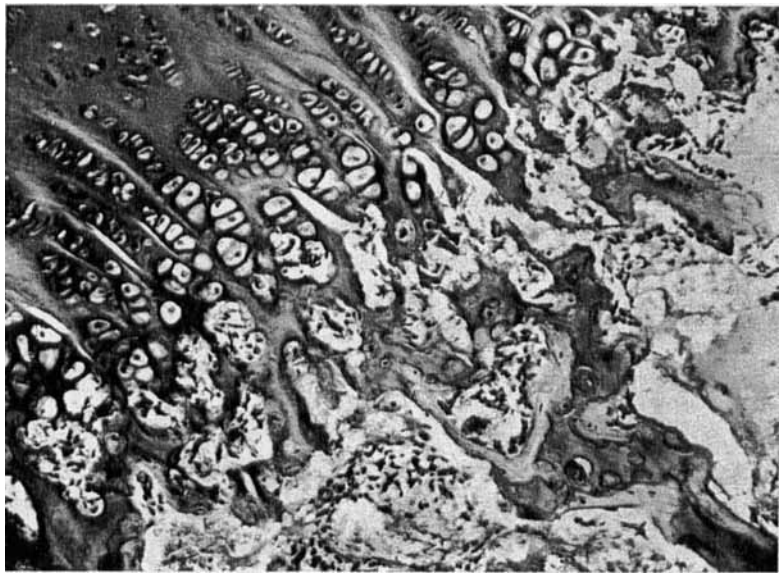

Fig. 1.

Boy aged 8. Frozen section. Stain: Htx-eosin. (× 130).
To the top left hyaline cartilage with calcified matrix. The cartilage-nuclei have proliferated and are arranged in columns. At the osseous junction the marrow spaces, which are filled with fibrous marrow and vessels, are open towards the cartilage. They are surrounded by bands and trabeculae of apparently new-formed bone. Some trabeculae enclose calcified cartilage-remnants.
(From the author's work: *On Defects in the bone-grafts*, etc.).

This is the case in a specimen from a boy aged eight years with a graft-defect about six months old. The space between the bone fragments is in this case filled with typically hyaline cartilage, traversed in the centre by a cavity. On both sides of the defect

the cell-nuclei of the cartilage are arranged in columns directed towards the line of ossification. At the osteochondral junction there is on one side a new growth of enchondral bone in profuse quantity, the picture resembling the zone of ossification at an epiphyseal line. (Fig. 1). On the other side endochondral ossification seems to have been scarce. Provided the new bone is not immediately absorbed, an endochondral ossification of this kind in the longitudinal direction of the bony bridge must involve a growth in its length. Considerable quantities of cartilage also occur in other investigated defects from adult persons. Here, too, the cartilage-nuclei show a columnar arrangement towards the line of ossification, where small areas of new-formed endochondral bone appear. — A girl aged 8 years, who ten months earlier had undergone an Albee operation for tuberculous spondylitis, exhibited signs of "graft-fracture", and a fresh operation was accordingly undertaken (*H. Waldenström*). It was then found that the lower point of the bony bridge had become detached from its seat in a spinous process. The resected tip of the bridge proved to consist of nucleus-stained bone, the tip itself being ensheathed with hyaline cartilage. The cartilage immediately adjoining the line of ossification was calcified, the nuclei presented columnar formation towards the osseous junction. The marrow spaces in the osteochondral junction contained fibrous marrow and were surrounded by strata and trabeculae of irregular, new-formed bone. The bony trabeculae at a greater distance from the cartilage contained pale remnants of cartilage matrix. (Fig. 2).

Ollier points out that an auto- or homo-plastic bone-graft covered with periosteum can heal into a bone defect with retained vitality, but that a graft which has been stripped of its periosteum and endosteum is absorbed. Under favourable conditions dead bone inserted in a bone defect may heal in. A graft of this kind is successively absorbed, to be replaced by new-formed living bone. Up to the present this view has been endorsed by numerous observers, mainly on the basis of macroscopical studies (*MacEwen, Hey-Groves, Albee,* etc.). On the strength of exhaustive microscopical investigations *Barth* claims that

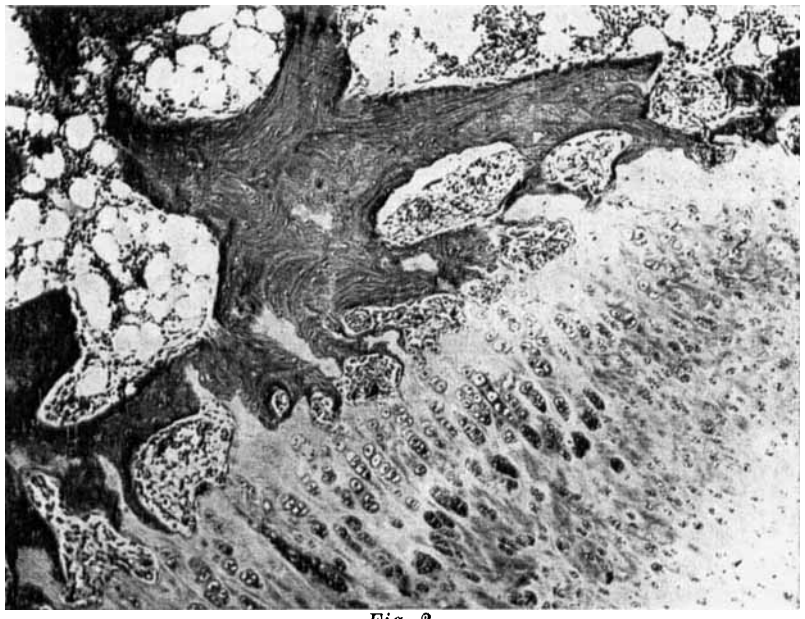

Fig. 2.

Girl aged 8. Stain: Htx-eosin. (× 75).

Hyaline cartilage to the right, nucleus-stained bone to the left at top. The cartilage-nuclei nearest the osseous junction show signs of proliferation with columnar arrangement. In and close to the line of ossification irregular bony trabeculae with enclosed pale cartilage-remnants are present.

transplanted bone always undergoes necrosis, that in spite of the necrosis the transplants can heal into a bone defect, that they are then gradually absorbed and replaced by new bone. In his original publication he stated that the periosteum and endosteum of the inlaid graft are of no importance for the regeneration of the bony tissue, an opinion that he modified later. On the basis of microscopical investigations numerous observers have subsequently arrived at results similar to *Barth*'s. Thus *Bull, Josselin de Jong* and *Eijkman van der Kemp, Leriche* and *Policard, Lexer, Orell, Imbert* and others contend that an autoplastic bone graft can heal into a bone defect without difficulty. During the process the periosteum and endos-

teum can retain their vitality to some extent. Almost the whole of the osseous substance becomes necrotic, only very small superficial portions of bone being able, under favourable conditions of circulation, to survive the transplantation. The regeneration of bone takes place from surviving periosteum and endosteum as well as from the living "osseous bed". Many research workers maintain that the bone-cells of the graft are able to retain their staining ability to some extent for a long time after the transplantation, but that this fact does not afford any proof of the vitality of the bony tissue. *Kornew,* on the strength of a large number of grafting experiments, asserts that after transplantation the osseous substance degenerates, which is also unmistakably evident from his account and illustrations. This degeneration, which manifests itself by the diminished staining power of the bone-corpuscles, is most pronounced in the superficial parts of the graft. The bone-marrow simultaneously shows wide-spread degeneration and, especially in the larger medullary cavities, necrotic disintegration. Under favourable circulatory and static conditions, however, considerable portions of the bone of the graft are thought to be capable of retaining their vitality and of "recovering". In my opinion, the latter assumption does not rest on sufficient evidence.

According to *Havers* all parts of the bony tissue of the skeleton take part in the longitudinal growth, this so-called interstitial growth of bone being considered the normal form of skeletal growth. As against this, *Hunter* contends that the skeletal bones grow only by bone-apposition at the surface and by endochondral bone formation at the epiphyseal lines. *Kornew,* who associates himself with *Havers*'s theory, considers that tubular bones of the skeleton grow "mittels interstitieller Auswachsung der Knochensubstanz der Diaphysen selbst". The chief function of epiphyseal cartilage is thought to be stimulation and control of the growth. He bases this opinion on numerous experiments on growing animals. Thus, in a large number of cases, he made transverse resections of the ulna or fibula. In some cases, the consequent defects were filled up with autoplastic grafts, in other cases they were left open. He applied

wire rings around the resection-stumps as well as around the grafts. In some cases wire rings were placed around an uninjured fibula or ulna. During the process of growth *Kornew* observed that the distances between the wire rings increased, this being so in the resection experiments as well as in the experiments on uninjured tubular bones. In my opinion *Kornew*'s resection experiments are too complicated to justify the drawing of general conclusions regarding the existence of interstitial osseous growth. In control experiments on undamaged tubular bones, the rings seem in a couple of cases to have moved along the bone, in one of the experiments the two parallel bones had fused together. Nor do I consider these experiments as evidence of the occurrence of interstitial bone growth. In experimental investigations on the longitudinal growth of the tubular bones in growing animals *Digby, Silfverskiöld* as well as *Bisgard* and *Bisgard* were unable to find signs of intersitial growth. On the other hand, the epiphyseal growth had been so regular that certain laws could be set up. *Silfverskiöld* is of opinion that the wire rings in *Kornew's* experiments had moved along the shafts of the tubular bones, and he is inclined to see in this an explanation of the divergence between *Kornew*'s and his own results. In some cases this explanation no doubt suffices, in others, probably, other factors had been contributary. After Albee operations and after paraspinal transplantations of bone on growing dogs and rabbits, *Kornew* observed in several cases a longitudinal growth of the paraspinal bone-bridge, the distance between the wire rings fixed on the graft having in a couple of cases increased during growth. One or two published radiographs from such experimental animals show defects and lines of rarefaction through the bony bridge. *Nussbaum* has carried out paraspinal bone-grafting with *Henle*'s technique on a number of young dogs. In one of the cases he found that the bony bridge had grown four centimetres in length in six years. At the level of the intervertebral discs the bridge had four defects, filled with fibro-cartilage. Such cartilage-filled defects in bone grafts or in bone bridges formed around grafts, *having at times the character of actual pseudarthroses,* have been described in the

literature. Among others *W. Müller* has described a cartilage-filled defect of this kind in a bone-bridge in a young rabbit, the defect presenting: "eine auffallende Ähnlichkeit mit der Verknöcherungszone einer Epiphysenlinie".

With the object of throwing some light on these conditions and, more especially, of inquiring into the possibilities of bone-growth in defects and pseudarthroses in paraspinal bone-grafts and bone-bridges, the author has carried out a number of animal experiments. On eleven half-grown rabbits autoplastic bone grafts were implanted paraspinally, in the furrow between the spinous processes and the articular processes of one side, on the periosteum-stripped vertebral arches. The implantations were made in the thoracolumbar region with pieces taken from the ulna, radius or rib, after these pieces had been stripped of their fibrous periosteum. Most of the grafts were furnished with a metal mark at each end. The operations were carried out during the period 17/9—10/10, 1934, on ten rabbits, which on the 15/9, 1934, had a weight of 1000 gm. A supplementary experiment was carried out in the spring of 1936. The operations were performed under anaesthesia with 6—10 c.c. of 10 % urethane solution injected subcutaneously, some animals receiving in addition a couple of drops of ether on a mask. After the operation the animals were allowed to move freely, so that grafts and callous tissues were exposed to mechanical stresses of various kinds from the outset. In rabbits 34, 31 and 32, two grafts from the longitudinally split diaphysis of the radius were implanted, in rabbit III whole diaphyses of the radius and ulna were transferred. Rabbit 38 received two grafts from a longitudinally split rib, rabbits 35 and 39 two whole ribs, rabbits 37, 5, 21 and 29 several costal-bone grafts of different lengths. The rabbits were killed 28—117 days after the operation. They were examined clinically, radiologically and patho-anatomically, and rabbits 34, 31, 32, 38, 35, 37, 21, 29 and III were submitted to more or less extensive histological examinations. The radiographs, (1) ventro-dorsal (V-D), (2) dorso-ventral (D-V), (3) side views (S), were all taken with the spine parallel to the film. The focus-film distance was 100 cm, except in the case

of rabbit III, in which it was 230 cm. The maximum distance measured from spinous process to film for side views was 5 cm.

The object of the present experiments has been to study possibly arising defects in the paraspinal bone bridge and to establish and measure any growth that may take place in the length of this bridge.

The vertebrae of the rabbit have a relatively thick body in the cranio-caudal direction; the intervertebral discs are fairly thin. The articular processes are large and powerful, extend far dorsally, and have an apophysis at their tip. In the thoracic region the spinous processes are long and slender, projecting caudo-dorsally; in the lumbar region they are short, point straight dorsally and are situated in the cranial part of the arch.

Rabbit 34.

Operation 17/9, 1934: Esmarch on right foreleg. Extirpation of a fully 20-mm-long portion of the radial diaphysis from the proximal epiphysis downward. The removed bone was split longitudinally into two strips, 20 and 23 mm long respectively. The neural arches of four vertebrae in the thoraco-lumbar region were exposed and stripped of periosteum to the right of the midline. The transplants were placed in line in the groove between the spinous processes and the articular processes of the right side, the short transplant cranially. They were fixed with catgut sutures; cutaneous suture. A postoperative paresis appeared in the right foreleg. 8/10: Paresis gone; healing by first intention. 22/10: Muscles of operation area still contracted.

X-ray examination 28/9, 34: S: A graft 20 mm long extends from upper part of sp. pr. Th. X to interv. space Th. XI—XII, another 24 mm long from this point to middle of body of L I, total length 43 mm. Contours of grafts sharply defined, calcium content good. Re-examinations 15/10, 29/10 and 12/11 showed contours of grafts to be blurred and surrounded by still denser callus shadows. Diastasis between the grafts, no bone defects visible. 23/11, 34: The rabbit, which has grown considerably,

is healthy and moves without restraint. It was killed 67 days after the operation.

X-ray: S, extension: Irregular bony bridge from sp. pr. of Th X to a point 3 mm below sp. pr. of L I. A narrow line of rarefaction at level of interv. space Th. XI—XII, at the site of the junction between the grafts. The bony bridge is 48 mm long. S, flexion: the entire back forms an even arch, narrow line of rarefaction level to the interv. space Th. X—XI.

The removed specimen of spine comprises Th. IX to and including half L II. To the right of the midline a powerful bony bridge extends from the sp. pr. of Th X to L I, including sp. pr. and articular processes of the right side. The vertebrae within this area show distinct intervertebral mobility on flexion and extension. These movements are accompanied by small displacements of the bony bridge at the level of the interv. spaces Th X—XI, XI—XII and Th XII—L I. These mobile parts together with the corresponding neural arches were excised for histological examination.

Specimen excision *a* comprises the bony bridge at the level of the interv. space Th X—XI. The caudal surface of the section shows a narrow band of cartilage with a small central lumen, mainly running in the sagittal direction. Specimen excision *b* comprises the portion at the level of the interv. disc between Th XI—XII, test excision c the portion at the level of the disc Th XII—L I. Here, the cranial surface of the section shows, at the midline, the transversely cut graft united to the surrounding bone. The caudal surface of the specimen corresponds to the upper part of L I. The graft here lies far dorsally, is surrounded by cartilage and is mobile as against the sp. pr. of L I. All of the specimen excisions were embedded in paraffin, stained with Htx-eosine, Weigert's htx-van Gieson as well as Hansen's staining. Specimen excision *a* was cut frontally, *b* and *c* sagittally.

All three specimen excisions show portions of nucleus-stained cancellous bone alternating with chondral and chondroid tissue. Larger or smaller non-nucleated osseous areas with lamellated structure, in all probability graft-remnants, are present in all the specimens, some embedded in nucleus-stained spongy bone,

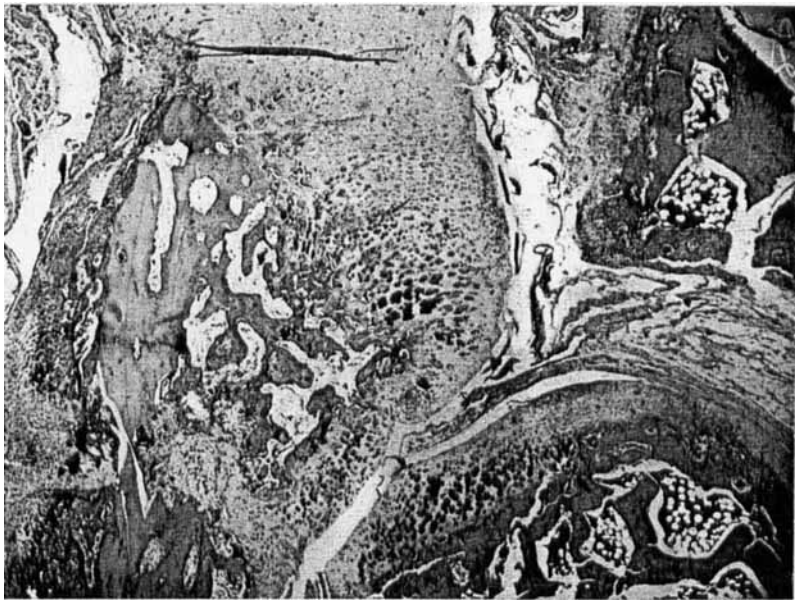

Fig. 3.

Rabbit 34. Stain: Htx-eosin. (× 17).
To the left a non-nucleated graft-remnant with irregular nucleus-stained deposits. A cartilage-lined fissure in the centre. The deeper layers of the articular cartilage show calcification and proliferation of the cartilage-nuclei; irregular new-formed trabeculae of bone are seen at the osteochondral junction.

some surrounded by cartilage and connective tissue. Several of the sections are traversed by irregular rimae lined with hyaline cartilage or richly nucleated connective tissue, some of them being typical joint-spaces and doubtless corresponding to intervertebral joints. At the border of the nucleus-stained bone the cartilage shows calcification and proliferation in several places; at the osteochondral junction trabeculae of osteoid and newly formed bone are visible. (Fig. 3). Specimen excision *b*, corresponding to the diastasis between the grafts, shows cranially a rather large portion of cancellous bone enclosing small graft-remnants. This portion is separated by a transverse band of connective tissue from a small patch of caudally located can-

cellous bone. Within the caudal portion of bone is a largish non-nucleated part with an abrupt cranial limit to the connective tissue. Its Haversian canals contain fibrous marrow and are surrounded by narrow bands of stained bone-cells. This osseous part probably corresponds to the cranial tip of the caudal graft.

Rabbit 31.

Operation 21/9, 34: Extirpation of diaphysis of right radius, during which the ulna was fractured. The extirpated bone was split longitudinally and the parts implanted paraspinally on five vertebral arches. Cranial graft 31.5 mm, a metal pin in its upper end. (I) Caudal graft 37 mm, a pin in its lower end. (II), no diastasis between the grafts.

22/10: Healing by first intention. Right foreleg demarcated and fell off, stump healed. Field of operation in the back mobile.

X-ray 28/9: S: Upper graft extends from sp. pr. of Th VIII to upper part of Th XII, lower one from upper edge of Th XII to sp. pr. of L II. Total length of grafts 65 mm, distance between metal-pin indicators 54.5 mm. Body of L II, 17.5 mm. Grafts intact. (Fig. 4).

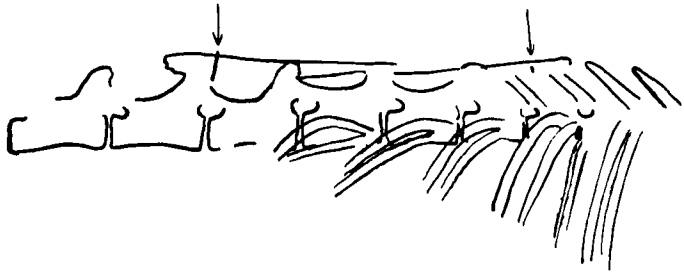

Fig. 4.
R. 31. Radiograph 28/9,34, S: Two radius-transplants paraspinally, with metal indicators at cranial and caudal ends.

X-ray exam. 15/10, 29/10 and 12/11: Graft contours blurred, increasingly dense callus-masses, indicators in same places. Lines of rarefaction at level of interv. discs. 23/11/34: The rabbit, which moved freely, was killed, 63 days after the operation.

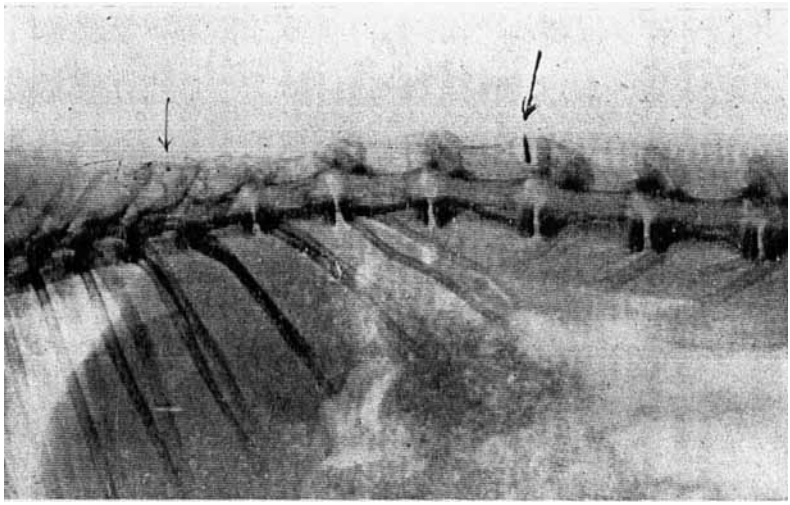

Fig. 5 A.

R. 31. Radiogr. 23/11,34. S. extension: Paraspinal bony bridge Th IX-L II. At level of interv. discs Th X-XI, Th XI-XII and Th XII-L I rarefactions surrounded on dorsal side by deposits.

X-rays, S, extension: Bony bridge between sp. pr. of Th VIII—L II broken by rarefactions at level of interv. spaces Th X—XI, XI—XII, Th XII—L I as well as cranially to sp. pr. of L II. Length of bridge 80 mm, distance between indicators 63 mm, L II's body 19 mm. (Fig. 5A). S, flexion: The back forms an even arch, with mobility between all the fixed vertebrae; diastases, with dorsal deposits, at site of rarefactions. (Fig. 5B).

The removed specimen comprises caudal part of Th VII to and including L II. To the left of the middle line, and including spinous processes and articular processes of left side of Th IX—L II, there extends a bony bridge varying in width from 5 to 10 mm. When the specimen is flexed or extended, the vertebrae shift in relation to one another, some slight movements being also observed in the bony bridge at the level of all the intervertebral discs. A superficial frontal section above the spinous process of L II shows that the bony bridge is here traversed by a V-shaped band of cartilage, with its tip caudally and with a

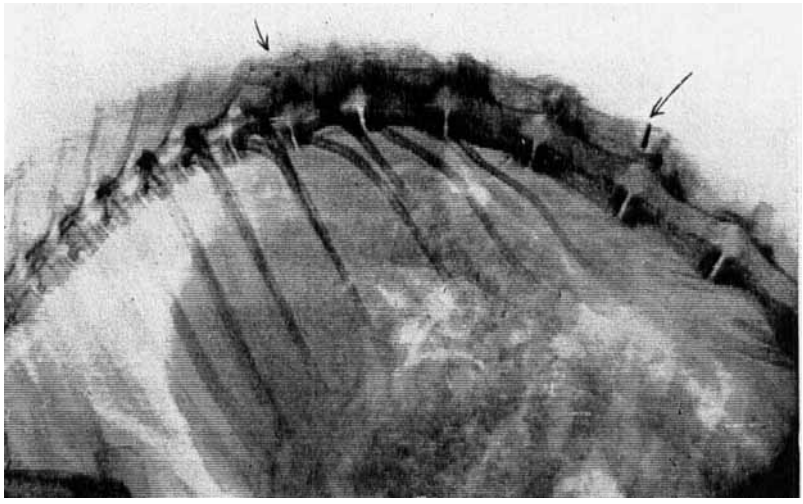

Fig. 5 B.
R. 31. Radiogr. 23/11,34, S, flexion: Good flexibility of the spine within the fixed area.

narrow fissure centrally. The cranial part of the band of cartilage corresponds to the intervertebral joints L I—L II. The fissure widens when the specimen is flexed, narrows when it is stretched.

Specimen excision *a*, the bony bridge and arch of Th X. Paraffin embedding, frontal sections: Staining: Htx-eosin and Hansen's stain.

The sections further dorsally strike the sp. pr. of Th X and the tip of Th XI's right upper articular process with its apophyseal cartilage. At the site of the left upper articular process of Th XI there is a considerable area of cancellous bone, likewise with apophyseal cartilage. Medial to this, stretching towards Th X's spinous process, lie elongated lamellar, nonnucleated osseous bundles, surrounded by connective tissue. Their Haversian canals contain fibrous marrow and are surrounded by a narrow concentric layer of bone with stained nuclei. A round defect with metallic precipitation is seen at the

cranial end of these graft-remnants. (Ind. I). More ventrally in the sections the graft-remnants have vanished, both the lower articular processes of Th X can be seen.

Specimen excision *b* comprises the bony bridge and the left part of Th XI's arch. Bedding and staining the same as in *a*, sagittal sections. The specimen consists of irregular patches of cancellous bone with myeloid marrow and adipose marrow. In the tissue lie dark, non-nucleated masses, surrounded by macronuclear cells, (catgut remnants?). The cancellous areas are separated by fasciculi of connective tissue, cartilaginoid tissue, and typical hyaline cartilage. Here, too, are rimae and typical articular spaces. In one section a small graft-fragment is seen.

Specimen excision *c*: Bedding, sectioning-direction and staining the same as in *b*. The sections comprise the left half of the bony bridge. The dorsal part of the specimen is traversed by an oblique, macroscopically visible defect. Microscopically, the sections show irregular cancellous areas, separated by considerable masses of hyaline cartilage and connective tissue. Here and there irregular cavities appear. In a couple of places a cavity is bordered by nucleus-stained bone with an irregular and ragged contour. Some of the bone-lacunae nearest the contour are empty, in the cavity small non-nucleated bone-spicules are seen. (Fig. 6). Small graft-fragments also occur. Both the non-nucleated and the nucleated bone exhibits signs of lacunar absorption with Howship's lacunae and osteoclasts.

Rabbit 32.

Operation 21/9,34: Extirpation of diaphysis of right radius. This was split longitudinally, and the strips were placed in line paraspinally to the left of the arches of six vertebrae, their ends being marked by metal pins. Length of cranial graft 40 mm, of caudal 44 mm. — 22/10: Healed by first intention, back actively and passively mobile.

X-ray 28/9, S: The upper graft extends from sp. pr. of Th IX to sp. pr. of L I; on a level with upper part of Th XII is a line of rarefaction (fracture during preparation). The lower

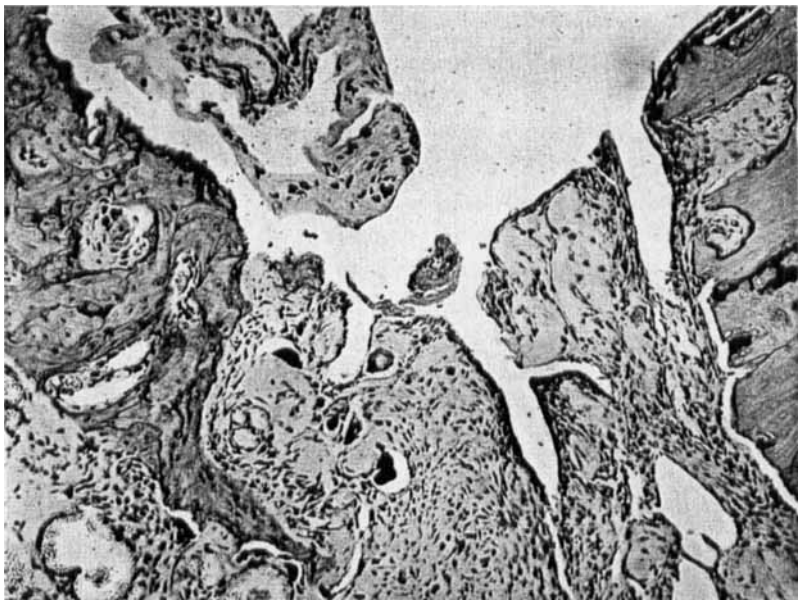

Fig. 6.

R. 31. Stain: Htx-eosin. (× 45).
Furthest to the right a graft-remnant, in a Haversian space fibrous marrow. To the left an irregular area of bone containing stained nuclei and bordering on an oblique cavity. The bone-contour of the cavity is ragged and uneven, a number of bone-lacunae adjoining the contour are empty.

transplant extends from middle of L I to sp. pr. of L IV. Line of rarefaction at middle of L II. Between the transplants is a diastasis 0.5 mm broad. The total length of the grafts is 82 mm, L II's body 15.5 mm. Radiographs 15/20, 29/10 and 12/11: Grafts surrounded by still denser callus masses, their contours blurred. Fracture of upper transplant consolidated (15/10), a defect has developed at site of lower fracture. The break between the grafts does not appear on radiogram 12/11.

The rabbit was killed on 23/11, 63 days after the operation.

X-ray; S, extension: Between sp. pr. of Th X and L IV a 95-mm-long bony bridge, with lines of rarefaction at level of interv. discs Th X—XI, XI—XII, Th XII—L I and L I—L II.

A broad defect at level of L II's body, the lower part of the bridge shows no break, extends to sp. pr. L IV. L II's body 19 mm. S, flexion: Spine curved in an even arch. Defect at L II wider, sp. pr. of L IV displaced towards the bony bridge as compared with position in extension view.

The specimen taken comprises the lower part of Th VIII to and including the upper part of L III. To the left of the mid-

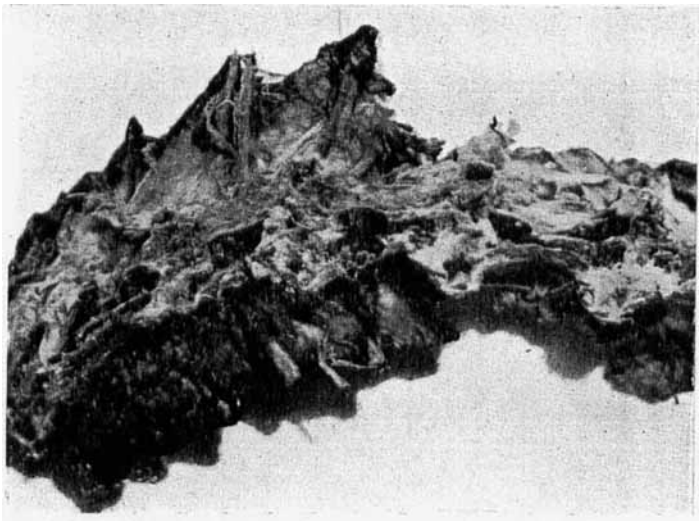

Fig. 7.

R. 32. Specimen taken from spine. The dark-coloured bone is traversed by a number of light bands of cartilage. The oblique cartilage-band between Th X and XI has a central, fissure-like cavity. No cavities appear in the irregular cartilage portions Th XI-XII, Th XII-L I and L I-II.

line, including spinous processes and articular processes of the left side, there stretches a bony bridge 3—9 mm wide. The vertebrae are mobile against one another, in the bony bridge there are mobile defects at the level of the intervertebral spaces. A superficial frontal section of the bridge shows a series of irregular cartilaginous bands traversing the bridge in a transverse or oblique direction. (Fig. 7). At the level of the intervertebral space Th X—XI the bridge is 5 mm broad; it is here traversed

by a 3-mm-wide band of cartilage running in direction cranially left to caudally right and containing centrally a narrow fissure. At the level of the intervertebral space Th XI—XII the bridge

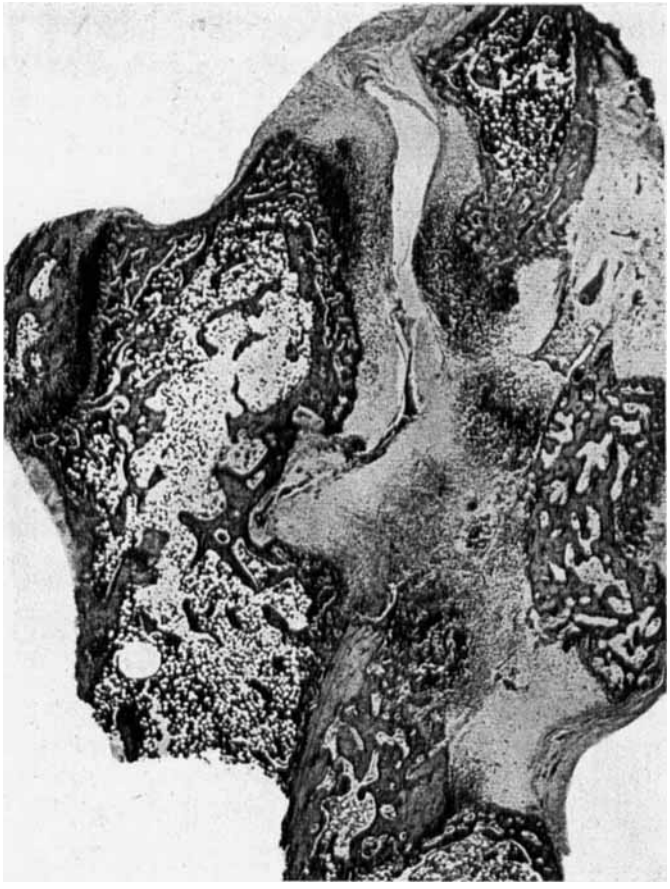

Fig. 8.

R. 32 a. Stain: Htx-eosin. (× 11).

Frontal section of bony bridge at level of interv. disc Th XI-XII. The osseous portion to left corresponds to Th XII's left upper art. process with apophysis and calcified apophyseal cartilage. The Y-shaped cartilage-band shows varying degrees of calcification and contains a narrow cavity in its left, cranial part. Furthest caudally and to the left is a largish graft-remnant, to the right and cranial to the centre smaller ones.

is 10 mm broad. From the upper edge of the left upper articular process of Th XII there runs, almost transversely, a band of cartilage that broadens towards the right and has a fissure-like cavity in its left part. At the level of the intervertebral space Th XII—L I there is a 3-mm-wide strip of cartilage with a central fissure taking direction from L I's left upper articular process caudally to the right. From the upper part of L II's left upper articular process runs a strip of cartilage with a small cavity obliquely caudally to the right. The site of the diastasis between the two grafts is filled up with solid bone.

Specimen excision *a* comprises the cartilaginous band at the level of the intervertebral disc Th XI—XII. Celloidin embedding, frontal sections, staining: Htx-eosin, Weigert's htx-van Gieson. (Fig. 8). At the site of the left upper articular process of Th XII, all the sections show a large area of nucleus-stained spongy bone with myeloid marrow and with band-shaped apophyseal cartilage and, laterally, an apophysis. This osseous area is caudally united with the bony bridge. Obliquely through the specimen caudally to the right, runs an irregular, Y-shaped band of cartilage surrounding a number of cavities, the largest cranially to the left. The cartilaginous band consists partly of large-celled hyaline cartilage, partly of small-celled cartilage with transition to fibro-cartilage, partly of portions resembling connective tissue. Some of the cavities are lined with cartilage arranged parallel to the surface. The cartilage exhibits calcification of varying degrees at the border against nucleus-stained bone, in the calcified areas the cartilage-nuclei show signs of active proliferation with columnar arrangement towards the line of ossification. (Fig. 9). The medullary spaces nearest the cartilage junction contain fibrous marrow and are open towards the cartilage. They are surrounded by thick, irregular trabeculae of bone with bands of osteoid and new-formed bone. Some of the trabeculae enclose cartilage-remnants. The quantity of new bone formation seems to vary at different parts of the osteochondral junction, and is largest cranially and caudally. Cranially, at the midline and enclosed on both sides by cartilage, lies a small patch of cancellous bone with stained nuclei. In its

Fig. 9.

R. 32 a. Stain: Htx-eosin. (× 150).
Proliferated cartilage-nuclei arranged in columns. In the line of ossification the marrow-spaces, which contain fibrous marrow, open towards the cartilage and are surrounded by bands of bone.

centre, narrow bundles of non-nucleated lamellated bone are to be seen. Caudally to the strip of cartilage lies a patch of non-nucleated, lamellated bone; far over to the right are small non-nucleated osseous areas enclosed in nucleus-stained spongy bone. The non-nucleated portions show irregular deposits of recently formed bony trabeculae containing numerous deeply stained corpuscles; around their Haversian canals narrow concentric rings of nucleated bone are present. The canals themselves are empty or contain fibrous marrow. The various graft-remnants do not correspond in structure, their Haversian canals running in different directions. Around small vessels in the cartilage narrow bands of nucleus-stained osseous tissue can be seen in a couple of places. (Fig. 10). The contour of the non-

nucleated as well as the nucleated bone is pitted in several places with Howship's lacunae, which contain typical osteoclasts. To the right, lateral to the cranial part of the bony bridge, the tip of Th XII's right upper articular process may be seen in deeper sections.

Specimen excision *b* comprises the bony bridge at the level

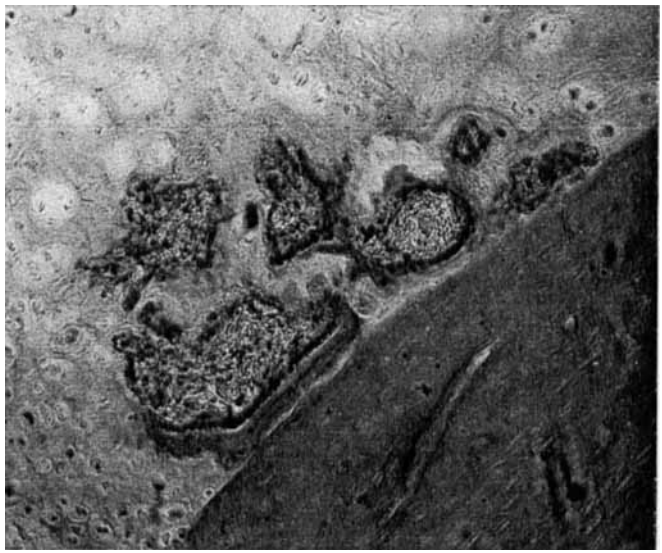

Fig. 10.

R. 32 a. Stain: Htx-eosin. (× 150).

To right non-nucleated graft-bone, upwards and to left cartilage. Some vessels, surrounded by narrow bands of young, richly-nucleated bone, are seen in the central part in the cartilage.

of the intervertebral disc of Th XII—L I. Paraffin embedding, frontal sections, staining: Htx-eosin, Weigert's htx-van Gieson, Hansen's staining. In the sections furthest dorsally there is seen a broad area of nucleated cancellous bone cranially and another one caudally. Between these, immediately cranial to the left upper articular process of L I, a broad strip of cartilage runs right through the bone-bridge, with a wide cavity centrally that is bordered on both sides with connective tissue membranes

resembling capsular ligament. The cartilage is of hyaline type; along the walls of the cavity its nuclei are arranged parallel to the surface. The cancellous bone is irregular, its marrow mainly

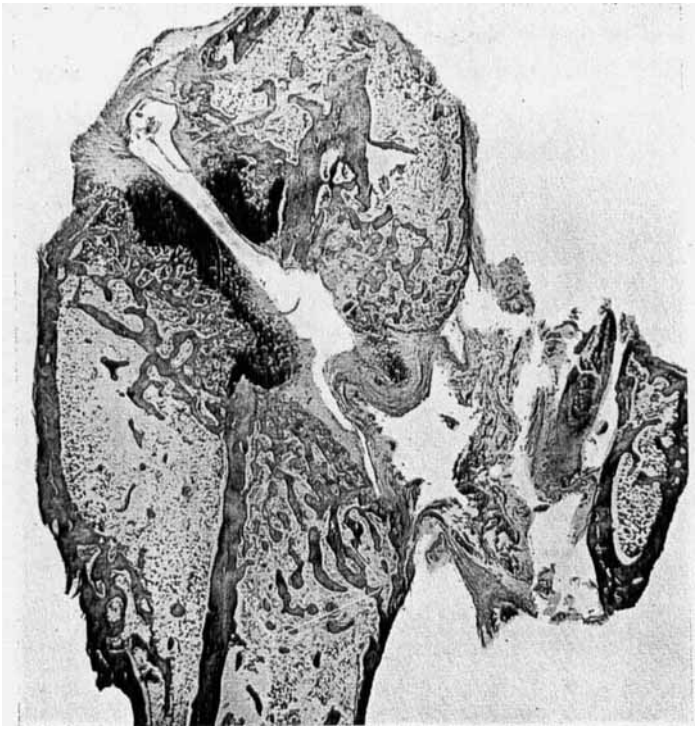

Fig. 11.

R. 32 b. Stain: Htx-eosin. (× 8).

Frontal section of bony bridge at level of interv. disc Th XII-L I. The bony bridge is traversed by an oblique, cartilage-lined fissure, demarcated to the sides by a connective tissue capsule. Marked calcification of the cartilage, especially to the left of midline. In the central part of the bony bridge there are elongated graft-remnants, directly connected with surrounding nucleus-stained bone. The grafts extend into the cartilage-lined cavity. To the right Th XII-L I's right interv. joint.

myeloid, being fibrous only nearest the cartilage. Further ventrally on the section there appear, cranially and caudally, pale elongated strips of lamellated bone with empty lacunae. These

Fig. 12.

R. 32 b. Staining: Hansen's. (× 45).
To the left cartilage, to the right new-formed bone. In deeper parts of cartilage proliferation with nuclei arranged in columns. Medullary spaces filled with vessels and open towards the cartilage are seen in the zone of ossification. The marrow spaces are surrounded by irregular bony trabeculae, enclosing pale cartilage-remnants.

strips are enclosed in and fused with the spongy bone through irregular, nucleus-stained bony trabeculae. (Fig. 11). The Haversian canals of the lamellated bone are partially surrounded by concentric rings of nucleus-stained bone. Some are empty, others contain vessels and fibrous marrow. The non-nucleated osseous parts stretch on both sides as far as the cartilage cavity. Their free contours are covered with cartilage that has its nuclei arranged parallel to the bone contour. The non-nucleated bone, covered on one side with nucleus-stained bony bands and bordered on the other side by the cartilage, extends a point into the central cavity; outside its contour, in the cavity, lie small fragments of bone. At the interspace between bone and cartilage

Fig. 13.

R. 32 b. Staining: Hansen's. (× 85).

Extending from the right towards the centre is a non-nucleated graft-remnant that runs out into a point surrounded by cartilage. Small bone-fragments lie outside this bony point. Above and below the non-nucleated bone, directly connected with the latter, are seen considerable areas of nucleus-stained bone with enclosed vessel-bearing cavities. Active endochondral ossification is in progress in the interspace between nucleated bone and cartilage, no reaction in the interspace between non-nucleated bone and non-vascular cartilage.

there are no signs of reaction and new bone formation. (Fig. 13). Around the small vessels present here and there in the cartilage and in the osteochondral junction thin osseous bands are seen, which partly cover the non-nucleated bone. At the interspace between these bands and the cartilage the new-growth of endochondral bone seems to be lively. (Fig. 14). The cartilage at the boundary of the nucleus-stained bone shows calcification of varying degrees, the cartilage-nuclei present, both cranially and

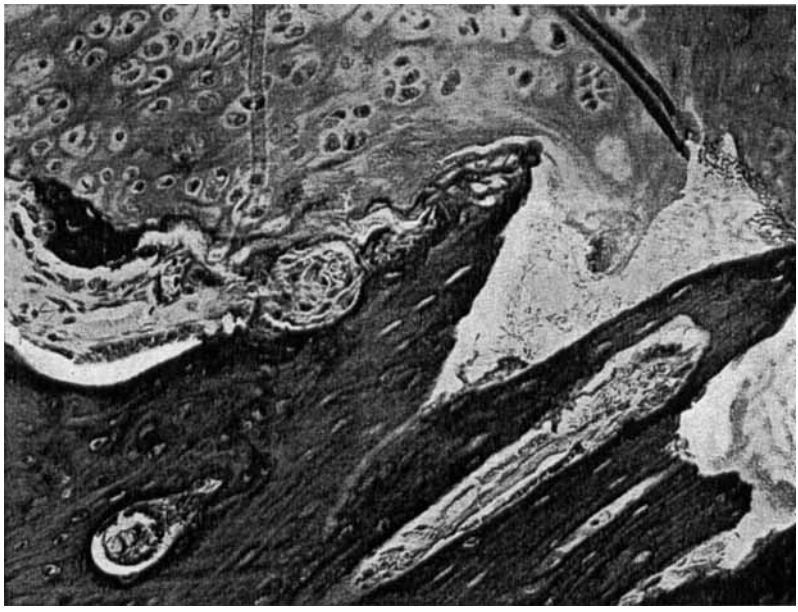

Fig. 14.

R. 32 b. Staining: Hansen's. (× 200).

Graft-tip projecting into the central cavity. Fibrous marrow and vessels in one of the longitudinally-cut canals of the non-nucleated bone. Upwards to the left, directly connected with the non-nucleated bone, is a layer of nucleus-stained bone with vessel-bearing marrow spaces centrally as well as on the border against the cartilage furthest upward. The cartilage shows a new-formed osseous band in the interspace towards the medullary space.

caudally, signs of proliferation with columnar arrangement. The marrow spaces of the cancellous bone are open towards the cartilage. They are filled with fibrous marrow and lined with osteoblasts, and are surrounded by bands and trabeculae of osteoid and new-formed bone enclosing pale remnants of cartilage basement substance. (Fig. 12). In the sections further ventrally the right intervertebral joints Th XII—L I can be seen.

Specimen excision *c* comprises the bony bridge caudally to *b* and the cartilaginous band at the level of the intervertebral disc L I—II. Celloidin embedding, frontal sections. Staining: Htx-

eosin, Weigert's htx-van Gieson. The sections show, cranially, a narrow portion resembling a tubular bone and, caudally, a broader portion that includes L II's left upper articular process and the cartilaginous band cranial to this. (Fig. 15). The right upper

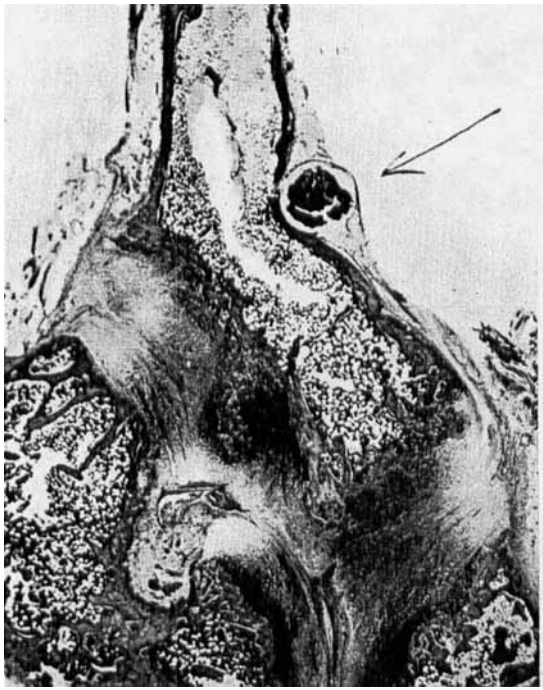

Fig. 15.

R. 32 c. Stain: Htx-eosin. (× 10).

Frontal section through bony bridge at level of interv. disc L I-II. Above, a narrow bony bridge, to the right mark left by indicator 3 (the cranial one in lower graft). The cartilage-band at level of interv. disc L I-II is Y-shaped, shows calcification of varying degrees and encloses small graft-remnants. To the left is L II's left upper articular process, fused with the bony bridge.

articular process of L II is seen to be free of the bony bridge. The "tubular bone" corresponds to the site of the intermediate space between the transplants, and shows a thin cortex with

lamellated structure and narrow Haversian canals; the medullary cavity contains myeloid marrow traversed by solitary narrow trabeculae of cancellous bone. In the right periphery the cranial metal mark of the caudal transplant can be recognized. On the inner side of the cortex of the right side and fused with it are narrow, elongated graft-remnants, visible on all sections all through past the metal indicator. Further caudally, the graft-remnants lie more to the left, but the structure has the same direction all through and therefore the site of the original intermediate space between the transplants cannot be exactly determined. This space is now entirely filled up with bone. The broad caudal osseous part consists of cancellous bone at the site of L II's left upper articular process as well as of a small area of spongy bone furthest caudally in the specimen. From the upper edge of the above-mentioned articular process to the right contour of the specimen, at the level of the right articular process, runs an irregular Y-shaped band of cartilage with a couple of narrow cavities centrally. Cartilaginous tissue of different types occur in the band, deeply stained collagenic fasciculi appear in some parts, tissue of the connective tissue type in other parts. Towards the line of ossification the cartilage shows calcification of varying degrees, in many places the cartilage-nuclei exhibit signs of proliferation, and in the osteochondral junction are new-formed trabeculae of osteoid and osseous substance, most abundant cranially and caudally in the centre of the specimen. A non-nucleated graft-remnant, surrounded and traversed by nucleus-stained deposits, lies caudally in the centre of the band of cartilage. The right upper articular process of L II consists, in the most dorsal sections, of apophyseal cartilage, in deeper sections, of cancellous bone with a layer of cartilage laterally; lively formation of new bone is observed in the osteochondral junction.

Rabbit 38.

Operation 3/10,34: Extirpation of the tenth right rib. It was split longitudinally, and the transplants were inserted para-

spinally to the right of the midline. Upper transplant 25 mm, lower 36 mm. 22/10: Free mobility in the field of operation.

X-rays 15/10,34: S: Upper transplant from sp. pr. of Th XII to upper part of L II, lower from upper part of L II to sp. pr. of L IV. Contours of grafts blurred. The lower transplant shows, caudally to sp. pr. of L III, a line of rarefaction. Total length of grafts 64 mm, L II's body 17 mm.

X-rays 29/10, 12/11 and 26/11 show the formation of an irregular bony bridge between sp. pr. of Th XII—L IV. On the tip of the upper articular processes of the lumbar vertebrae are —29/10—rounded apophyses, separated by a rarefaction from the articular processes. On the 12/12,34 the rabbit was killed, 70 days after the operation.

X-rays: S: extension: A fully 70-mm-long bony bridge from sp. pr. Th XII to L IV free from discernible bone defects. L II's body 18.5 mm. S, flexion: The fixed vertebrae form an even arch. At the level of the intervertebral space L II—III the bone-bridge shows an irregular rarefaction.

The removed specimen comprises Th XII to and including the upper half of L IV. From the sp. pr. of Th XII, to the right of the midline, a bony bridge extends to the sp. pr. of L IV. It is thin and narrow at the lower part of Th XII and L I, broad and stout as from the sp.pr. of L II, fused with the right upper articular process of L III. There is mobility between all the vertebrae of the specimen; movements can be detected in the bony bridge at the level of the intervertebral discs Th XII—L I, L I—II, L II—III and L III—IV; the movable parts are dorsally covered with a compact connective tissue membrane. A superficial frontal section shows, at the level of the intervertebral disc L II—III, a narrow, irregular strip of cartilage through the bridge, in its centre a narrow cavity.

Specimen excision *a* comprises the bony bridge above the lower part of L II and upper part of L III along with L II's and L III's free left articular processes. Celloidin embedding, frontal sections. Staining: Htx-eosin, Weigert's htx-van Gieson. The cranial part of the bony bridge is fairly narrow, has a thin cortex and myeloid marrow. The left upper articular process

of L III lies free, the right one is fused with the caudal part of the bridge and the base of L III's spinous process. The narrow cranial part and the broad caudal part of the bony bridge are separated by a band of multicellular tissue that has the character of connective tissue and is traversed by a fissure-like

Fig. 16.

R. 38. Stain: Htx-eosin. (× 17).

Frontal section of bony bridge at level of interv. disc L II-III. The left side shows L III's right upper articular process and the right intervertebral articulation L II-III with articular cartilage, joint-capsule and villi. The cranial part of the bony bridge terminates in a "bud-like" protuberance on the right side. The "joint-cavity" around the prominence seems to communicate with the joint-cavity of the intervertebral joint.

cavity. The cranial part shows cancellous bone with deeply stained nuclei; enclosed here and there in this are pale, non-nucleated graft-fragments. The cranial bony portion runs caudally out

into two rounded "protuberances", a narrow fungus-shaped one on the left side, a broader one on the right. (Fig. 16.) The left protuberance contains both fragments of non-nucleated bone with signs of lacunar absorption and multi-nucleated connective tissue. The stem consists of nucleated and non-nucleated bone

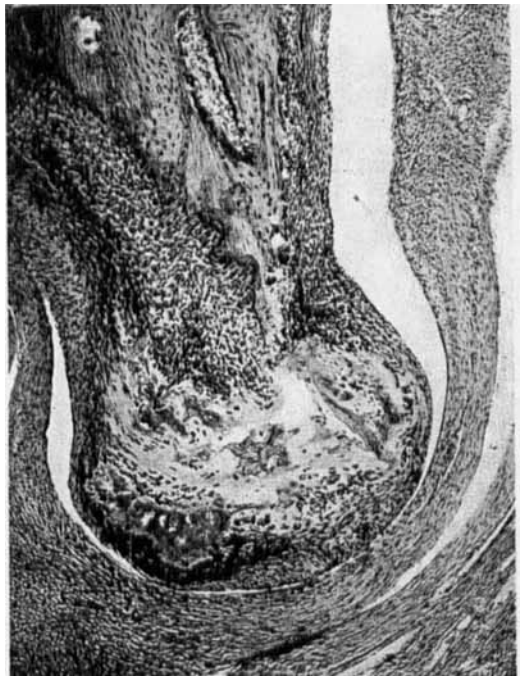

Fig. 17.

R. 38. Stain: Htx-eosin. (× 70).

The protuberance contains nucleated and non-nucleated bone as well as connective tissue very rich in cells. The non-nucleated bone is partly divided into fragments. The joint-fissure is lined with connective tissue very rich in cells.

surrounded by connective tissue rich in cells. (Fig. 17.) The right protuberance is composed of nucleus-stained bone; in the marrow spaces fibrous marrow and osteoblasts, in the periphery signs of new bone formation. The cranial fragment of the bony bridge is limited to the right by the intervertebral-joint space

with articular cartilage, villi and capsule. Both the "protuberances" are surrounded by a narrow, continuous joint-cavity, which communicates with the space of the intervertebral joint. The joint-cavity around the protuberances is limited by a many-celled substance resembling connective tissue. The caudal bridge-fragment is connected with the spinous process and the projecting right upper articular process of L III, and is composed of irregular spongy bone with myeloid marrow. Here, too, small non-nucleated graft-remnants can be seen. L III's left upper articular process consists, in the furthest dorsal part of the sections, of a broad strip of cartilage; caudally and cranially to this is a narrow layer of cancellous bone, in deeper sections mainly of bone.

Rabbit 35.

Operation 3/10,34: Extirpation of 10th and 11th right ribs, which were implanted paraspinally, on the right side, on the arches of six vertebrae. Upper transplant 32 mm long, lower 35 mm. 22/10: Healed by first intention, spinal column considerably immobilized. 12/11: Spine freely movable, actively and passively.

X-rays 15/10: S: Upper transplant between sp. pr. of Th IX —L I, lower from sp. pr. of L I to middle of L III. The grafts show no defects; they are surrounded by thin callus-shadows, their aggregate length is 72 mm. L II's body 15 mm. Radiographs 29/10, 12/11, 26/11, 12/12 show formation of a bony bridge between sp. pr. of Th X—L III.

The rabbit was killed on 14/1,35, 103 days after the operation. X-rays; S, extension: Bony bridge sp. pr. Th X—L III, 90 mm long. The sp. pr. of Th X free. At level of intervertebral discs Th XI—XII and Th XII—L I the dorsal contour of the bridge exhibits deep notches. Over L II's lower part the bridge is not clearly visible. L II's body 19 mm.

The removed specimen comprises the spine from the lower part of Th IX to the upper part of L IV inclusive. From sp. pr. of Th X to Th XII's lower part runs a powerful bony bridge,

including the articular processes of the right side and the spinous processes. On a frontal surface section the cranial part of the bony bridge shows a cartilage-lined fissure running obliquely through the bridge, the width of the fissure changing in response to movements between Th X and Th XI. In the 8-mm-wide bony bridge a 1-mm-broad strip of cartilage with a central lumen may be seen running from the right cranially to the left caudally, at the level of the intervertebral disc Th XI—XII. To the right of the midline the bridge continues as far as the union between Th XII—L I, where, at the site of the interspace between the transplants, it has a 3-mm-broad defect filled with connective tissue. Below the defect the bridge continues as a 4-mm-broad crista between L I's spinous process and right articular process, forming a peg-like process that is separated by a band of cartilage from L II's right upper articular process and spinous process. Movements between L I and L II give rise to narrow articular spaces in the cartilaginous bands. Between the extension of the bony bridge and L III's right upper articular process there is a similar movable union, although without a pronounced fissure in the cartilage. The bony bridge is fully 80 mm long.

Specimen excision *a* comprises the bony bridge with the defect on a level with the interv. space Th XII—L I. Paraffin embedding, frontal sections. Staining: Htx-eosin, Weigert's htx-van Gieson. The sections include a cranial portion of cancellous bone above, and a caudal one below the defect. The defect consists of a band of cartilage and connective tissue. In the centre there is an articular cavity, running from the right cranially to the left caudally. The cranial portion of bone shows, towards the cartilaginous junction, thick, irregular trabeculae. Here the Haversian spaces are filled with fibrous marrow. The cartilaginous band consists for the major part of hyaline cartilage, which presents varying degrees of calcification. Around the medullary vessels growing into the cartilage there are bands and trabeculae of osteoid and richly-nucleated bone. To the left the cartilage merges into multicellular and very vascular connective tissue. This tissue has numerous cavities, which do not

communicate with the articular cavity. Here the bony trabeculae pass without sharp demarcation into connective tissue. The caudal bone-fragment comprises the articular process and its apophyseal cartilage. The cancellous bone is irregular, the marrow myeloid. Nowhere in the sections can indubitable graft-remnants be identified. Active lacunar absorption is observed in the left part of the sections.

Rabbit 39.

Operation 8/10,34: Extirpation of 10th and 11th right ribs, which were placed paraspinally to the right on six vertebral arches. Upper transplant 36 mm long, lower 37.5 mm. The latter was boiled one minute before the transplantation. 12/11: Healed by first intention, field of operation mobile.

X-rays 15/10,34: S: Upper graft between sp. pr. of Th IX—XII 34 mm long, presents a somewhat blurred contour. Lower graft 35 mm long, extends from sp. pr. of Th XII to lower part of L II, has well-defined contours. L II's body 16 mm. Radiographs 29/10, 12/11, 26/11, 12/12 and 7/1,35 show how the upper transplant is rebuilt and how the lower one remains unchanged.

The rabbit was killed on 14/1,35, 98 days after the operation. X-rays: S, extension: Stout, 40-mm-long irregular bony bridge covering sp. pr. of Th IX—XII. L II's body 19.5 mm. Caudal graft 36 mm long, its lower tip at level of middle of L II, its contour sharp, shape unchanged.

The removed specimen comprises Th IX to and including the upper part of L II. From spinal process of Th IX to that of Th XI extends a stout bridge, including articular processes of the right side and the spinous processes and with a maximum width of 5 mm. At the level of the lower part of Th X it is traversed, from the right cranially to the left caudally, by a band of cartilage with a narrow, fissure-like lumen centrally. Above this point the bridge exhibits no defect. Between Th X and XI there is good mobility, between Th IX and X there is none or extremely little. The bridge shows, at the level of the

intervertebral disc Th XI—XII, a 2-mm-broad gap filled with connective tissue. Between Th XII's right upper articular process and spinous process lies a piece of bone 5 mm long. The caudal graft is unchanged in shape, it does not exceed 37 mm in length, its caudal tip is soft. The whole graft is movable as against the vertebrae.

Rabbit 37.

Operation 8/10,34: Extirpation of the 10th and 11th right ribs (pneumothorax). The ribs were divided into 5-mm-long pieces and these were implanted one behind the other paraspinally on the right side. 24/10 (16 days after the operation): Swelling and fixation in the field of operation. Its lower part was laid open: Beneath the skin masses of fibrin; to the right of the spinous processes a large, firm mass of callus. Extirpation of caudal part of callus: The excised specimen consists of firm callus with an embedded rib-transplant that has undergone but little change.

The rabbit was killed on 5/11, 28 days after the operation. X-rays 15/10 and 22/10, S: A series of short grafts, surrounded by callus. X-rays 5/11, S: Blurred, irregular bone-shadow to the dorsal side of the bodies of Th IX—L II; no graft discernible.

The removed specimen comprises Th VIII—L II. The spinous process of Th VIII is free; from Th IX's arch downward there is a fairly soft callus to the right of the midline. The spinous processes of Th X—L I—which were extirpated on 24/10—are missing.

Histological examination: Specimen excision 24/10: Paraffin embedding. Staining: Htx-eosin, Hansen's staining. The sections present, longitudinally and obliquely cut, elongated portions of bone with lamellated structure and mostly empty lacunae, in all probability rib-grafts. Their Haversian canals are filled with red blood cells and pale, non-nucleated masses studded by numerous leucocytes or by fibrous bone marrow. In the medullary cavity of the rib lie aggregations of red blood corpuscles and non-nucleated substance containing solitary leucocytes

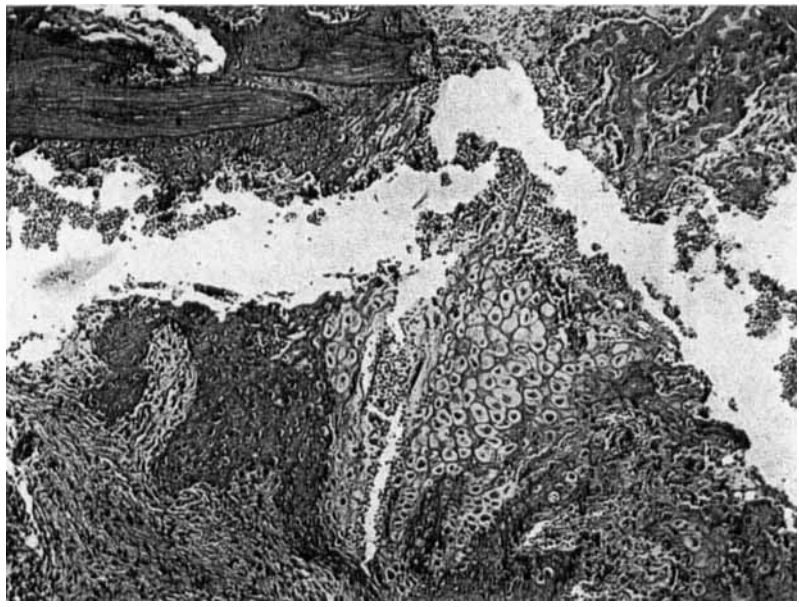

Fig. 18.

R. 37. Specimen excision 16 days after the operation. Staining: Hansen's. (× 45).

At the top to the left is a non-nucleated graft-remnant with nucleus-stained deposit. In the centre large-celled cartilage, merging into very vascular osteoid tissue. Above to the right irregular trabeculae of spongy bone enclosing remnants of cartilage.

and round cells. From adjacent soft parts a very vascular tissue resembling fibrous bone marrow is growing into the medullary cavity of the grafts. The graft-remnants are surrounded by callus-tissue of varying types, irregular, very vascular cancellous bone, hyaline cartilage, and connective tissue. (Fig. 18.) The trabeculae of cancellous bone have coalesced with the graft-remnants. The hyaline cartilage occurs in large rounded masses, its nuclei to some extent show columnar arrangement. Other callus-parts have the character of connective tissue rich in vessels and partly undergoing transformation into fibrous cartilage. The callus-tissue shows haemorrhages here and there. Sections from the postmortem specimen, embedded and stained

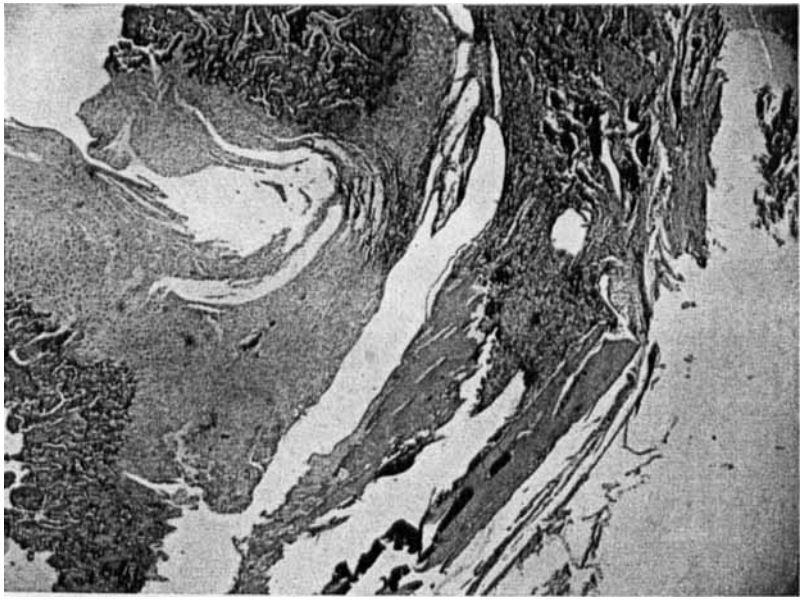

Fig. 19.

R. 37. Post-mortem specimen 28 days after operation.
Staining: Hansen's. (× 17).
Rib-transplant below to the right. Invading its medullary cavity from above is a tissue very rich in cells resembling connective tissue. To the left is hyaline cartilage, enclosed on both sides by spongy-bone trabeculae.

in the same way, show transplant and callus of almost the same appearance as the specimen excision 12 days earlier. (Fig. 19.) The callus-tissue contains more bone. The new growth of cancellous bone forms an irregular network with numerous large corpuscles; its Haversian spaces contain fibrous marrow. The cartilage-nuclei in general present a columnar arrangement, here and there the connective tissue exhibits transitions to osteoid tissue and bone.

Rabbit 5.

Operation 10/10,34: Extirpation of 11th and 12th right ribs. These were divided into four transplants, which were implanted paraspinally to the right on five vertebral arches, four spinous

processes being cut through at their bases. The transplants were 14, 15, 10 and 12.5 mm respectively in length. The lowest was boiled before insertion. 22/10: Healed by first intention, field of operation fixed, swollen.

X-rays, S: The three uppermost grafts show slightly blurred contours and somewhat reduced calcium content, the lowest has a well-defined contour and unchanged calcium content. The cut spinous processes lie free, parts of them dorsal to the grafts, which extend from the upper part of Th XII to the middle of L IV. The total length of the grafts is 72 mm, of the three uppermost 54 mm. L II's body 17 mm.

Radiographs 5/11, 26/11, 12/12, 1934, and 7/1, 1935, show that grafts I—III are surrounded by callus and undergoing reconstruction into a bony bridge. Graft IV shows successive reduction in the calcium content and a somewhat blurred contour, but is not surrounded like the others by callus.

The rabbit was killed on 4/2,35, 117 days after the operation; the spine showed normal passive mobility.

X-rays, S; extension: From middle of Th XII to middle of L III a 62-mm-long, irregular bony bridge, thick cranially, thin caudally. Irregular rarefactions at the level of the interv. discs. Graft IV lies as a thin shadow dorsal to L IV. L II's body 19 mm.

The extracted specimen comprises Th X—L V. Th XII's spinal process is powerful. From here there extends a thick bony bridge caudally, covering the spinous processes and articular processes of the right side to and including L III. On a level with the interv. discs Th XII—L I and L II—III the bridge is traversed by broad bands of cartilage, at the level of the interv. disc L I—II by a narrow, cartilage-lined, V-shaped fissure with its point directed caudally. This fissure increases in width on flexion of the specimen. Graft IV was not united with the spinal column and was removed with the soft parts.

Rabbit 29.

Operation 10/10,34: Extirpation of the 10th and 11th right ribs, one of which was divided into three pieces. The transplants

were implanted paraspinally, the whole rib caudally, on five vertebral arches, the corresponding spinous processes being cut through at their bases. The ends of the transplants were furnished with metal pins.

22/10: Healed by first intention. Considerable fixation at the site of operation.

X-ray, S: Grafts extend from body of Th X to lower edge of L II; their total length 76 mm; contours somewhat blurred. L II's body 17 mm

Radiographs 5/11, 26/11, 12/12, 1934, and 7/1, 1935, show progressive reconstruction of the bony bridge.

The rabbit was killed on 14/1,35, 96 days after the operation. At this time the spinal column was freely mobile, actively and passively.

X-ray; S, extension: Irregular bone-shadows are seen, dorsally to the arches of Th X—XII, on the site of the grafts. From L I's spinous process caudally, at the site of the grafts, there appears a broad, irregular bone-shadow with two dorsal processes separated from L II's arch by a rarefaction. The total length of the bony bridge is 82 mm.

The extracted specimen comprises Th IX up to and including L III. In its upper part, to the right of the midline, lies a powerful bony bridge, fused with the right upper articular and the spinous processes of Th X, XI and XII. The bridge is separated from Th IX's spinous process by a sagittal strip of cartilage containing a central fissure. The slight movements possible between Th IX and X cause the width of the fissure to vary. At the level of the intervertebral disc Th X—XI the bony bridge shows a break that allows movements between these vertebrae; at the level of the disc Th XI—XII it has a similar wide break. A narrow, irregular bony bridge runs caudally from the right aspect of Th XII's spinous process, but free of the latter. It is firmly united to the right surfaces of L I's and L II's spinous process as well as L I's arch and right upper articular process, and runs out into a point above L III's spinous process. Th XII and L I are movable against each other, as are also L I and L II. Movements between L I and L II disclose that the bone-bridge

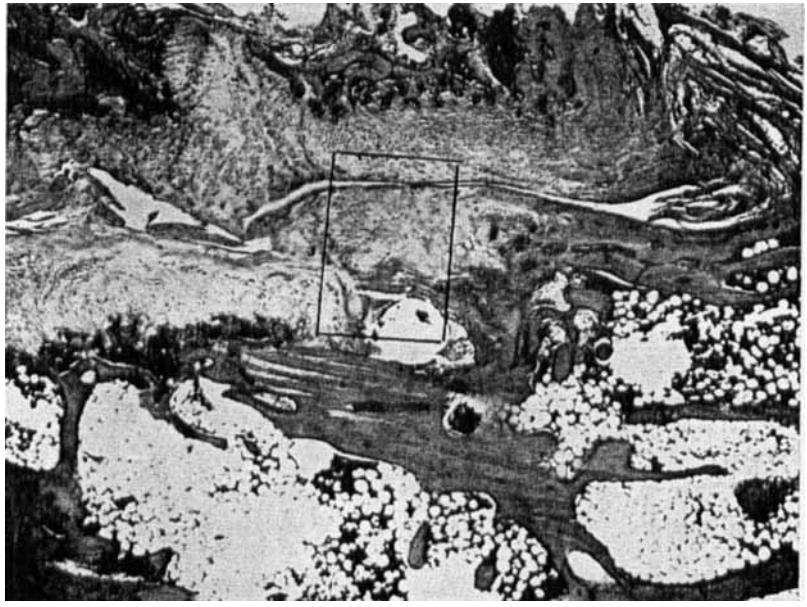

Fig. 20.

R. 29. I, section 85. Staining: Weigert's htx-van Gieson. (× 17). Frontal section through upper end of bony bridge. Below is the upper tip of graft I with the round defect left by indicator 1. The graft-remnant is covered by nucleus-stained spongy bone. Above is a broad irregular band of hyaline cartilage, traversed by a central fissure.

is fixed to L I and in its entirety movable as against the articular process and arch of L II.

The arches were sawn off the vertebral column, divided into three parts, embedded in celloidin, and cut serially into frontal sections. Staining: Htx-eosin and Weigert's htx-van Gieson.

Summary of the histological examination: Specimen I comprises the arches of Th IX, X and XI as well as the tip of Th XII's upper articular process. The plane of section is chiefly frontal with a slight inclination to the right. That part of the bony bridge which is attached to Th X's right upper articular process and arch encloses remnants of graft I. Indicator 1 is located medially in Th X's right upper articular process, indicator 2 in the bone-bridge corresponding to the

lower part of Th X's arch. (Fig. 20. Fig. 21). Around and between the indicators are non-nucleated remnants of graft I. The bony bridge is separated from Th IX's lower articular process and arch by a broad, irregular, longitudinal band of cartilage

Fig. 21.

R. 29. I, section 85. Staining = Fig. 20. (× 100).
Below to the left the round defect left by indicator 1, its upper border formed by narrow bundles of non-nucleated graft-bone. Irregular cartilage with proliferating nuclei occupies the upper part of the picture. The fissure-shaped cavity is seen at the top.

with a central cavity (see Fig. 21). The right intervertebral joint Th X—XI presents a normal picture; the bony bridge is intercepted at the level of the intervertebral space Th X—XI by a broad gap filled with connective tissue. Indicator 3, placed at the upper end of graft II, is to be found in a graft-remnant

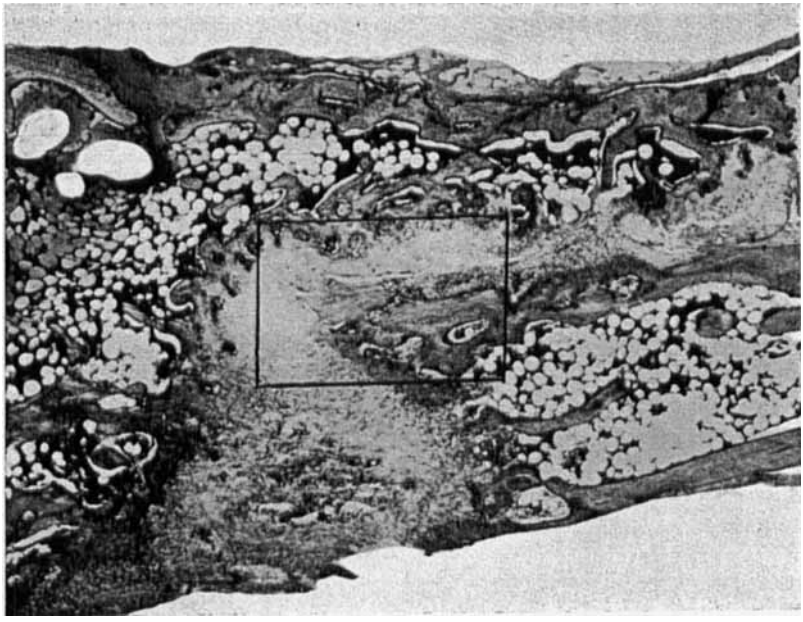

Fig. 22.

R. 29. II, section 105. Staining: Weigert's htx-van Gieson. (× 17). Frontal section through bony bridge at level of intervertebral disc L I-II. The bony bridge is traversed by an angular cartilage-band. In the centre are graft-remnants, the rest of the bridge consisting of nucleus-stained cancellous bone.

within the bony bridge in the upper part of Th XI's arch, indicator 4, placed in the lower end of graft II, is situated in the bridge at the lower part of the same arch. Between and around these indicators there are patches of non-nucleated bone. The bridge also shows a broad defect at the level of the intervertebral space Th XI—XII. From the medial aspect of Th XII's right upper articular process streaks of non-nucleated bone run obliquely to the right caudally; cranially in this graft-remnant lies indicator 5. Medially to L I's right upper articular process, separated from the latter by cartilage, lies an annular graft-remnant containing indicator 7. The remnants of this lowest graft, a whole rib-bone, continue over the arches of L I and L II down to L III's spinous process, though without union to the

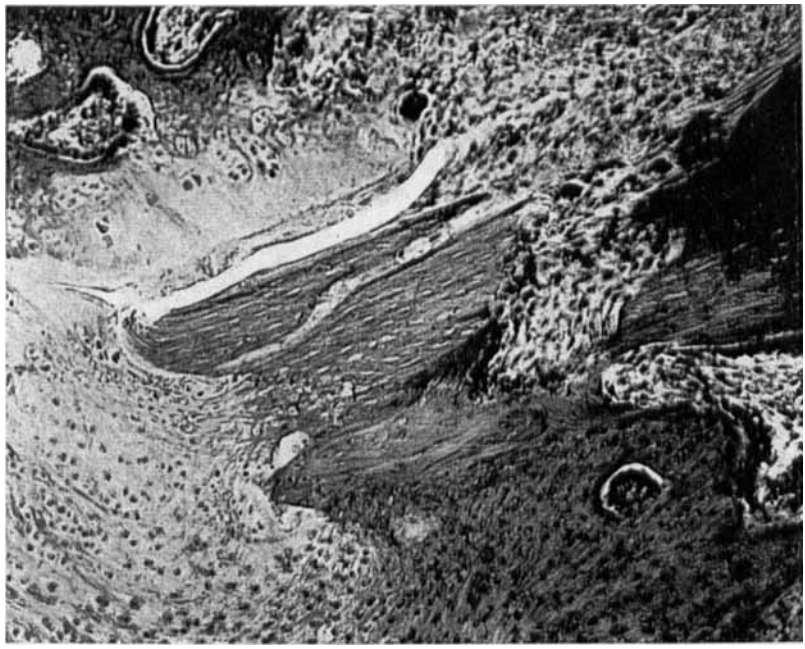

Fig. 23.

R. 29. II, section 111. Staining: Weigert's htx-van Gieson. (× 100). Detail picture from cartilage-band Fig. 22. In the centre, partly bordered by the cartilage, partly by a small cavity, is a non-nucleated graft-fragment. Below and to the right are bone, osteoid and connective tissue.

latter. Just above the intervertebral space L I—II the graft-remnant and the bony bridge are traversed by an angularly bent band of cartilage. (Fig. 22, Fig. 23, Fig. 24.) The bony bridge has a broad union with the arch of L I, continues beyond the intervertebral space L I—II to a point just above the tip of L III's upper articular process, and in its lowest tip contains indicator 8. In this its lowest part the bridge contains large, non-nucleated graft-remnants, which are surrounded and invaded by nucleus-stained bone. Between the bridge and L II's arch lie large masses of cartilage and connective tissue, no signs of osseous union between bridge and arch of L II.

Rabbit 21.

Operation 10/10,34: Extirpation of the 11th and 12th right ribs, which, divided into six pieces, were implanted paraspinally to the right on five vertebral arches, the corresponding spinous processes being cut through at their bases. The transplants were

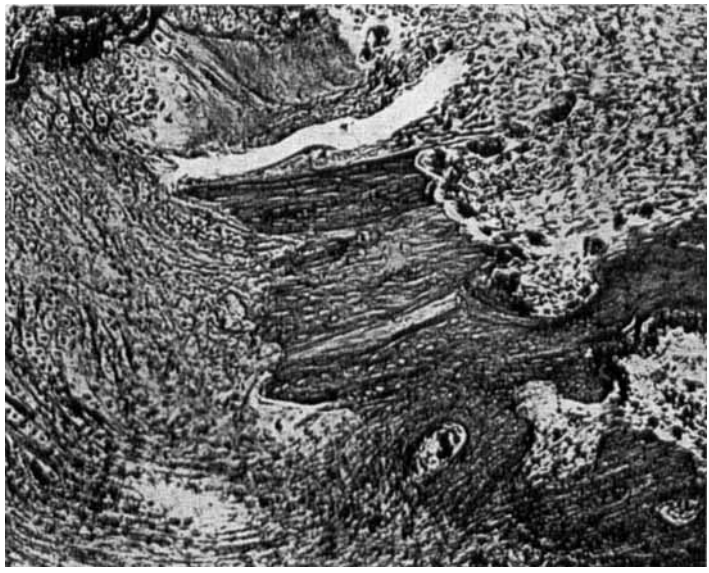

Fig. 24.

R. 29. II, section 113. Staining: Weigert's htx-van Gieson. (× 100). To the left fibro-cartilage, in the centre a non-nucleated graft-remnant. The right contour of the graft-remnant is notched by Howship's lacunae containing osteoclasts.

marked at each end with metal indicators. 22/10: Healed by first intention. Field of operation swollen, fixed.

X-rays, S: The grafts show sharp contours; they extend from upper part of Th XII to middle of L IV. The five upper grafts have an aggregate length of 61 mm. L II's body 17.5 mm. Radiographs 5/11, 26/11, 12/12, 1934, and 7/1, 1935, show the grafts surrounded by callus under successive transformation into a

bony bridge. The rabbit was killed on 4/2/35, 117 days after the operation.

X-rays; S, extension: Irregular bony bridge dorsal to the arches of Th XII—L III. Its length (corresponding to the five upper grafts) is 70 mm. Dorsally above L II is a free bony arch; to the ventral side of the arch are two indicators.

The excised specimen consists of Th XI to and including L IV. The spinous process of Th XII deviates to the left, is broad and thick. A bony bridge stretches from the medial aspect of Th XII's right upper articular process to the lower part of L I, covering spinous and articular processes. From the medial aspect of L II's right upper articular process to L III's spinous process there extends a 17-mm-long osseous bar without attachment in the arch and consisting of bone and cartilage. To the ventral side of this bar, the vertebral arch has a narrow ridge of bone, in which indicators 7 and 8, which had been placed in each end of graft IV, are firmly fixed in the bone. The spinous process of L II is missing, that of L III is powerful; the furrow between the latter and the articular process of the right side is filled up with bone. From the spinous process a narrow bony ridge continues caudally in the medial line. (On L IV there is a similar ridge, though narrower.) The upper bony bridge shows a mobile break at the level of the intervertebral disc Th XII—L I. The connections between L I—II, L II—III and L III—IV are also mobile. Indicator 4, inserted in lower end of graft II, and indicator 5, in upper end of graft III, are both situated firmly in the bony bridge on L I's arch. All of the specimen excisions were embedded in paraffin and stained with Htx-eosin and Weigert's htx-van Gieson.

Specimen excision *a:* Transverse section of the whole spine at the level of the intervertebral disc Th XI—XII. The section strikes the left dorsal corner of Th XI's body and cuts through the markedly calcified apophyseal cartilage, in the dorsal edge of which lively endochondral ossification appears to be in progress. On the right side the intervertebral disc is cut. Both the intervertebral joints cut by the section present a normal picture. At the osteochondral junction, the articular cartilage of the

articular processes contains nuclei arranged in columns; at the osseous margin, bands of new-formed bone are seen around the medullary spaces. The apophyseal cartilage in Th XII's right upper articular process is cut by the section. The rib-graft on the vertebral arch is cut transversely. Its outer contour is irregular with numerous Howship's lacunae, some with osteoclasts, while very small bands of new-formed bone are present. The structure of the graft is irregular, solitary empty lacunae are visible, but otherwise the corpuscles show normal shape and are well stained. The periosteum is rich in cells, with bands of osteoblasts close to the bone. The medullary cavity of the graft contains myeloid marrow, the Haversian canals contain fibrous marrow, vessels and bands of osteoblasts. No osseous union between graft and arch is visible in the section.

Specimen excision *b:* The specimen comprises a transverse section of the entire bony bridge, which extends from the middle of Th XII to the middle of L I, corresponding to the lower part of graft I and the upper part of graft II. Macroscopically the specimen is composed of two pieces of bone, movable against one another and separated by a band of soft parts that runs from the right cranially to the left caudally. Serial frontal sections: The sections furthest dorsally show cranially a wide, irregular area of cancellous bone with stained corpuscles and myeloid marrow. Within this bony area is a patch of cortex abruptly cut caudally, probably the lower tip of graft I. Caudally there is a small, irregular area of bone with stained corpuscles and myeloid marrow. Between the fragments lies a 3-mm-broad strip of connective tissue poor in cells and traversed by irregular cavities. Osteoblasts and bands of new-formed bone may be seen at the margin of the bone. On more ventral sections no fragments of graft I are traceable. The right intervertebral joint Th XII—L I adjoins the right side of the connective tissue band.

Specimen excision *c* comprises that part of the bony bridge which is immediately caudal to *b*, corresponding to L I's arch at the site of the interspace between grafts II and III, and the indicators 4 and 5 in the bony bridge. Serial frontal sections were cut.

The whole specimen consists of cancellous bone of irregular structure. The nuclear staining is good, only an insignificant number of empty lacunae are present. The bone marrow is myeloid, in solitary Havèrsian canals it is fibrous. Lacunar absorption occurs in small areas. The indicators are surrounded by rather coarse trabeculae of cancellous bone; within small areas here the lacunae are empty. At the site of the interspace between grafts II and III, between indicators 4 and 5, the osseous structure exhibits no notable irregularities and no break. Graft-remnants are not visible.

Rabbit III. Weight 1050 gm.

Operation 23/3,36: Exarticulation of the right forearm. Diaphyses of radius and ulna freed from soft parts, epiphyseal cartilage thoroughly removed. Radius-diaphysis 35.5 mm long, ulna-diaphysis 39 mm. Metal marks (silver wire) drilled into ends of both grafts. The grafts were implanted paraspinally in the thoracolumbar region, the radius cranially and ulna immediately caudally to the radius. The wounds healed by first intention, the rabbit grew considerably, but had difficulty in moving. It was killed on 16/6,36, 84 days after the operation.

X-rays; S and V-D: Two grafts paraspinally to the left, radius from upper part of Th IV to middle of Th X, ulna from upper part of Th XI to lower part of L I. Upper part of radius surrounded by large deposits and united to the spinous processes of Th V—VIII. Upper part of ulna surrounded by small deposits, appears to be free of Th XI and, at the level of intervertebral disc Th XII—L I, is traversed by a narrow zone of rarefaction. Below this rarefaction, at the site of the caudal part of the ulna-transplant, there is an irregular callus-shadow, without graft-fragments, containing the caudal indicator of ulna, the distance between the grafts is 10 mm, Th X's broad spinous process occupies the middle of the gap.

Postmortem specimen: Th IV's spinous process long, downward bent, free of radius-transplant. Latter movable as against Th V, firmly fixed to Th VI—VIII, and movable as against Th

IX. Gap between radius and ulna occupied by powerful spinous process of Th. X. Upper end of ulna extends to lower edge of Th X, its upper part, which has preserved its shape and shows insignificant deposits, is movable as against Th XI and solidly united to Th XII's arch and spinous process. At the level of the intervertebral disc Th XII—L I the graft is embedded in

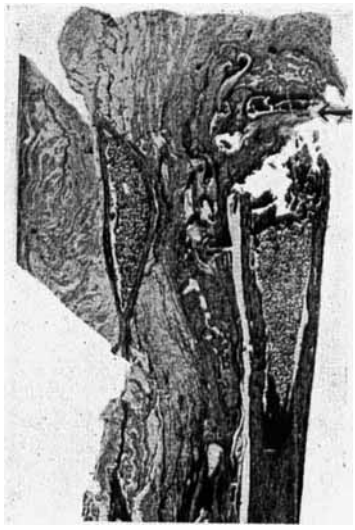

Fig. 25.

R. III, section 109. Staining: Weigert's htx-van Gieson. (× 12). Frontal section through bony bridge at level of Th X-XI. The cranial part of the ulna-graft appears to the right, its cranial indicator is marked by a metallic precipitate, cranially enclosed by deposit. To the left of the ulna-graft is a deposit. Cranially the bone-marrow is of myeloid type, further caudally there is dark-coloured necrotic substance in the marrow-cavity.

callus-substance with a mobile interruption. There is a powerful bony bridge on the left side of L I's arch. The distance between metal marks in the ulna is 35 mm. In the area of the radius-graft the bony bridge showed no interruption, and accordingly this part was not histologically examined. The ulna-graft aggre-

gate was embedded in celloidin and cut into a series of frontal sections. Staining: Htx-eosin and Weigert's htx-van Gieson.

Microscopical examination: The cranial end of the ulna-graft with its cranial metal mark lies at the level of the sp. pr. of Th

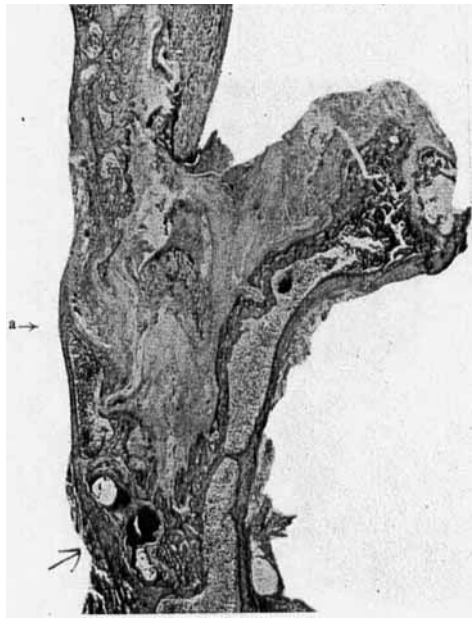

Fig. 26.

R. III, section 125. Stain: Htx-eosin. (× 12).

Frontal section at level of Th XII-L I. At top to the right is the ulna-graft but little changed, chiefly necrotic; to the left of this are deposits. L I's left upper articular process is large and projecting to the right, is connected downwards (caudally) with the bony bridge. At the level of the process the specimen is traversed by a band of connective tissue enclosing a horseshoe-shaped graft-remnant. *a.* The bony bridge is intact caudally to the connective tissue, consists of cancellous bone that contains a metallic precipitate at the site of the caudal indicator of the ulna-graft. There are no graft-remnants within this area.

XI, but without bony union with the latter. The fragment is surrounded by deposits and has been divided from the large more caudal ulna-graft. (Probably fractured during preparation, no

reaction at the fracture surfaces). The cranial two-thirds of the main ulna-graft present the picture of a tubular bone with a mostly necrotic cortex containing empty lacunae and pale osseous substance. The Haversian canals here and there contain bundles of nucleus-stained fibrous bone-marrow as well as small vessels. (Fig. 25.) Around the canals, on the subperiosteal surface and also within the medullary cavity, small areas of apparently new-formed, nucleus-stained bone are noticed. The medullary cavity is filled partly with nucleus-stained myeloid marrow and adipose marrow, partly with dark-stained masses devoid of cellular structure. Around the graft, though without visible osseous union with it, lie irregular deposits of nucleus-stained cancellous bone. These deposits have no visible bony union with Th XI, but merge directly into Th XII's processes and arch. The graft breaks off abruptly at the level of the intervertebral disc Th XII—L I, and the deposits are traversed by a broad, transverse strip of connective tissue that contains larger and smaller necrotic fragments of bone. Caudal to the connective tissue strip, within the area for L I's arch, lies a powerful bony bridge to the left of the midline, fused with the articular process and arch of L I. The bony bridge is here built up of irregular nucleus-stained cancellous bone; no graft-remnants can be seen. The caudal metal indicator of the ulna-graft is found about 5 mm cranially to the intervertebral articulation between L I—II. (Fig. 26.)

GENERAL DISCUSSION

In all the rabbits the untreated grafts were soon surrounded by callus tissue, which was found to contain connective tissue, cartilage, and bone, as early as 16 days after the operation. The grafts became fixed to the vertebral arches through the callus tissue. A powerful paraspinal bridge of bone in course of time developed at the site of the grafts. In several cases this bony bridge, or parts of it, increased in length during the time of observation. This increase was evidenced by measurements on radiographs as well as on anatomical specimens from the ani-

mals killed: when the experimental animal was killed the bridge was longer than the aggregate length of the grafts measured at the operation and on the earliest radiographs. In a couple of cases in which the metal indicators had preserved their position in the bone, longitudinal growth within the bony bridge could be inferred from the increased distance between the indicators. The greatest growth in length was observed in rabbit 31, the aggregate length of grafts on the radiograph taken seven days after the operation being 65 mm and the length of the bony bridge on a radiograph taken 62 days after the operation being 80 mm. The distance between the two metal marks had simultaneously increased from 54.5 to 63 mm. On the radiographs it is possible to follow the formation of an irregular bony bridge with numerous defects, most of them located at the level of the intervertebral discs, some assymetrical in relation to these. Some grafts had fractured while being prepared. A couple of such fractures had consolidated, these having been located at the level of the centre of a vertebral body. Defects were formed at the site of other primary graft-fractures of this kind. (Rabbit 32.) In two cases, rabbits 39 and 5, one of the transplants was killed by boiling before the operation. These boiled transplants did not become surrounded by callus or united with the vertebral arches. In rabbit 39 the boiled transplant lay free in the soft tissues 98 days after the operation, its shape and size unchanged, its surface smooth without deposits.

On macroscopical examination the excised specimens of the spine showed paraspinal bony bridges of varying width and thickness, including the spinous processes and the articular processes of the one side. Some of the inserted metal marks had disappeared, others could be found in the soft tissues, others were seated firmly in the bony bridge. The vertebrae included in the specimens showed normal or almost normal mobility between themselves, a fact that is also to be seen from lateral views of killed rabbits in which the spine was either flexed or extended. (Fig. 5A. 5B). There was a rather solid union between Th IX and X in rabbit 39, and between Th VI—VIII in rabbit III. All of the bony bridges exhibited numerous breaks

and defects of varying widths. Movements between the originally fixed vertebrae were rendered possible by the bridge-defects, most of which were at the level of the intervertebral discs. The different segments of the bony bridges were solidly united with the arches and processes of the vertebrae. In some cases the defects had the character of broad gaps filled with connective tissue (R. 39, Th XI—XII; R. 34, Th XI—XII; R. 21, Th XI—XII; R. III, Th XII—L I). In other cases the defects resembled an irregular cartilaginous disc traversing the bony bridge, irregular cavities often occupying the centre of the disc (R. 32, Th XI—XII and L I—II; R. 29, Th IX—X). In still other cases the bone-defect had developed into a joint with an articular space, articular cartilage and a capsule lined with endothelium (R. 32, Th XII—L I; R. 35, Th XI—XII). In certain cases the new-formed articular cavity appeared to be connected with the intervertebral joints of one or both sides (R. 31, L I—L II; R. 38, L II—III; R. 5, L I—II). The width of the articular spaces varied in response to movements between the vertebrae. In some cases a part of the bony bridge had solid union with a vertebral arch and extended without interruption over to another arch, from which it was separated by cartilaginous or connective tissue substance, and against which it was movable (R. 34, caudal part of bony bridge movable as against L I's arch; R. 32, caudal part of bony bridge attached to L III's arch and movable as against L II and L IV; R. III, upper part of ulnar graft movable against Th XI's arch). These irregular defects allowed movements between the vertebrae to the same extent as did the defects located at the level of the intervertebral discs.

HISTOLOGICAL EXAMINATIONS

In rabbits 34, 31 and 32, in which longitudinally split radius-transplants had been inserted, and in rabbit III, in which radius- and ulna-transplants had been inlaid, the graft-remnants were readily discerned by their strictly lamellar structure and their abundance of compact bone. The graft-remnants observed

in these animals showed a pale colour and empty bone-lacunae. The rib-grafts possessed a less characteristic structure, with thinner and more irregular cortex. A specimen excision taken 16 days after the operation from the bony bridge in rabbit 37 disclosed a rib-graft with empty lacunae and, in the medullary cavity as well as the Haversian canals, bone-marrow that was necrotic and studded with haemorrhages. At the ends of the graft a tissue that was rich in nuclei and had the structure of fibrous bone-marrow grew into the marrow cavity and the Haversian canals and spaces. The graft lay embedded in callus tissue composed of richly nucleated connective tissue, fibrous cartilage, hyaline cartilage, and irregular trabeculae of osteoid and new-formed bone with numerous large corpuscles. The bone trabeculae were directly united with the necrotic graft. The cartilage, which was present in greater abundance than in any other experimental animal, lay more especially around the gap between the grafts. On the specimens from the same animal 16 and 28 days after the operation, the cartilage-nuclei lay arranged in irregular columnar rows, and at the junction with the bone a lively endochondral ossification appeared to be in progress. The amount of new-bone formation appeared larger and that of cartilage less in the specimen excised 28 days after the operation. In rabbit III there remained, 84 days after the operation, considerable necrotic remnants of the cranial part of the ulna-graft, this part being movable in relation to Th XI's arch and firmly attached to Th XII's arch, while its caudal part was entirely absorbed and replaced by a new-formed bony bridge that had fused with L I's arch. In rabbits 38 and 29 pale graft-remnants with empty lacunae were found in various parts of the specimens 70 and 96 days respectively after the operation. In rabbit 21 there were no graft-remnants after 115 days; the bony bridge here showed signs of being under reconstruction. Rabbit 35 showed no graft-remnants 105 days after the operation. In rabbits III and 21 the defects of the bony bridge contained no cartilaginous tissue.

As a rule frontal sections afforded a better topographical survey than sagittal ones. The bony-bridge defects that were

filled with connective tissue did not present any specific picture. These defects coincided in rabbits 29 and 34 with the joints between the grafts. In rabbit 21 a defect of this kind was found at the site of graft II. The defects in rabbit 32 at the level of the intervertebral discs Th XI—XII and L I—II, and those in rabbit 29 at the level of the intervertebral space Th IX—X, had the character of cartilaginous discs containing irregular central cavities. There was a typical formation of an articulation in rabbit 32 at the level of the intervertebral space Th XII—L I. The articular cartilage here showed wide-spread calcification and active osseous new-growth bordering on live cancellous bone. Necrotic graft-remnants invaded the articular cavity from both sides. The nearthrosis in rabbit 38 was seen to communicate with the right intervertebral joint L II—III; the articular surfaces were covered with a tissue rich in cells resembling connective tissue. In rabbit 34 the tip of the lower graft was surrounded by cartilage and connective tissue and was movable as against L I's arch; the cranial part of the graft was osseously united to Th XII's arch. The bony bridge in rabbit 29 had solid union with L I's arch; at the level of the caudal part of the arch it was traversed by an irregular strip of hyaline cartilage. Between the powerful bony bridge and L II's arch was a layer of cartilage and connective tissue. In cases where two transplants had been placed end to end at the level of the middle of a vertebral body, the bone-defects had entirely consolidated (R. 32: Fig. 15, test excision *c*). On the surface adjoining live bone the cartilaginous bands as well as the cartilage of the nearthroses, in particular in the cranial and caudal parts, showed signs of proliferation with cartilage-nuclei arranged in columns against the line of ossification. Here the medullary spaces were filled with fibrous marrow and lined with osteoblasts. They were open towards the cartilage and surrounded by bands and trabeculae of osteoid and irregular bone containing numerous large corpuscles. At a further distance from the cartilage-line the bony trabeculae in several places enclosed remnants of cartilage matrix. (Fig. 2, Fig. 12). New-formed bone could be observed around the vessels that

perforated the hyaline cartilage. (Fig. 10). At the junction between necrotic bone without vessels and cartilaginous patches there was no new-bone formation. The articular cartilage of the intervertebral joints showed proliferation, calcification and endochondral ossification at the margin towards the bone.

CONCLUSIONS

In his work "On defects in the bone-graft after Albee's operation for tuberculous spondylitis" the author points out that defects of the kind in question have their site at the level either of the tuberculous destruction of the vertebral bodies or of an uninjured intervertebral union peripheral to the destruction, that they are produced by the strain of bending and tension acting upon the graft or upon the bony bridge formed around this graft at the level of the axes of spine movements, and that they have the character of acute or insidious fractures. The defects observed in the bony bridge formed around the grafts placed in the experimental animals are in most cases situated at the level of the axes of motion running through the intervertebral discs, i.e. at those points which are exposed to the greatest stress from movements of the spinal column. The fracture-defects thus arising restore to the fixed portion of the spine a normal or almost normal mobility. Primary transplant defects and fractures, if placed level with the centre of a vertebral body, will in some cases consolidate. The view advanced by the author in the work cited above—that defects in an Albee-transplant or in the bony bridge constructed around the latter are produced by mechanical stress called forth by movements of the vertebral columns—has received further corroboration from the animal experiments described in the present work.

The author's histological examinations confirm the present view that, in rabbits, transplanted autoplastic bone to a very great extent indeed undergoes necrosis and is secondarily replaced by living, new-formed bone. Those defects which arise in the bony bridge as a result of the movements of the animals are filled up with connective tissue, with cartilaginoid tissue,

or with typical hyaline cartilage. At times the defects develop into pseudarthroses with a central cavity, in some cases into true nearthroses. Sometimes these nearthroses are connected with the intervertebral joints. On the boundary of the living bone of the bony bridge, in particular cranially and caudally, the cartilage shows active proliferation with signs of endochondral new growth of bone. The junction between bone and cartilage here presents the appearance of an irregular zone of ossification in an epiphyseal line. Against this zone there is occasionally seen a new-formed osseous layer of not inconsiderable width and of the same appearance as the layer of bone which was observed in a boy of eight years and which has been illustrated in Fig. 6 in the author's above-cited work.

In several of the experimental animals a growth in length of the bony bridge is observed. It has not been possible by measurements to determine the spot at which this growth takes place. In several cases the bony bridge is found to contain long, coherent graft-remnants with interruptions at the defects of the bridge. Longitudinal growth of necrotic bone is excluded, interstitial growth of bone in the completed bony bridge appears extremely improbable. The histological investigation shows that in the experimental animals zones of growth with endochondral new-bone formation occur in the cartilage-filled defects of the bony bridge. It is accordingly assumable that in the experimental animals growth in the length of the bony bridge depends on an endochondral ossification in cartilage-filled defects in the bony bridge. In a girl aged eigth years a zone of growth with endochondral new-bone formation has been observed at the tip of the bony bridge. From what has been adduced above, therefore, it is evident that in a growing individual a paraspinal bony bridge that has developed around an autoplast is capable of longitudinal growth both at possibly arising transverse defects and at its terminal points.

ZUSAMMENFASSUNG

Verf. hat an einer Anzahl halbwüchsiger Kaninchen eine paraspinale Transplantation von autoplastischem Knochengewebe vorgenommen. Das Knochentransplantat war in kurzer Zeit von Callusgewebe umgeben, welches es an die Wirbelbögen und den Dornfortsätzen fixierte. In der solcherart entstandenen paraspinalen Knochenbrücke traten nach einiger Zeit quer verlaufende Defekte auf. Die auf operativem Wege fixierte Rückgratspartie bekam auf diese Weise wieder eine fast normale Beweglichkeit. Die meisten Defekte liegen in gleicher Höhe mit den Zwischenwirbelscheiben und den durch diese verlaufenden Bewegungsachsen des Rückgrates. Dieser Umstand stellt eine weitere Stütze dar für die in einer früheren Arbeit geäusserte Ansicht des Verfassers, dass Defekte in einer paraspinalen Knochenbrücke von mechanischen Faktoren hervorgerufen werden, hauptsächlich von der Biegungs- und Zugbelastung bei den Bewegungen des Rückgrates.

Die histologischen Untersuchungen des Verf.s bestätigen die übliche Auffassung, dass eine transplantierte autoplastische Knochensubstanz bei Kaninchen zum grössten Teil nekrotisiert und von neugebildetem Knochengewebe ersetzt wird. Bei den meisten Versuchstieren findet man langgestreckte, kernlose Knochenbögen an der Stelle des Transplantats wieder. Die obengenannten Defekte in der Knochenbrücke sind von Bindegewebe, knorpelähnlichem Gewebe oder typisch hyalinem Knorpel ausgefüllt. In gewissen Fällen haben sich Pseudoarthrosen oder wirkliche Nearthrosen im Knorpel ausgebildet. Insbesondere kranial und kaudal im Knorpelbande zeigt der Knorpel Zeichen von Proliferation, Degeneration mit Verkalkung und reichliche Neubildung von enchondralem Knochengewebe, und die Knochen-Knorpel-Grenze zeigt das Bild einer unregelmässigen Epiphysenfuge. Verf. hat das gleiche Phänomen in einem Defekt einer paraspinalen Knochenbrücke bei einem 8jährigen Knaben beschrieben. Es wird ein weiterer analoger Fall mitgeteilt; bei einem 8jährigen Mädchen wird die Spitze der Knochenbrücke von einer Schicht hyalinen Knorpels bedeckt. An der Grenze

gegen den Knochen hin zeigt diese Knorpelschicht Zeichen einer enchondralen Knochenneubildung.

Bei den Versuchstieren konnte ein Längenwachstum der paraspinalen Knochenbrücke festgestellt werden. Die Stelle dieses Längenwachstums konnte jedoch durch die ausgeführten Messungen nicht festgestellt werden. Ein Längenwachstum von nekrotischem Gewebe ist ausgeschlossen, ein interstitielles Wachstum nach Havers innerhalb der voll ausgebildeten Knochenbrücke erscheint äusserst unwahrscheinlich. Durch histologische Untersuchung konnten Wachstumszonen in den Defekten der Knochenbrücke nachgewiesen werden. Es erscheint aus diesem Grunde wahrscheinlich, dass das Wachstum der Knochenbrücke von einer enchondralen Knochenneubildung in diesen Zonen bedingt ist. Wachstumszonen von gleicher Art sind bei zwei 8jährigen Kindern konstatiert worden, das eine Mal in einem Defekt einer paraspinalen Knochenbrücke, das andere Mal in der Spitze einer solchen Brücke. Ein Längenwachstum einer paraspinalen Knochenbrücke in ihrer Gesamtheit ist vom Verf. beim Menschen nicht beobachtet worden.

SUMMARY

On a series of half-grown rabbits the author has made paraspinal transplantation of autoplastic bone. After a short period the transplants were surrounded by callous tissue, which fixed them to the arches and the spinous processes. After some time transverse defects appeared in the paraspinal bony bridge thus formed. In this manner the part of the spine immobilized by operation regains an almost normal motility. The majority of the defects are situated on level with the intervertebral discs and at the site of the axes of motility which have their seat here. This phenomenon is a further support of the view expressed by the author in a previous work: The defects in a paraspinal bony bridge are brought about by mechanical factors, mainly the loading of bending and tension due to the movements of the spine.

The histological examinations made by the author verify the common opinion that in rabbits transplanted autoplastic os-

seous tissue mostly necrotizes and is replaced by new-formed bone. In the majority of the experimental animals long bands of osseous tissue without nuclei are found at the site of the transplant. The above-mentioned defects in the bony bridge are filled up by connective tissue, tissue resembling cartilage or true hyaline cartilage. In some cases pseudarthroses, or true nearthroses have been formed in the cartilage. Especially in the cranial and caudal parts of the cartilaginous bands there are signs of proliferation, degeneration with calcification and ample formation of enchondral bone, the bone-cartilage limit presenting the picture of an irregular epiphyseal line. Previously the author has described the same phenomenon in a defect in the paraspinal bony bridge of an eight year old boy. Another analogous case is reported: In an eight year old girl the point of the bony bridge was covered by a layer of hyaline cartilage. At the limit of the osseous tissue this layer of cartilage presented signs of enchondral new-formation of bone.

In the experimental animals it was definitely established, that the bony bridge had increased in length. It has, however, not been possible by the measurements carried out, to determine the site of this growth. An increase in length of necrotic bone is out of the question, interstitial growth like Havers' within the ready formed bony bridge seems very unlikely. Histological examination has shown zones of growth in the defects of the bony bridge. Based on this it seems likely that the growth of the bony bridge is due to enchondral new-formation of bone in these zones. Zones of growth of the same kind were found in two children of eight years, in one case in a defect in a paraspinal bony bridge, in the other case at the tip of such a bridge. Increase in length of the whole paraspinal bony bridge has not been observed by the author in man.

RÉSUMÉ

L'auteur a pratiqué une transplantation paraspinale d'os autoplastique chez un certain nombre de lapins mi-adultes. Au bout de peu temps la transplantation osseuse se trouva entourée

de tissu callus qui la fixa à l'arc et à l'apophyse des vertèbres. Il apparut, après un certain temps, des défectuosités traversant le pont osseux paraspinal ainsi formé. La partie de la colonne vertébrale fixée par voie opérative reprend de la sorte une mobilité à peu près normale. La plupart des défectuosités constatées sont situées au niveau des disques intervertébraux, atteignant par conséquent les axes de mobilité de la colonne vertébrale. Ce fait constitue une nouvelle preuve à l'appui de l'opinion énoncée par l'auteur dans un travail antérieur, à savoir que les défectuosités d'un pont osseux paraspinal sont provoquées par des facteurs mécaniques, principalement sous l'effet de la flexion et de la traction, lors des mouvements de la colonne vertébrale.

Les recherches histologiques de l'auteur confirment l'opinion généralement admise que la majeure partie de la substance osseuse autoplastique transplantée chez les lapins se nécrose et qu'elle est remplacée par une nouvelle formation osseuse. Chez la plupart des animaux d'essai, on a retrouvé à l'endroit de la transplantation de longues parties osseuses dépourvues de corpuscules. Les défectuosités précitées du pont osseux sont remplies par du tissu conjonctif, du tissu d'apparence cartilagineuse ou du cartilage de caractère hyaline typique. Dans certains cas, des pseudarthroses ou de véritables néarthroses se sont formées dans le cartilage. C'est notamment dans les parties craniennes et caudales que le ligament cartilagineux montre une tendance à la prolifération, à la dégénération avec calcification et une abondante nouvelle formation d'os enchondral; la limite de l'os cartilagineux a l'aspect d'une ligne d'épiphyse irrégulière.

L'auteur a antérieurement décrit le même phénomène d'une défectuosité dans un pont osseux paraspinal chez un garçonnet de 8 ans. Il communique encore un cas analogue, chez une fillette de 8 ans où le sommet du pont osseux est recouvert de cartilage hyaline. A l'endroit où elle touche à l'os, cette couche cartilagineuse montre des signes de nouvelle formation osseuse enchondrale.

Chez les animaux d'essai, on a pu constater un allongement du pont paraspinal. Il n'a toutefois pas été possible de déterminer, par des mesures, en quel endroit la croissance avait lieu.

Un accroissement de longueur dans un os nécrotique est impossible, un accroissement interstitiel à l intérieur d'un pont osseux entièrement formé, paraît très invraisemblable. Par des recherches histologiques, il a été possible de prouver dans les défectuosités d'un pont osseux des zones de croissance. Sur cette base, il semble donc probable que l'acroissement d'un pont osseux dans ces zones était conditionné par une nouvelle formation enchondrale. Des zones de croissance de la même espèce ont été constatées chez deux enfants de 8 ans, dans l'un des cas à l'endroit d'une défectuosité d'un pont osseux paraspinal, dans l'autre au sommet d'un pont de ce genre. L'auteur n'a pas observé de croissance dans l'ensemble d'un pont osseux paraspinal chez l'homme.

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