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CHANGES IN THE WHOLE-THICKNESS SKIN GRAFT BURIED IN TISSUE

EXPERIMENTAL STUDY

BY

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To my Wife

PREFACE

The subject of the present study was suggested by Professor K. E. Kallio, M. D., Head of the Orthopedic Clinic, University of Helsinki. He spent much time in following the progress of my work and gave most valuable directions and advice. I use this opportunity to express my warm gratitude to my former teacher.

My sincere thanks are due to Assistant Professor Martti J. Mustakallio, M.D., for expert guidance in various phases of the studies.

The animal experiments were made at the Institute of Anatomy, University of Helsinki. I thank Professor Göran Hjelmman, M. D., Head of this Institute, for allowing me to work there, and the former Head of the Institute, Professor Niilo Pesonen, M.D., who in the early stages of the investigation instructed me in the analysis of the histological preparations.

I owe thanks to Mrs. Irene Fristedt whose technical knowledge contributed to making the histological preparations come out successfully, and to Lector Aune Tuomikoski, Mag. Phil., for the translation into English.

I also wish to record my indebtedness to many colleagues who were helpful with advice and suggestions from which my work profited.

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Risto Kivilaakso

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INTRODUCTION

Repair of extensive tissular defects is often a difficult task for the surgeon. This is why methods are continuously being developed to solve the problem. In recent years there has been a tendency to repair defects of tissue such as large herniae by using dead material such as tantalum and perlon mesh. Though the organism does tolerate foreign bodies, they never become an organic part of it but form as it were a frame along which the new connective tissue developed by the organism grows to effect the ultimate repair of the defect.

A biologically-minded surgeon feels no particular inclination to use a dead substance, but prefers to transfer living tissue of the organism itself to fill up such a defect. Kirschner's method of implanting a fascial strip is well-known and much used everywhere. The drawback of the procedure is that only limited amounts of fascia are usually available and in obtaining it the donor site is weakened and damaged. The fascia, moreover, only tolerate stretching in the direction of the fibres; in any other direction, owing to its structure, it easily breaks up into strands (BENNINGHOFF 1931).

In recent years an increasing number of studies have been published on the use of disepithelialized skin or skin with epithelium for repairing such tissular defects. Clinically the matter seems to have been solved, for more and more comprehensive statistics show almost without exception good end results. Yet in the literature one finds only scanty and mainly superficial treatment of the histological aspect of the problem. Many experimental series contain some few specimens examined microscopically after varying intervals of time. I have not met a single study dealing systematically with the changes taking place in whole-thickness skin with epithelium, embedded in a tissular defect. With this in mind I have endeavoured to elucidate these processes by means of animal experiments.

GENERAL SURVEY OF THE LITERATURE

A. Clinical Use of the Cutis Graft

By the term "cutis graft" we understand in the present work a piece of skin from which the epithelial layer has been removed, implanted in tissue. Apparently the German Otto Loewe was the first to use this kind of material for the repair of tissular defects. In 1913 he described nine cases in which he had repaired a tendon defect or strengthened hernial plastics by means of a cutis graft. The results seemed encouraging in spite of one case which became infected, so that he continued with the method. In 1929 he published the results of different reparative measures performed on about 100 patients, such as treatments of post-operative herniae, repairs of torn joint ligaments, closure of an injured dura etc. From the end results, which were on the whole good, he concluded that cutis grafts healed and easily united with the tissue even in unfavourable circumstances, and gave it sufficient support.

Rehn started experimenting with cutis grafts without being aware of Loewe's work. He reported on his first results in 1914 and has since then consistently used this procedure except on patients requiring repair of post-operative or ventral hernia, also on those with recurrent inguinal hernia, excessive lateral motion of the knee joint, rupture of the tendon of m. biceps brachii, conditions of finger tendons requiring plastic operations etc. After making a thorough study of the procedure both in its clinical application and in animal experiments he had in 1931 come to the opinion that cutis is the best material for the repair of defects, since it answers best to the requirements of tissular regeneration and because its internal structure, which consists of markedly strong fibrous twine, is well suited to the functions of a transplant.

The Austrian Eitner during the First World War used cutis, fat, and fascia either separately or together to fill up different subcutaneous tissular defects in plastic operations. When reporting on his experience in 1920 he concluded that the use of cutis would guarantee more permanent results than those obtained with other filling material. Yet in his publication he does not mention any preceding workers. Some other plastic surgeons have also occasionally used cutis for repairing subcutaneous defects in tissue; for instance STRAATSMA (1932) repaired a saddle nose successfully by this method and considers it simple and serviceable.

The use of cutis grafts aroused no particular attention among surgeons until UIHLEIN published in the Archives of Surgery in 1939 the results of 104 cases operated upon since 1928. Among these cases were 15 wound infections, in 9 of which the end result was good, being poor only in 6. Four died of pneumonia. The whole series consisted of 65 cases of post-operative hernia, 11 cases of inguinal hernia, 9 of ruptures of the knee ligament and 20 other reparative operations. Eighty-four patients had presented themselves at a follow-up examination; for 70 of them the end result was good and for 14 poor.

After this the method began to gain ground rapidly in America. There CANNADAY, who was the first to publish his results, had used it in 14 cases by 1942, and in the following year in 37 cases. He became an eager advocate of the procedure and, when reporting in 1946 on the results of 120 cases, among which 3 of the patients had died in consequence of anaesthesia, pneumonia and shock, each of one of these causes, and in which only 2 severe infections had occurred with loss of a cutis graft in only one of them, he came to the same conclusion as REHN: "Cutis vascularizes quickly, takes easily and well and is gradually transformed into fibrous tissue. We have made use of cutis tissue whenever and wherever we would have used fascia lata in the past — and, we feel, with superior results".

In recent years an increasing number of workers have dealt with the use of cutis graft in papers published in different parts of the world, either reporting on results obtained or describing new ways of using it or technical improvements (PEER 1940, SCHULZE 1947, LAUBER and ARESIN 1947, MAY and SPANN 1948, v. BRANDIS 1950, BROWNE 1951). They have all without an exception been satisfied with the procedure, there have been no complications in the course of the healing process nor have the end results been accompanied by any.

Opinions differ to some extent among the users of cutis graft as to how thoroughly the epidermis should be removed. Loewe removed it only by scraping with a knife and some others also considered this enough (Giegerich 1951). In Rehn's opinion such scraping was apt to traumatize the transplant too much and, besides, it leaves behind an unnecessarily large amount of epidermal debris. He therefore removed the epidermis with a Thiersch knife along stratum papillare, so that point-like haemorrhages from dermal capillaries on the sectional surface show when the sectional surface is at a suitable depth. On this point several workers agree with him (Dantlo 1946, Bätzner 1949).

Swenson and Harkins (1943) first had recourse to the dermatome when removing the epithelium. Besides helping towards the removal of the epithelium completely at the same depth, the procedure made it possible to cover the skin defect of the donor site by an epithelial layer of even thickness. To obtain a cutis graft of equal thickness throughout and with a smooth surface so as to make it merge well with the surrounding tissue, Scola (1944) developed a special method in which a strip of cutis was first excised with a dermatome from the subcutis by leaving it fastened at the other end. After this the epidermis was removed by an excision in the opposite direction.

Yet Harkins (1945) demonstrated that some epidermal elements were always left behind in this kind of cutis graft, because sweat and sebaceous glands and hair follicles extend so deep into the cutis that all efforts to remove these epithelial remnants only resulted in thinning and weakening of the cutis without ensuring the complete removal of epithelial cells.

B. Clinical Use of the Whole-thickness Skin Graft

Mair (1945) who since 1938 had been using whole-thickness skin to strengthen hernial plastics considered the removal of the epidermis unnecessary. He thought that quantitative reduction of the epithelium did not guarantee its disappearance in the tissue; what was decisive was the implantation of the graft so as to provide tension. When reporting in 1946 on a series of 149 inguinal herniae all operated upon with the help of whole-thickness skin grafts, he found the possibility of a cystal formation negligible; in other respects the results were well comparable with those obtained at other clinics by the use of other methods.

MARSDEN (1948) described 163 cases of inguinal hernia, among which 136 operations had been followed for 12 months. The patients, most of whom had previously used a hernia belt, were poor operative objects. Surface infection was noted in 10 of these cases, in one a collection of sebaceous mass was suspected because of swelling. Recurrences took place in 9.8 per cent of the cases, more frequently than in MAIR's series.

STRAHAN (1951) reported on 413 cases of hernia repaired with whole-thickness skin grafts. Wound infections occurred in 4.8 and recurrences in 6.8 per cent of the cases, while cysts were revealed in 9 and suspected in 6 cases. He did not think the results differed significantly from those obtained by other methods used for plastic repair of herniae. "Unfortunately", he states, "it is often just in those cases where the most extensive repair is necessary that the skin is found to be of the poorest quality".

GOSSET and BONVALLET (1951), after experience in 12 operations, recommend the use of skin strips for the repair of joint ligaments. They consider the stability achieved by this measure, which allows early mobilization, a special advantage.

The procedure has become increasingly popular, and reports on experience of its use are continuously being published (GOODALL and GUTHRIE 1947, PATARO and Zavaleta 1947, GORNI 1948, MARTINI 1949, LIMBOSCH 1949). The end results have on the whole been good and the whole-thickness skin graft is considered a suitable measure especially in severe cases.

In the Scandinavian countries, however, very little attention has been paid to the method, the Norwegian HOMB (1952) being the only worker who has described and recommended it from the experience of 7 cases of his own. In Finland KALLIO (1954) has used whole-thickness skin grafts in some reconstructive operations. The primary results have been good, but there are so far no end results from which conclusions may be drawn.

Yet HARKINS, in spite of the brilliant results reported from the use of whole-thickness skin grafts, finds the risk greater than with cutis graft. He suggests that when stronger support is required, a double cutis graft might be advisable. CHODOFF (1949) on the other hand gives preference to the whole-thickness skin graft: "Whole skin", he writes, "is easier to obtain than cutis; operating time is consequently shortened. If removal of the epidermal layers of the skin is not necessary to prevent infection or the formation of inclusion and retention cysts, there is apparently no reason for not using whole skin instead of cutis".

Others see no difference between the use of skin with and without epidermis (KILIAN 1947, 1951, JOLICOEUR 1949, EISELE and STARKLOFF 1951).

To avoid making another skin incision some workers (MAIR 1945, JUNGHANNS and JUZBAŠIĆ 1940) perform an excision at the margin of the skin incision to obtain the skin or cutis graft. PONE (1948) goes to the length of embedding, in post-operative herniae, a detached cutis scar to strengthen the plastics and claims that it resists well against tension. On this point he disagrees with BIER, who sees in cicatric tissue certain flaws, for instance, under tension it stretches easily.

REHN finds it more advantageous and safer to use the strong skin of the anterior lateral surface of the thigh, since often over and around herniae the skin is atrophic and contains striae.

C. Previous Experimental Studies

REHN (1914) used dogs and SCHWARZ (1922) rabbits when experimenting on the Achilles tendon, on which they made a defect subsequently repairing it with a twisted cutis strip. They believed that the functional irritation caused a conversion of the cutis into tissue resembling a tendon which could with difficulty be distinguished from a normal tendon. This transformation took about 10 weeks. The experiments confirmed the theory put forward by HISS in 1865 that wherever in the organism connective tissue was subjected to continuous pull or tension, tendon tissue was formed. According to REHN a fascia transplant regenerated more slowly and was more often subject to failure. SCHWARZ noted more frequent necrosis in a cutis transplant and therefore, though considering cutis quite serviceable, preferred fascia.

EITEL (1933) proved quite convincingly that cutis remained longer alive and was more active than fascia and therefore more suitable for plastic repairs. Using WARBURG's method he made metabolic studies on strips of human cutis and fascia obtained at operation. The cutis proved more viable in different age groups.

SCHNEIDER (1936) noted that the cutis, like other tissue which is capable of regeneration, contains no reduced glutathion. Reduced glutathion, he stated, was a sign of oxidation and reduction of the tissue. He also noted that tissue containing this reduced substance did not easily regenerate in the transplantion, less easily in proportion to the amount present.

PEHR and PADDOCK (1937) carried out interesting studies with the human cutis by embedding it in connection with operations for nasal repair in the wall of the thorax and by removing the specimens after different periods ranging from 7 days to one year. They found that normal cutis was gradually converted into fibrous tissue. Sebaceous glands and hair follicles were the first elements of the skin to degenerate, while the sweat glands degenerated very slowly. They tried to remove the epidermis completely before implantation but in microscopy nevertheless remnants were always revealed. In early specimens they found cysts of a microscopic size containing horny material and fragments of hair. In later specimens, at 7—12 months, these cysts had lost their epithelial layer.

UIHLEIN (1939) was in a position to take specimens for microscopy from 2 patients on whom a cutis graft repair had been done four years earlier. These preparations represented an apparently normal connective tissue with characteristic fibrous and fatty components, blood vessels, and nerves. No remnants of the original epithelium were revealed, neither were there any epithelial cysts visible to the naked eye or in microscopy. This showed that a complete metamorphosis had taken place in the transplant.

MAIR (1945) made experiments on rabbits by removing a strip of lumbo-dorsal fascia and by embedding in the depression, under strong tension, a strip of skin from which the hair had been shaved. After 5 months it was difficult to distinguish with the naked eye this region from normal fascia. Microscopy revealed some strongly degenerated dermal papillae while the epidermis, sebaceous glands, and hair follicles had disappeared completely. The remnants of hair were surrounded by tissue subject to massive foreign body reaction, which in turn was being encapsulated off by a dense fibrous stroma. In a three-week specimen macroscopically the skin had the appearance of white, fibrous tissue; microscopically all elements of the skin could be identified, although a fibroplastic reaction was in progress and the margins of the implant were surrounded by granulation tissue. No signs of epidermoid cyst formation could be seen.

Less extensive studies pertaining to transformation of whole-thickness skin have been carried out continously (BEHREND and BEHREND 1950, GREENE Jr. and WOLLGAST 1949), with good results. But GRAY et al. (1951) who experimented on dogs, though achieving metaplasia of the connective tissue, repeatedly noted on the epidermal surface keratinous debris which did not unite with the surrounding tissue and was therefore susceptible to infection and fistular formations. From these experiments they considered it wiser and safer, in the repair of large herniae, to use foreign material such as tantalum mesh or polythene whenever the fascial layers are weak of absent.

STRUCTURE OF THE SKIN, TENDON AND APONEUROSIS

In the following I shall have to deal in detail with the reactions of the different elements of the skin, tendon and aponeurosis. I therefore think it advisable to recall, before describing my experiments, the normal structure of these tissues (BROMAN and HÄGGQVIST, v. MÖLLENDORFF, ZIELER etc.)

Skin

Histologically, the skin may be divided into two layers:

1. Epidermis, which is ectodermal in origin,
2. Corium, or cutis, which derives from the mesoderm.

In the latter lie the dermal glands, the sweat glands, and the sebaceous glands. The sebaceous glands open into hair follicles, each of which is furnished with a hair. The ducts of the sweat glands lead in a spiral through the epidermis. In the skin of the rabbit sweat glands occur only in the groin bend and in atrophied forms in the skin of the lips (KRAUSE 1884).

The corium consists of the layer underneath the epidermis, stratum papillare, and an underlying thicker layer, stratum reticulare, which borders on subcutaneous connective tissue formed of loose connective and fatty tissue. The corium is made up of connective tissue formed of three kinds of interlaced fibres, collagenous fibres, elastic fibres, forming around them a delicate mesh, and reticular fibres. (The latter, having characteristics in common with collagenous fibres, are considered precollageneous).

Formerly the epidermis and the corium were supposed to be connected by means of a special basement membrane of partly elastic tissue (HERXHEIMER 1916, BORN 1921). Nowadays it is generally thought that tonofibrils which unite with epidermal cells pass from the basal cellular layer into the stratum papillare and unite with the fine fibrils of the connective tissue. DICK (1947) regards these fibres as reticular.

The corium also contains smooth musculature, attaching to the hairs, particularly, from the follicles of which they penetrate into the papillary layer.

The arteries of the skin proceed from the subcutaneous layer into stratum reticulare, where they form a new vascular network, rete cutaneum. It branches out into the surface layers, where the branches form a new vascular system, rete subpapillare. The veins follow the course of the arteries, but are always twofold in number.

Tendon

The tendon is built up of closely packed collagenous fibres with their parent cells. The bundles are bound together by a layer of fine connective tissue, endotenon. The tendon is covered by endothelial tissue, epitenon, and those parts of the tendon not enclosed in the tendon sheath are surrounded by loose, fatty areolar tissue, paratenon. In the sheath the tendon with its epitenon is attached by mesotenon to an endothelial layer on the inside of the sheath.

The tendon was formerly supposed to lack blood vessels or to have a very scanty circulation. Yet studies making use of staining or roentgenography have revealed in the endotenon a considerably supply of vessels which are connected with the vascular system of the surface of the tendon and the paratenon (EDWARDS 1946, BROCKIS 1953).

Aponeurosis

By aponeurosis we understand a flat band of connective tissue which serves as an investment for muscles moving in different directions. It may be characterized as a complex tendon which contains connective tissue fibres proceeding in all the directions in which the muscles attaching to it are pulling. As in the tendon so in the aponeurosis the fibres unite to bundles which, however, lie in layers. Between the bundles is loose connective tissue corresponding to endotenon. The different layers are separated from each other by interstitial connective tissue.

PURPOSE OF THE STUDY

The purpose of the present study is, firstly, to find out the fate of the epithelium of the whole-thickness skin graft under tension, both in the abdominal cavity and in subcutaneous tissue.

Secondly, the object is to try to discover how the attachment of the whole thickness skin graft to muscular tissue takes place and how the graft attaches to tendon tissue.

The third object is to study the changes which occur in a whole-thickness skin graft embedded in tissue so as to come under tension, and when subject to a pull in different directions as in a muscular defect, and on the other hand when subject to a pull in one direction as in a tendon defect.

MATERIAL AND TECHNIQUE

Experimental Animals and Anatomical Remarks

Only rabbits were used for the experiments. Most of them were of the white breed and only 4 were mongrels. The majority were adults, between 6 and 8 months old, weighing from 2 to 2.5 kg. No notice was paid to sex. No pregnancies occurred in the animals in the course of the experiments.

The studies were carried out in the course of a year and the rabbits were given normal miscellaneous food (MUSTONEN and HELVE 1940), in the summer, besides, some fresh grass. They were kept in a light shelter at room temperature, each in a spacious cage of its own.

To study changes in the skin graft in a muscular defect, the lateral part of the abdominal walls was used. This consists of skin with m. cutaneous maximus, three muscles covered by fascia, viz. the external oblique and the internal oblique muscles and the transverse muscle, and the parietal peritoneum (BENSLEY 1948).

The Achilles tendon was used for a study of the tendon defects. In the rabbit this tendon is made up of two bundles of m. gastrocnemius and one bundle of m. soleus, which are all inserted in the calcaneus. The tendon of m. plantaris is closely connected with the Achilles tendon, and in this study it is dealt with as a part of this tendon.

Material

The material consists of 25 rabbits in all. Three operations were performed on each, in the abdominal wall and in both the Achilles tendons. The total number of operations made in the abdominal wall was thus 25 and of those performed in the Achilles tendon 50. Infections occurred in 1 of the former and in 6 of the latter experiments. These cases were omitted from the material, so that 24 preparations from the abdomal wall and 44 from the Achilles tendon were ultimately used for the investigation. The durations of the different experiments appear from Table 1.

Two animals were lost because of post-operative complications within the first 24 hours. These were also excluded from the series, likewise the animals on which some preliminary experiments were carried out with a view of developing a serviceable method for the operations and the examinations.

Table 1

Time in Days	Number of Cases	
	Abdominal Wall	Tendon
3	1	
5		1
7	1	2
9		1
10	1	2
14	1	1
15	1	2
20	1	2
23		1
25	2	2
28		1
30	1	2
35		1
40	1	2
45	1	2
50	1	2
60	1	2
70	1	2
80	2	2
90	2	2
100	1	2
120	1	2
130	1	2
150	1	2
180	1	2
300		1
360	1	1

Operative Measures

Before the operation the rabbits were kept fasting for 6 hours. Only water was given to them. In the operative field the hair was first shortened with scissors and then shaved with a razor; this was done very closely on the area fixed for the implantation. No chemical depilators were used, since they may cause skin irritation (Vainio 1948, Carstam 1953). The operative field was scrubbed thoroughly with soap and water and finally cleansed with ether and alcohol. The operations were then performed under strictly asceptic conditions.

The animals were first anesthetized with Vinesthene (Vinyl ether) under which they fell asleep easily; the narcosis was then continued under ether. The Vinesthene facilitated the work of the anaesthetist considerably, since each of the rabbits was anesthetized three times at least and it became progressively more difficult to make them sleep.

In the wall of the abdominal cavity the following technique was used. A longitudinal incision of 5 cm was made at the height of the navel somewhat laterally from the median line. From the upper end of the incision a whole-thickness skin strip measuring 1.5×1.5 cm was removed for use as a transplant. Through the bottom part of the incision the knife was introduced subcutaneously into the lateral wall of the abdominal cavity, where a 2.5×2.5 cm defect was made by removing the muscular layers and the peritoneum from this region. The skin graft was sutured into this gap, the epithelial surface facing the abdominal cavity. The suture included the graft on the one side and the peritoneum and three wall muscles on the other. An interrupted suture was used, at distances of about 0.5 cm, so that the implant came under as even a tension as possible. No subcutaneous tissue was drawn over the graft, the skin was simply closed with interrupted stitches. The wound was covered with gauze which was fixed with adhesive tape.

In the tendon defect operation an incision was made in the lateral side of the hind leg along the Achilles tendon. The paratendon was split and drawn aside, and a 2 cm piece was cut from the middle of the tendon. A whole skin piece 1.5 long and 1 cm broad was taken from the lateral side of the thigh and folded evenly so that the epithelial surface was outwards and the subcutaneous surfaces faced each other. This double whole skin graft was fixed with Bunnell's suture to the two ends of the tendon. Adaption sutures were added, ventrally and dorsally, between the tendon ends and the graft. The paratendon was then drawn round the transplant without sutures. The skin was closed with interrupted stitches and the wound was covered with gauze. The leg which had been operated was finally put in wooden splints so that for three days the rabbit was unable to use it.

Only No. 40 cotton thread was used for the sutures. THOREK (1946) after using cotton in more than 1000 operations stated that it only caused slight tissue trauma, that infections and draining sinuses were rarer than with silk and it was much cheaper than silk and easier to sterilize. Cotton thread, moreover, did not cause any difficulties in the sectioning of the preparations, as metal thread would have done.

To obtain the tension necessary for the transplant, the defect was always made larger than the transplant.

This was the standard technique used in all the experiments.

The rabbits tolerated the operations well, but generally a three-week interval occurred between them and not more than one transplantation was made at the same time. This had to be carefully observed in operations on the extremities, especially, as it could be noted that if the one extremity was operated upon before the other one had healed completely and the rabbit had begun to use it again, the rabbit's general condition declined somewhat, it lost its appetite for some days and became listless.

Methods of Study

The changes in the graft were studied both with the naked eye and microscopically. Macroscopic processes were first observed weekly and later monthly. The healing of the wounds was followed at the same time as well as the progress made in walking. The operative field was also examined after the animal had been killed.

Histological changes were observed by always killing the test animals after the lapse of a definite time from the operation, after which the transplant and the muscular and tendon tissue attaching to it were subjected to microscopy. Some of the animals were killed by striking the cranium, the rest were anaesthisized before killing and 10 cc of Indian ink was injected into the abdominal aorta. After this the animal was kept under narcosis for 20 minutes, which was then rapidly deepened to an exitus stage. The purpose of the Indian ink was to bring out the blood vessels more clearly and thus be able to follow the points of departure and the development of the blood vessels in the tendon defect.

To ensure the largest possible correlation for the histological specimens obtained from the animals killed after periods of different lengths, the specimens were taken, as far as possible, from identical spots. In the muscular defect the specimen was taken from the central part of the transplant, to include the muscular wall of the abdominal cavity on both sides of it (Fig. 6). In the tendon transplants on the other hand, the Achilles tendon was split in the centre in the sagittal direction, and the preparations were cut from the surface of the split.

The specimens were fixed in 10 per cent formalin solution for 24—48 hours. After this they were embedded in paraffin, cut lengthwise into 5 μ thickness so that the adjacent muscular or tendon structure was included. In some cases cross sections were made of the central part of the tendon transplant to determine the relation between the transplant and the paratenon.

The preparations were stained with van Gieson's haematoxylin, but for a closer analysis of the cellular infiltrates the May Grünwald-Gimsa stain was used (Romeis 1948). Synthetic orcein (Gurr) was employed for the study of the elastic tissue, because natural orcein stains the background a disturbing red colour (Darrow 1952).

Macroscopic Changes in the Whole-thickness Skin Graft

I. In the Abdominal Wall Defect

At 1 Week

After the operation the depression at the site of implantation remains palpable all the time. At the end of the week, due to a thickening at the points of attachment, there is a kind of deepening. On the surface of the graft the skin moves rather freely. When the skin is opened, considerable oedema is revealed in the subcutaneous tissue, and between the subcutaneous tissue and the transplant some soft transparent exudate, bluish grey in colour, has settled. During the first days it is somewhat loosely attached to the transplant, but by the end of the week much more firmly. The surface facing the abdominal cavity shows an exudate layer of the same kind that fills the depression at the site of the implantation, so that its surface becomes on a level with the peritoneal surface. At first the surface is velvety, but in the preparation at 7 days it is evenly glossy while the whole structure of the exudation deposit has become more solid. The skin graft itself is easily distinguishable by its lighter colour and firmer structure. No necrosis nor contraction can be noted in it.

At 2—3 Weeks

Palpation gives the impression that the depression above the transplant is gradually filling and that the skin unites quite closely with this tissue. The points of attachment can be clearly felt as wall-like even thickenings. There is considerable subcutaneous oedema, which seems to disappear with time. On both sides the transplant is surrounded by greyish transparent tissue which almost completely flattens the depressions formed in the abdominal wall. Its peritoneal surface is smooth and shiny; the organs of the abdominal cavity do not adhere to it. The adjacent muscular tissue is slightly oedematous and the tissue overlying the transplant seems to continue into the fasciae which cover the muscles. In the sectional surface the graft is still clearly distinguishable though it seems to have thickened slightly, apparently due to the oedema, and its structure has become more delicate, especially in the third week. No necrosis can be noted, but there is incipient contraction which seems to increase and is about 20 per cent at the end of the third week. A great number of capillaries from the subcutaneous tissue running into the structure which covers the transplant can be noted. After the detachment of the skin these are seen in the form of small point-like haematomata (Fig. 1).

At the End of the First Month

The skin on the surface of the transplant moves more and more freely. There is still some thickening at the points of attachment,

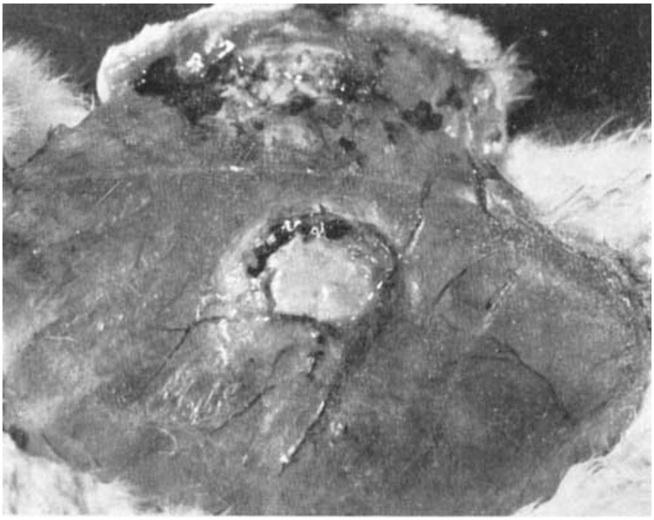

Fig. 1. Repair of a defect in the abdominal wall, viewed from the subcutaneous surface, at 10 days. Loose granulation tissue on the surface of the graft, from whose ruptured vessels some blood is oozing.

but otherwise the site of the implantation unites with the abdominal wall without any depression. There is some slight oedema in the subcutaneous structure, which seems to decrease rapidly with time. The tissue covering the transplant becomes firmer and much stronger, assumes a greyish red colour and at the same time grows slightly turbid. In the sectional surface the original transplant is still discernible though its margin on the tissue covering it is very indefinite in many places. The surface facing the abdominal cavity is smooth, shiny, and to the naked eye indistinguishable from the peritoneal surface (Fig. 2). The transplant has contracted to about 25 per cent of its original size. The fasciae covering the musculature have thickened somewhat and seem to merge into the area of the implantation without any distinct margin.

At 2 Months

The oedema in the subcutaneous tissue is beginning to disappear, the thickening at the attachment to become levelled and the tissue in the wall defect to take on a homogenous appearance so

Fig. 2. Repair of a defect in the abdominal wall, at 30 days, viewed from the peritoneal surface. The depression first present at the site of implantation is filled with new tissue, the surface of which is smooth and glossy and closely resembles a normal peritoneal surface.

that one can no longer see what belongs to the transplant and what is new tissue that has formed around it. In colour this tissue is pinkish grey and somewhat turbid. When stretched and sectioned it appears strong and firm. The contraction has no longer increased.

At 3—12 Months

After two months no noteworthy changes can be seen macroscopically. The tissue filling the defect merges more and more smoothly into the fasciae overlying the muscles and into the peritoneum covering the peritoneal cavity. The tissue becomes more solid and stronger with time, but is still distinguishable from the lighter fascia owing to its reddish grey colour.

2. In the Tendon Defect

At 1 Week

Palpation reveals no noteworthy changes in the implanted skin graft. It feels flat in the frontal plane, and is comparatively mobile in relation to the skin and the underlying tissue. No stretching can be noted. The subcutaneous tissue shows slight oedema. The implant is surrounded by a bluish grey, transparent layer with an appearance of homogeneity — obviously precipitated exudate, which seems to increase with time and is about 2 mm thick at the end of the week on the ventral side but considerably thinner dorsally. This may be due to more abundant vascularity on the ventral side of the tendon. The paratenon is markedly thickened around the defect and the tendon stumps, especially around the sutures. The stitches are clearly visible and no necrosis can be noted near them with the naked eye. The splitting brings out the tendon stumps still more distinctly, due to the white tendon-like gloss which they retain. The implant itself is also clearly distinguishable from the adjacent loose tissue by its light colour and firm structure.

At 2 Weeks

The animals for the most part are beginning to use their operated extremity. As a general observation it may be said that those of them that underwent a first operation did not begin to use their leg until toward the end of the second week. On the other hand, those whose other leg had been operated before, its function being still rather less than normal, began to use the leg operated upon later as early as during the last days of the first week.

The skin attaches to the implant fairly firmly, and at the junctures the thickening has palpably increased, but they are at the same distance from each other as in the operation, so that no stretching of the transplant has taken place. In the subcutaneous tissue the oedema has increased markedly. The paratenon is much thickened and between it and the implant, on the ventral side, greyish, transparent, rather loose new tissue is seen. On the dorsal side there is much less of this tissue. The tissue is abundantly vascularized, and the course of the blood vessels is excellently traced by the Indian ink injection. They seem to originate, especially, in the blood vessels of the connective tissue surrounding the newly-formed tissue ventrally. The graft itself is clearly distinguishable, as are also the ends of the tendon stumps.

At 3 Weeks

In some of the cases the walking capacity continues to improve, in a smaller part obvious deterioration is noted after a fairly good start in walking, probably due to the stretching of the transplant. This was especially marked in the 2 cases in which the other leg was operated before a lapse of 3 weeks from the first operation. Because of the splint the rabbit was compelled to use only its other limb which was on the way to being healed.

There is still considerable subcutaneous oedema, but no increase in it, in fact rather the contrary. The loose structure surrounding the transplant has increased considerably, filling the depressions ventrally and dorsally from the transplant, mainly on the ventral side.

This young tissue is pinkish grey in colour and markedly firmer than the one noted in the preceding experiments. In the split preparation the original graft is fairly well distinguishable, though its margins are becoming indistinct and its structure is considerably looser and has the appearance of oedema. This loosening of the structure accounts for the stretching of the graft. Another reason for the stretching of the defect area may be the partial detachment of the skin graft from the tendon stump, which was apparent in the second specimen taken at the end of the third week.

At 4 Weeks

On palpation the area of the defect feels somewhat thicker than a normal tendon, but after the skin has been opened this is found to be due to the markedly thickened paratenon. The new tissue ventrally from the transplant fills the depression in the defect completely, but it does not yet do it fully on the dorsal side (Fig. 3). The site of the implantation is very nearly as mobile in relation to its surroundings as a normal tendon, especially on the ventral side, but on the dorsal side there are still some adherences. In colour the area in question is dull grey and clearly distinguishable from the tendon stumps. No additional stretching has occurred at the site of the implantation so that usually the walking capacity improves or remains unchanged. In two cases only, in which decubitus

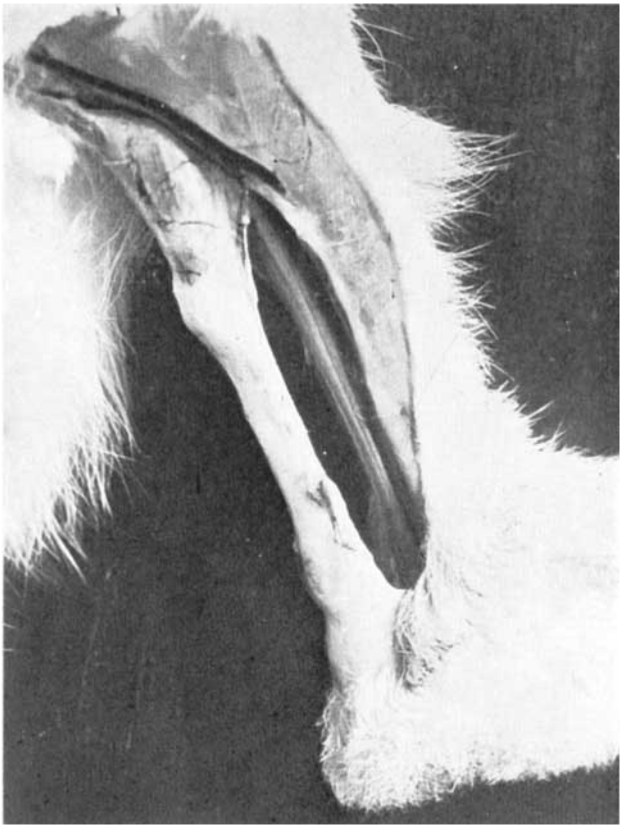

Fig. 3. Tendon repair at 25 days. The new tissue has filled the depression ventrally from the graft, but dorsally a slight depression is still discernible. The points of attachment are slightly thickened.

ulcers developed in the heels, it deteriorated further. In the split preparation the transferred skin graft could no longer be distinguished with the naked eye.

At 2 Months

The depression still existing dorsally of the graft is filling up, so that at the end of the second month the site of the graft is round in the transverse section and even considerably thicker than the normal tendon. The paratenon, likewise, is thicker than normal,

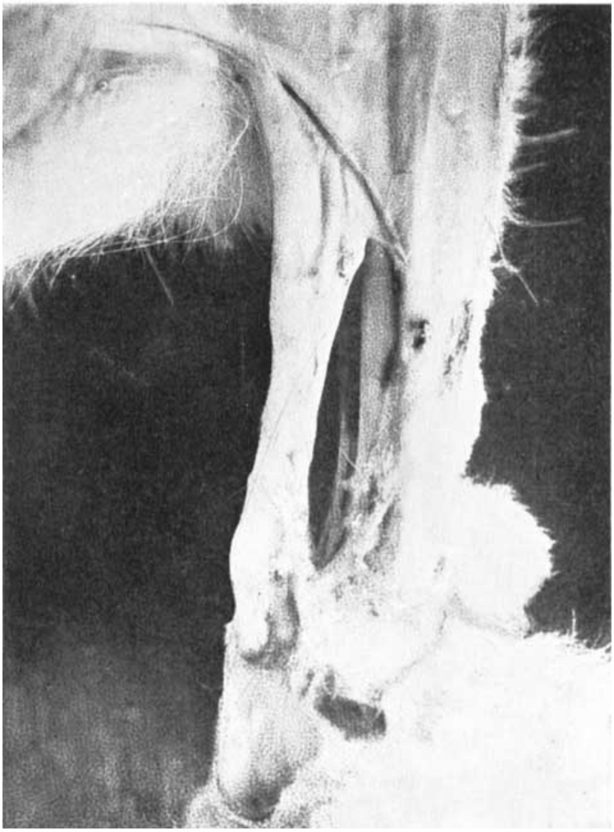

Fig. 4. Tendon repair at 60 days. The site of implantation is of the thickness of a normal tendon, but its surface is still somewhat uneven.

but it is gradually beginning to become thinner, and forms around the whole site of the implantation a similar even layer, though it was partly damaged on the dorsal side at operation. Because of this layer there are no adherences to the surrounding connective tissue (Fig. 4).

At 3 Months

The diameter of the site of implantation begins to diminish and towards the end of the third month it is almost of the thickness of a normal tendon. The paratenon likewise takes on a normal appearance. The colour of the site, which is pinkish grey, differs sharply from that of the normal tendon; moreover, it is dull, and has not got the gloss typical of the tendon. Walking capacity continued to improve also in the cases where the skin graft had stretched. Apparently this improvement was due to the contraction of the muscles attaching to the Achilles tendon, which compensates the lengthening of the tendon. In these cases the stretching of the site of implantation was less than 1 cm. Only in the two cases in which heal decubituses developed in the fourth week, was the extension more than 1 cm. In neither of the two was there any noteworthy improvement of the walking capacity with time. One of these rabbits was allowed to live for 70 days, the other 90 days. Apparently the muscles invested in the Achilles tendon were unable to compensate a stretching of more than 1 cm in the tendon.

At 4—12 Months

After three months no marked changes take place in the site of implantation. Although this site merges more and more smoothly with the tendon stumps and adjacent connective tissue, it is easily distinguishable macroscopically from the normal tendon, for within the time the experiment lasted it did not develop a normal tendon-like gloss and remained pinkish grey in colour. The capacity to walk was restored to normal within about 3—4 months, as far as it was possible to judge this in a rabbit (Fig. 5).

I carried out some quite superficial experiments to compare the firmness of the tendon and that of the site of the implantation. To test the tension I used that part of the split tendon which was left over from microscopy. Each time the tendon broke up at the point of juncture or in the site of implantation. This seems to imply that a graft area possibly can not be compared with a normal tendon in firmness.

Synopsis of the Results

Both in an abdominal and a tendon defect exudate first accumulates around the grafts, filling and levelling the depressions there. Apparently some of it is also diffused into the adjacent tissue

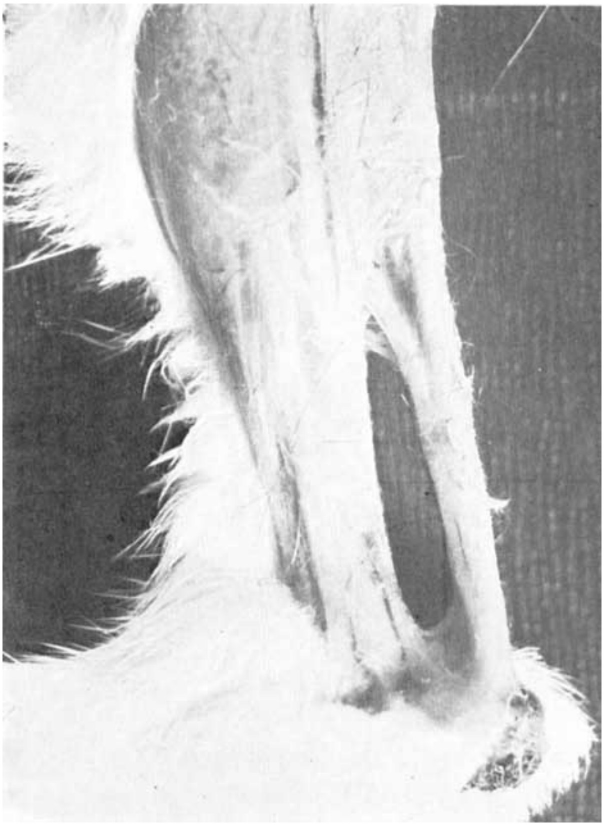

Fig. 5. Tendon repair at 1 year. The site of implantation bears a close resemblance to a normal tendon, though its surface is somewhat rougher and lacking in tendon gloss. The Fig. shows clearly how the groove between the different parts of the tendon on the lateral side breaks off on the graft area.

causing oedema, especially in the subcutaneous tissue. At the beginning of the second week this loose and fragile exudate is replaced by a loose structure showing an abundance of blood vessels. At the same time the velvety surface of the transplant which faces the peritoneal cavity begins to resemble the glossy peritoneal surface. At the end of the second week the transplant is completely surrounded by new loose tissue of this kind, which in the third week begins to become firmer and stronger. At the same time the skin graft transferred into the abdominal defect seems to contract and the one transferred into the tendon defect begins to show signs of extension. This goes on to some extent in the fourth week, when the transplant detaches itself from the adherences which unite it with the adjacent tissue. The walking capacity of the animals also begins to be restored to normal. During the second month the transplant can no longer be distinguished from the adjacent new tissue, the oedema in the surrounding tissue disappears, the tendon becomes round and is encompassed by structure with a full resemblance to the paratenon. The tissue of the site of implantation is pinkish grey in colour, somewhat turbid and lacks the gloss of the fascia or the tendon. Nor will it acquire this gloss within a whole year but that region will remain without the white colour and gloss characteristic of the tendon and the fascia. Functionally the sites of implantation well fulfill the requirements set by the pressure of the abdominal cavity, and in the tendon tissue they are capable of performing the functions needed for movements. Apparently the transplant tissue cannot acquire the strength inherent in normal tendon tissue.

Disappearance of the Epithelium

I. In the Abdominal Cavity

Since the skin grafts were always inserted so that the epithelial surface came to face the abdominal cavity, the disappearance of the epithelium can be followed in the abdominal cavity.

At 3 Days

A layer of exudate, whose detailed structure resembles a mesh of thin ribbon-like fibres, has precipated on the epithelial surface. In the mesh are interspersed lymphocytes and some leucocytes. In this layer here and there small round or oval empty cavities which seem to be covered by what looks like a membrane can also be seen. Whether they were produced secondarily while the preparation was in the making or whether they have some definite function is not apparent from the preparations.

An abundance of lymphocytes and leucocytes, about 50 per cent among them being lymphocytes, 30 per cent neutrophil leucocytes and 20 per cent eosinophil cells, have gathered between the

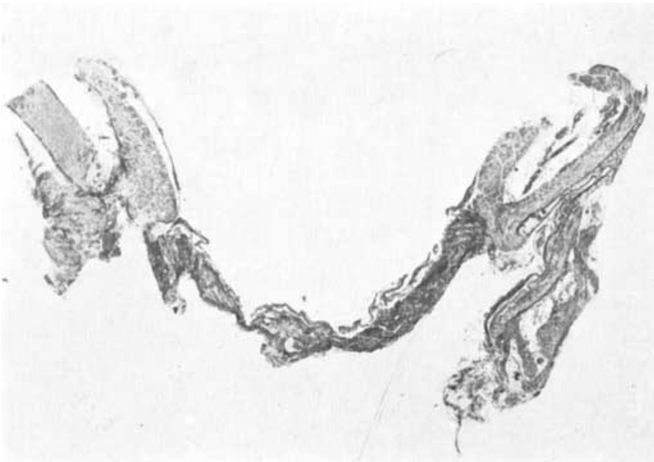

Fig. 6. Graft in the abdominal wall, attaching closely to the muscles on both sides. A continuous thin layer of exudate is visible on the peritoneal surface. ×4.

exudate layer and the epithelium. These cells contain numerous small granules, apparently detached fragments of the epithelium which have been fagozymitized by the cells. The whole of the epithelium adheres to the connective tissue and the nuclei of the cells in its bottom layer stain well and are regular in shape. In the connective tissue immediately below the epithelium the fibril bundles seem to have become partly detached from each other — apparently due to oedema, and some lympho- and leucocyte shave gathered to these extended interstitial spaces. A similar phenomenon can be noted around the oral parts of the hair follicles while their basal parts have not changed. There are no changes in the sebaceous glands (Figs. 6 and 7).

At 7 Days

The epithelium is seen as a consistent layer in which the nuclei stain imperfectly and reveal disintegration here and there. The exudation deposit on the surface of the epithelium and the accumulation of cells have been replaced by loose granulation tissue rich in cells and capillaries, where the cells lie in parallel layers showing abundant mitoses. This loose granulation tissue has also penetrated

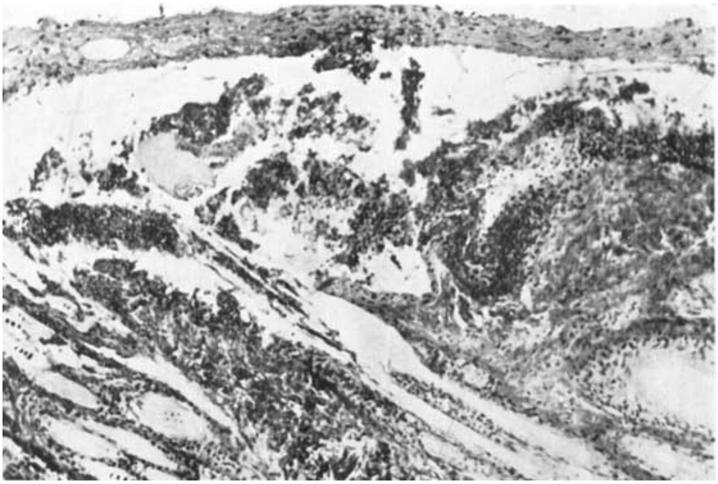

Fig. 7 connects with Fig. 6 and shows the edge bordering on the abdominal cavity. Exudation deposit is seen, with cells and underlying abundant infiltration. The epithelium adheres to the corium, likewise the hairs in the follicles. × 180.

in a thin layer between the epithelium and the connective tissue underlying it. Interspersed below the epithelium are groups of lympho- and leucocytes which give the impression of forcing the epithelium upwards, and the granulation tissue follows this upwards bulge. The hair follicles have spread considerably and flattened, and here too the granulation tissue pushes between the corium and the root epithelium. A considerable accumulation of lympho- and leucocytes is noted round the hairs (Fig. 8).

At 10 Days

At many places the granulation tissue has penetrated through the epithelium dividing it into small islets round the root sheaths. Here and there in these islets the epithelium looks viable with nuclei that stain well, while elsewhere the nuclei take on the stain imperfectly or not at all. On the margin of the granulation tissue bordering on the peritoneal cavity is a somewhat denser layer consisting of cells which have a flattened appearance (Fig. 9).

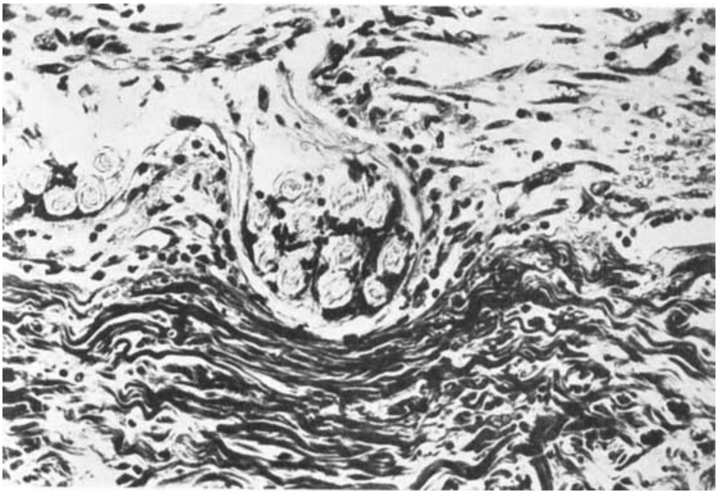

Fig. 8. Abdominal wall defect at 7 days. Loose connective tissue penetrates between the epithelium and the corium into the bottom of the hair follicle, the whole of which has flattened and spread. In the region of the corium the interstitial spaces between the fibril bundles have extended and are filled with exudate and cell infiltration. × 380.

At 15—360 Days

No epithelial cells are to be seen any longer. The surface of the skin graft facing the abdominal cavity is covered by a markedly thick layer of young tissue in which the number of fibroblasts is decreasing and the number of fibril strands forming between them is increasing with time. The hair stumps of the follicles are visible on the border of the young tissue and the corium and from the 15th day onwards they line up parallelly with the fibrils. In the beginning they are surrounded by numerous cells, mainly lymphocytes, but later these cells decrease in number and after 60 days no reaction can be noted any longer round the hair stumps in the tissue; the fibril bundles only curve out around them as if forming a sheltering capsule (Fig. 10).

2. In the Tissue

The disappearance of the epithelium in the tendon defect is probably a counterpart to its usual disappearance in connective tissue. It resembles roughly the process taking place in the abdo-

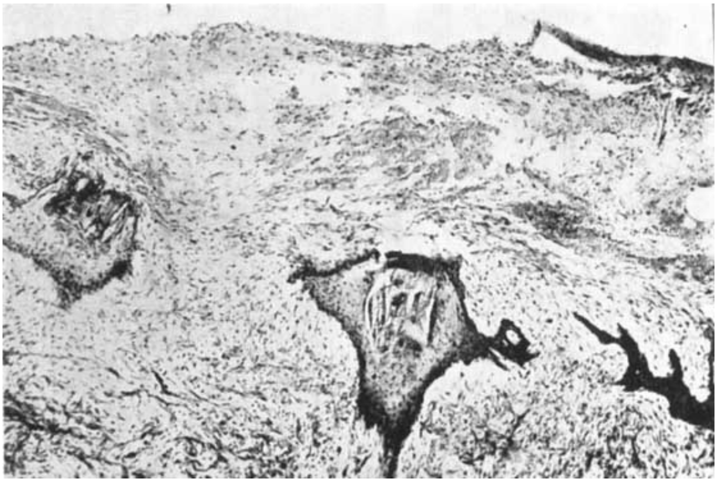

Fig. 9. Abdominal wall defect at 10 days. The young tissue has at several points penetrated through the epithelium breaking it up into small islets around the hair follicles. The nuclei of some of the epithelial cells stain, others do not. The margin of the young tissue which borders on the abdominal cavity is even, formed of a denser layer of cells. × 90.

minal cavity, though the preparations give the impression of a somewhat more rapid action there. Whether this is due to the leg having been splintered for 3 days or to a difference in circumstances, does not appear from the preparations.

At 5 Days

An exudation deposit with a great amount of lympho- and leucocytes merging with its surroundings with indefinite borders everywhere, is seen on the epithelial surface. The epithelium attaches to the corium in all its parts, although below it the interstices between the fibril bundles have widened and are filled with lympho- and leucocytes.

At 7 Days

The amount of exudate which has settled on the surface of the epithelium has increased and a wedge-like cell infiltrate underneath it, consisting of lympho- and leucocytes, penetrates in various

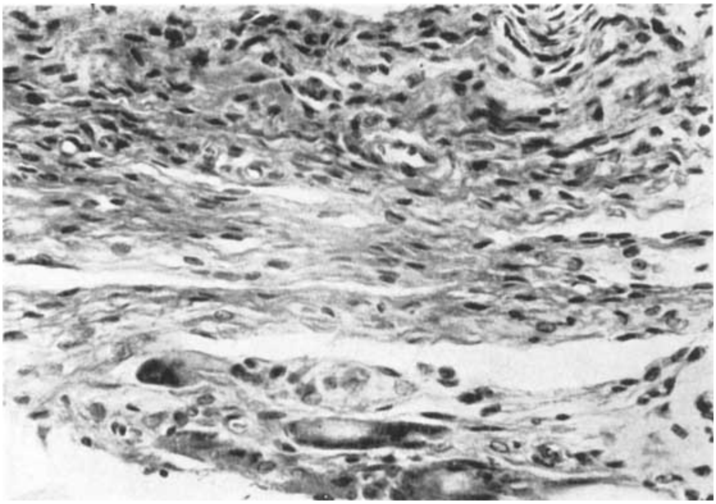

Fig. 10. Abdominal wall defect at 30 days. Remnants of hair at the demarcation line between the new tissue and the corium, seen at the bottom of the Fig., is what is left of the epithelium. They have arranged themselves parallel with the fibril strands. The young tissue is fairly well vascularized and contains thin undulating fibril strands. × 500.

places between the epithelium and the corium and seems to detach the epithelium from its base. In places the cell infiltrate extends down to the bottom of the hair follicles. Some of the nuclei of the detached epithelium stain well, others imperfectly, and some disintegration is revealed (Fig. 11).

At 10 Days

From the connective tissue rich in cells, which surrounds the transplant, numerous cell columns push their way into the exudate layer on the epithelial surface and in places fill it completely. In some places this granulation tissue has penetrated through the epithelium and begins to extend between it and the corium, which however so far mainly consists of lympho- and leucocyte infiltration.

At 15 Days

The epithelium has disappeared almost completely and the transplant is surrounded by abundant granulation tissue. Here and

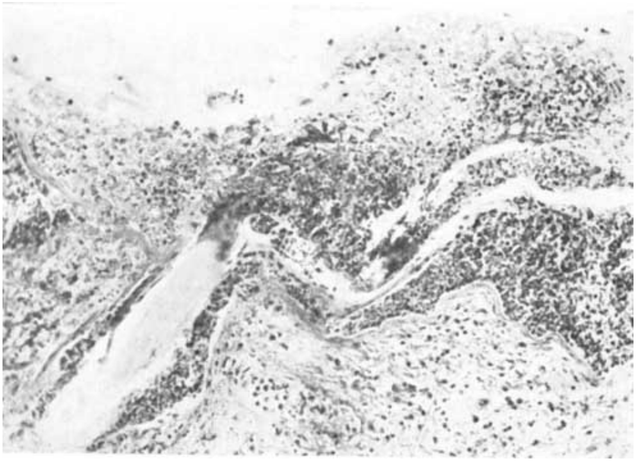

Fig. 11. Tendon repair at 7 days. Cell infiltration consisting of lympho- and leucocytes penetrates between the epithelium and the corium, detaching the epithelium. On the other side the infiltration has penetrated to the bottom of the hair follicle, on the other it approaches the hair follicle in a wedge-like form. The interspaces between the fibril bundles in the corium have widened and are filled with exudate containing lympho- and leucocytes. × 330.

there, however, can be seen remnants of hair follicles with some interspersed epithelial cells, the nuclei of which on the whole respond weakly to staining.

After this no epithelial cells occur unless a complication, such as an epithelial cyst, develops.

Synopsis of the Results

As early as after 3 days a thick layer of exudate has precipitated on the epithelial surface, apparently as an attempt on the part of the organism to isolate this foreign body. At the same time lympho- and leucocytes accumulate on the surface of the epithelium probably with the purpose of destroying this foreign tissue. Towards the end of the first week the accumulation of lympho- and leucocytes has pushed between the epithelium and the corium where it thrusts its way onward like a wedge, detaching the epithelium whose cell nuclei stain poorly and manifest disintegration. At the end of the first week and the beginning of the second the exudate is replaced by granulation tissue containing an abundance of capillaries, which first divides the epithelial tissue into small islets round about the hair follicles. These, too, disappear by the beginning of the third week, and the young tissue begins to grow poorer in cells and firmer. Apparently such abundant granulation tissue affords but poor living conditions to epithelial cells. The hair stumps inside the follicles as a rule line up parallel with the tension from the beginning of the third week, and such fragments occur even in transplant sites of a year's duration without any reaction being noted in adjacent tissue.

Epithelial Cysts

The fear of an epithelial cyst being produced must have been one of the deterrents to a more general use of a whole-thickness skin graft. A good deal of research was done earlier on traumatic epithelial cysts, but there is still no agreement as to their origin. REVERDIN (1887) declared that due to trauma a piece of epidermis becomes torn off and pushes deeper into the corium and that a cyst then develops from this implanted graft. A great many workers agree with this view (GARRÈ 1894, WÖRZ 1897, BLOND 1922, WIEN and CARO 1934).

KAUFMANN (1884) produced a cyst under the skin of a cock's comb by making an oval incision through the skin and then suturing the margins of the skin together over the oval area. In this case, formation of the cyst out of the epidermis was unmistakable, since the skin of the cock's comb contains no hair follicles nor glandular epithelium.

PELS-LEUSDEN (1905) put forward a different view claiming that the cyst had its origin in the epithelium of the glands or their ducts. He arrived at this conclusion by experiments carried out on the rabbit's ear. He inserted an absorbable magnesium disk deep into the corium through an incision made with a sharp knife to avoid accidental implantation of epidermis during the operation. Round this disk there developed a cyst which was surrounded by all the layers of normal epidermis. He definitely attributed these cysts to proliferation from the epithelium of the glands which had been unavoidably injured. HESSE (1912) came to similar conclusions in his experimental series. Yet he found no papillae in the walls of these cysts and maintained that implantation of a complete epidermis was necessary to produce papillae.

DAVIS and TRAUT (1926) inserted a free whole-thickness skin graft beneath the skin on dogs, under normal skin tension. This resulted in cysts or tubes covered with epithelium, depending on the shape of the skin strip. They also noted that the epithelial layer became macerated by the increased pressure inside the cyst if the cyst was allowed to exist longer than 40 days. Unfortunately they state nothing about the histological changes in the hair follicles and the glandular epithelium.

ZIMCHES (1931), experimenting on dogs, embedded whole thickness skin strips into the muscle without fixing them in any way. He noted that they curved in the shape of a horse shoe and that the epithelium gradually united with that of the opposite side and formed a closed epithelium lined cyst.

MAIR claimed that the formation of an epithelial cyst could be precluded by using a whole-thickness skin transplant, if the embedded skin was put under strong tension. He had no cysts in a series of 149 inguinal herniae which had been treated by whole-thickness skin implantation. Nor did MARSDEN note any certain cyst formations in a series of 169 cases though in one case a cyst was suspected because of swelling.

Recently, however, there have been reports on isolated cases in which epithelial cysts have occurred after the use of whole-thickness skin graft. DUMONT and VAN DER GHINST (1949) found the skin transplant covered by sebaceous mass and hairs in two cases reoperated because of recurrences. STRAHAN noted a cyst in 9 cases out of 413 in his series while suspecting one in 6 additional cases. Other reports on one or two cases have also been published (POWELL and EWING 1952, CLARKE 1952, GIBBON and LOTHIAN 1952), but they all agree that the skin graft method should not be given up because of this apparently very rare complication.

The present series contains two types of cyst formations.

Firstly there occurs a cyst the wall of which forms out of epithelium with no hair follicles. They are small, from one to two mm in diameter. A considerable amount are encountered if a sufficient number of preparations are obtained. They are invisible to the naked eye. In the present series their number may be estimated at 30 per

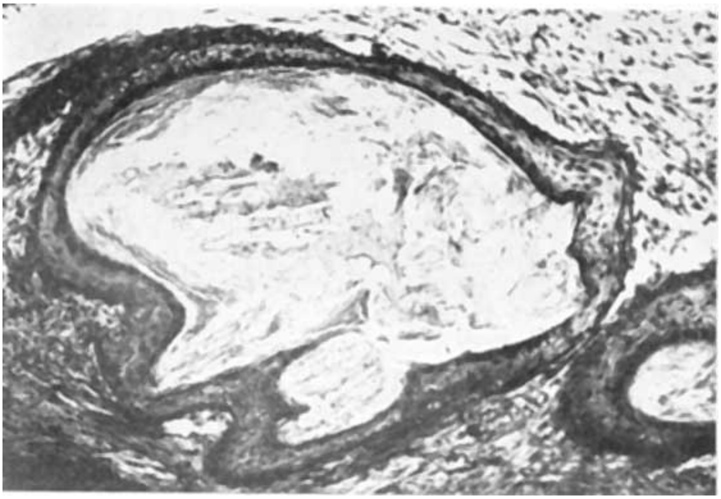

Fig. 12. Epithelial cyst of 15 days in a tendon defect. The wall of the cyst is lined by a thick epithelium. Inside the cyst can be seen how the hair follicle forms a part of the wall. × 200.

cent. They do not seem to have any appreciable effect on the healing of the implant nor on the use of the tendon. Cysts of this type did not occur until the 3rd week.

At 15 Days

An epithelial accumulation with a cavity containing dead epithelial debris among the cells, is noted. In the wall the cells are in several layers, the cellular nuclei of the interior layers staining weakly and those in the external layers well (Fig. 12).

At 25—40 Days

The size of the cysts seems to increase continuously, apparently due to the fact that epithelial remnants and dead cells are pushing their way from the surface parts of the epithelium into the cyst. The epithelial lining of the wall becomes thinner at the same time, down to 1—3 layers, while the cells spread and flatten. The cystal wall, however, is lined throughout with epithelial tissue (Fig. 13).

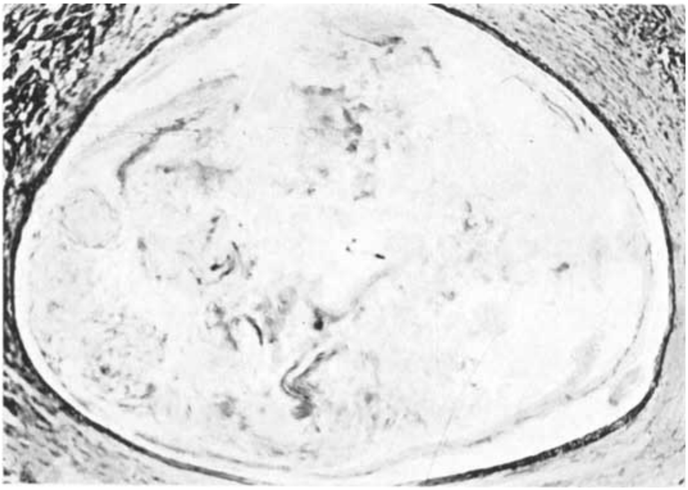

Fig. 13. Abdominal wall defect at 30 days. Epithelial cyst the wall of which consists of some flattened cell layers. The epithelium is continuous. There are no hairs in the cysts. × 90.

At 40—360 Days

The obviously increasing pressure of the cystal content in some areas macerates the epithelial wall which covers the cyst, so that here granulation tissue containing an abundance of giant cells only, prevails. In part of the wall the epithelium is preserved and its cells are again in many layers. Apparently it is through this granulation tissue that the partial resorption of the cystal content takes place, so that the pressure in the interior becomes reduced, the epithelial layers increase and the cyst no longer grows with time but often appears to have collapsed slightly (Fig. 14). In these cysts there is a balance between the epithelial secretion and the resorptive power of the granulation tissue. Their content is a thin somewhat turbid fluid without any hair remnants.

The other type of cyst is of macroscopic size, sometimes as large as 1 cm in diameter. There occurred only 2 of these cysts in the tendon and 2 in abdominal implantations. Their walls showed in places skin epithelium with hair follicles, elsewhere again only granulation tissue lacking any epithelium. There is no doubt that the actual skin graft participates in the formation of the wall of these cysts at the very point where epithelium with hair follicles occurs in the wall.

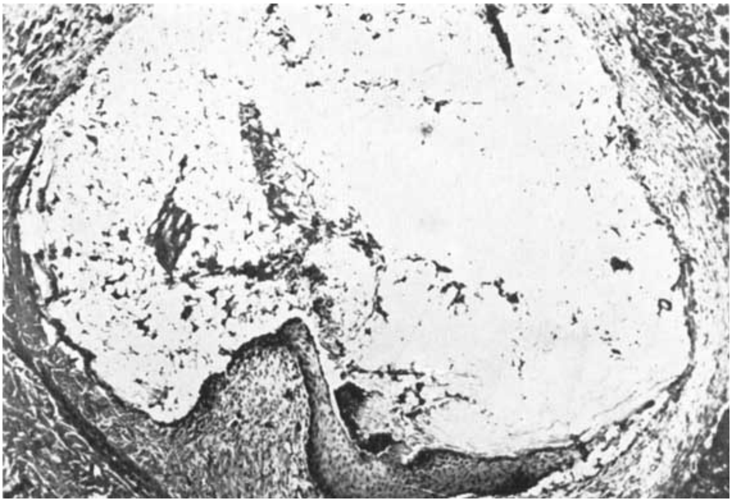

Fig. 14. Epithelial cyst of 100 days. Part of the wall is lined by epithelium in many layers, part of it consists of granulation tissue. No hairs occur inside the cyst. × 90.

Very little can be said of the development of these cysts on the basis of the present material, because all the cases were more than 2 months old, so that no young forms were seen. The reason at least in one of the cases with a tendon cyst was the disappearance of tension, since one end of the transplant had become detached. Apparently the disappearance of tension causes the epithelium to retain its viability at some point, so that it first develops into a closed epithelial cyst. Along with an increasing pressure within it when epithelial remnants gather there, the epithelium becomes macerated in part of the wall, with the result that here only granulation tissue persists; and here partial resorption of the content obviously takes place.

The content of these cysts is a light cheeselike sebaceous mass with plentiful hairs. The hairs seem to go on growing in their follicles in the wall, and becoming loose enter the content of the cyst. A bacterial study was made of each cystal content, but no bacteria were found (Figs. 15 and 16).

Both cystal types were surrounded by connective tissue in a loose structure, its fibres twisted into a network, especially in the

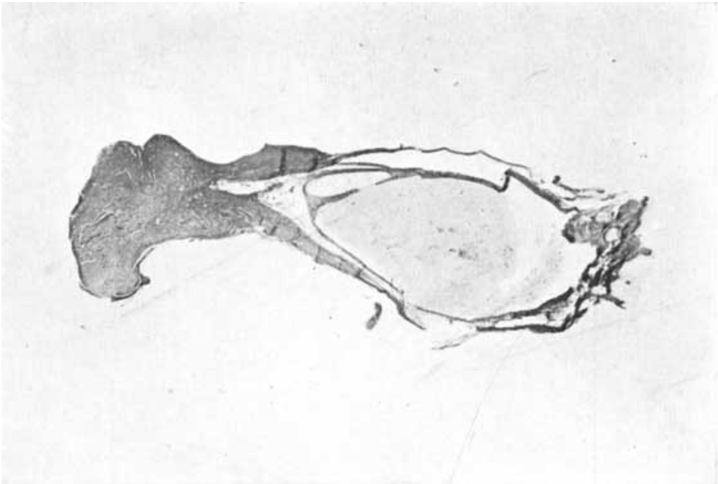

Fig. 15. Tendon repair at 70 days. One end of the suturation had become detached, which resulted in a large cyst. There are hairs within the cyst. × 4.

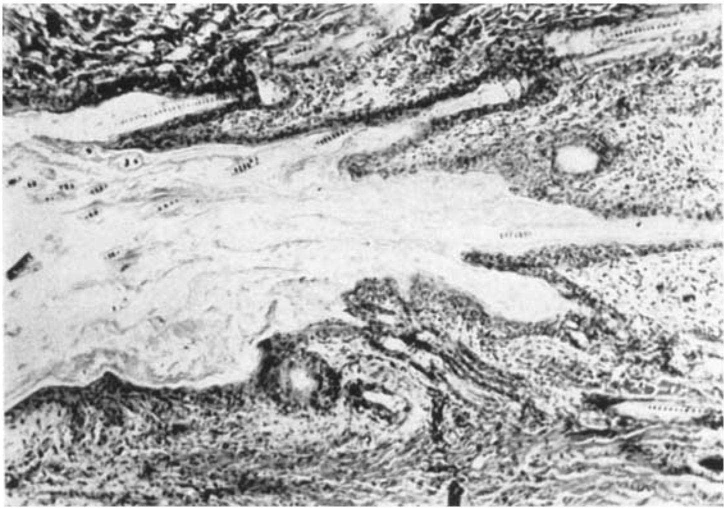

Fig. 16. Connected with Fig. 15. Epithelium with a hair follicle is seen in a section of the cyst wall. The hairs continue growing; some hairs are visible in the content of the cyst. × 150.

Fig. 17. Tendon repair at 4 months. Wall of the cyst, containing no hairs, from a region covered by epithelium where the cell nuclei stain well. Rough-fibred mesh-like connective tissue which has a normal appearance, connects the epithelial wall of the tendon tissue. × 280.

tendons, obviously with the purpose of preventing, as far as possible, any disturbance it might cause to movement (Fig. 17). Yet cysts of a macroscopic size are sources of severe disturbance. In the case where the graft had become loose the rabbit walked with difficulty and its heel developed a decubitus. In the other case with a cyst, too, the rabbit was badly lame in one leg, though there was no decubitus. When occurring in the abdominal wall these cysts seemingly caused no particular trouble even when felt by palpation as bulges the size of a bean.

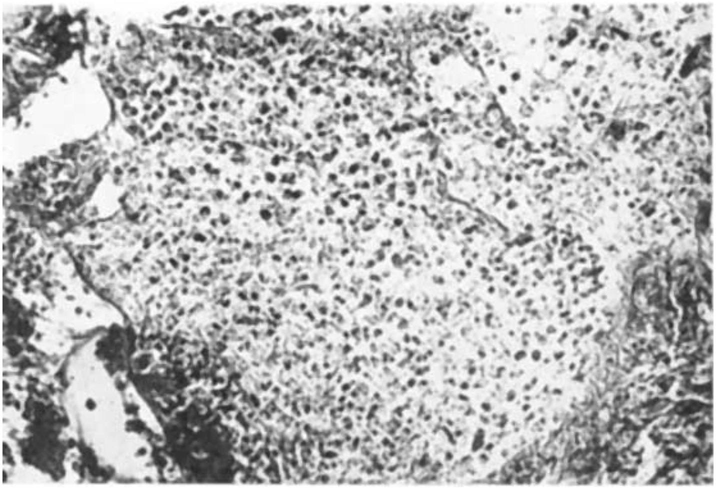

Fig. 18. Abdominal wall defect, at 3 days. Attachment of muscle and graft showing exudation deposit with numerous lympho- and leucocytes. Cells are also seen in the interspaces of the muscular fibres. × 380.

Attachment of the Graft

I. To Muscular Tissue

At 3 Days

Sometimes there is no space between the margin of the transplant and the muscular tissue, sometimes a fairly wide one is noted. A deposit of exudation occurs here, resembling a dense network in structure and containing a large amount of cells, of which 50 per cent are lymphocytes, 30 per cent neutrophil leucocytes and 20 per cent eosinophil cells. An abundance of small granules is revealed in the cells, apparently tissular remnants fagocytized by the cells. Numerous mitotic figures in the nuclei point to a lively formation of new cells. The connective tissue between the muscular fibres, perimysium internum, has extended somewhat in the region bordering on the defect, probably due to tissular oedema. The extended interstitial spaces, too, contain some cell infiltration, which penetrates deeper into the tissue in wedge-like formations. In the margin parts of the transplant itself in places widely apart slightly widened intersitial spaces between the bundles of fibrils are seen (Fig. 18).

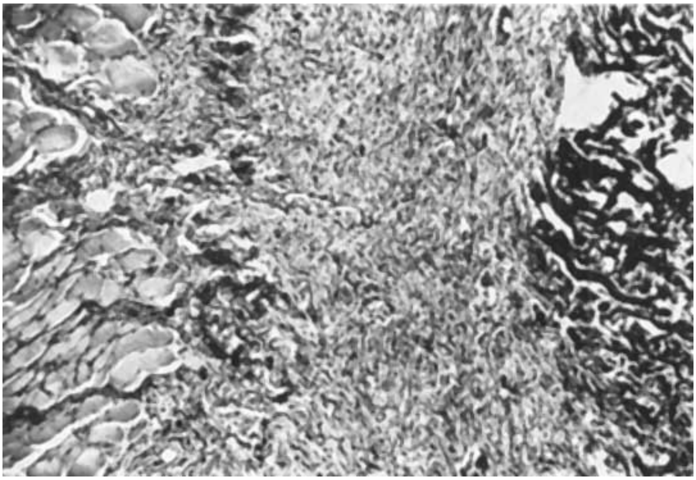

Fig. 19. Point of attachment between graft and muscle, at 7 days, filled with granulation tissue. This seems to push forth from the connective tissue between the muscular fibres. The interstitial spaces between fibril bundles in the graft are widened, and the granulation tissue tends to penetrate into the widened spaces. × 300.

At 7 Days

The connective tissue between the muscular fibres shows an increased number of cells and penetrates dispersing in a fan-like form into the tissue between the muscle and the transplant, which is loose granulation tissue. It contains numerous cells with oval-form nuclei, fibroblasts, but also a considerable amount of lymphocytes and neutrophil leucocytes and eosinophil cells. The margin of the muscular tissue shows abundant vascularity with thin capillaries and at several points the capillaries are seen to proceed from the connective tissue between the muscular fibres into this young tissue.

Due to increasing oedema the fibril bundles in the graft have been forced farther from each other and the marginal new tissue penetrates some way into the spaces left. In other respects the transplant seems to respond negatively to the young tissue which extends to both the upper and lower surfaces of the transplant (Fig. 19).

At 10 Days

The cell concentration of the young tissue in the intermediate region has been reduced, especially the number of lympho- and leucocytes. Between the fibroblasts which have drawn away from each other here and there some few thin parallel undulating fibril strands and an abundance of capillary lumina are to be seen. This young tissue extends a long way between the fibril bundles of the transplant and now some mitotic figures is revealed in the graft, especially in its marginal parts, as a sign that vital functions have begun there too.

At 15 Days

The cell concentration has diminished further, along with an increase in the number of fibrils. In places they tend to form thin bundles with a parallel course, which seem to proceed from fibril bundles between muscular fibres. At the same time it is evident that these fibril bundles of perimysium have themselves solidified. The number of the mitotic figures has remained almost unchanged.

At 25 Days

The fibroblasts unite closely with the fibril bundles which pursuing a slightly undulating course in a consistent strand proceed from between the muscular fibres so that the border between the perimysium and the actual new tissue is indistinguishable. Yet there is a clear difference compared with the fibril bundles of the transplant which are coarser in structure, and whose course has not concurred completely with the bundles of the intermediate tissue. The mitotic figures and the capillary lumina have decreased considerably in number. The lymphocytes, neutrophil leucocytes, and eosinophil cells occur either in isolation or in widely interspersed small accumulations (Fig. 20).

At 30 Days

The membranes of connective tissue covering the muscles, the external perimysia, have thickened and the fibril bundles within them have increased in number and thickness; they pursue an

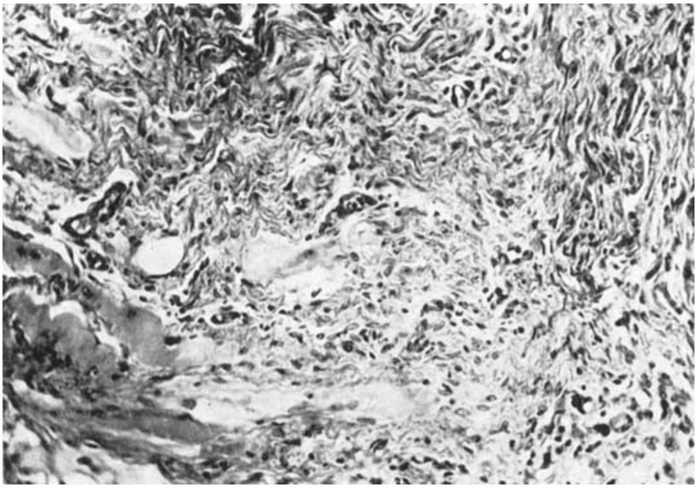

Fig. 20. Point of juncture between graft and muscle, 25 days. The connective tissue between the muscular fibres, abundant in cells, extends into the new tissue the cells and thin fibril strands of which run parallel with the perimysium fibres. The fibril bundles in the graft stand out clearly because of their coarser structure and differing direction of course. × 300.

unbroken course into the intermediate tissue. On the border of the transplant the structure and the direction of the fibril bundles show a sufficiently great difference for the border still to be established.

At 45 Days

The border between the intermediate tissue and the transplant is no longer distinguishable, the fibril bundles of the perimysium seem to run a parallel course into the transplant the fibril strands of which have mainly joined the course of those proceeding from the connective tissue of these muscles. Vascularity has diminished, likewise the cell concentration, and an ever increasing number of stab forms occur among the nuclei of the connective tissue cells.

At 60—360 Days

Especially the connective tissue covering the muscles strengthens along with the increase in it of fibril bundles, until at about 90 days a balance is reached. After this no appreciable changes take place at

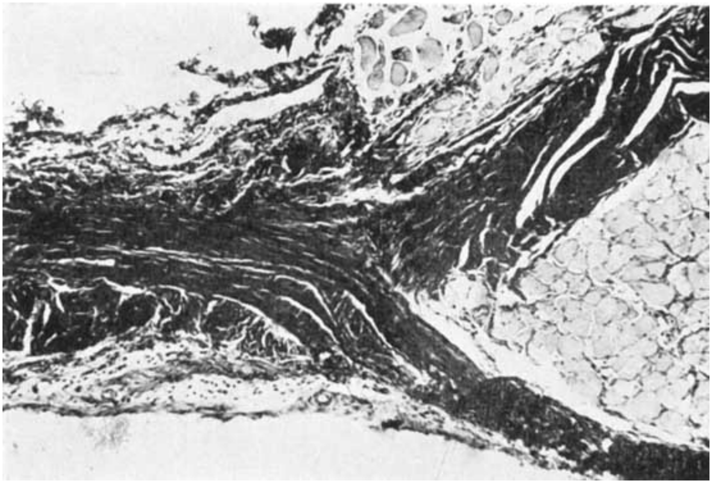

Fig. 21. Abdominal wall graft, at 3 months. Fasciae covering the muscles proceed in thick strands into the site of implantation where the course of the fibril bundles continues parallelly with muscular fasciae. The centre of the graft is of denser tissue, on both sides the structure is looser, vascularized. × 40.

the point of attachment except a reduction in the amount of cells and an increasing proponderance of stab forms among the nuclei of the cells of the connective tissue (Fig. 21).

2. To the Tendon

This occurs on the whole in the same manner as in the muscular tissue. As could be noted with the naked eye, the regenerative changes first took place mainly on the ventral side where no damage was done to the paratenon in the operation, but after 20 days the process on the dorsal side has reached approximately the same point.

At 5 Days

The intermediate space is filled with exudate containing considerable amounts of lymphocytes and neutrophil leucocytes as well as eosinophil cells. The tendon fibrils manifest no changes, but in the endotenon, on a narrow strip, some extension is seen, obviously

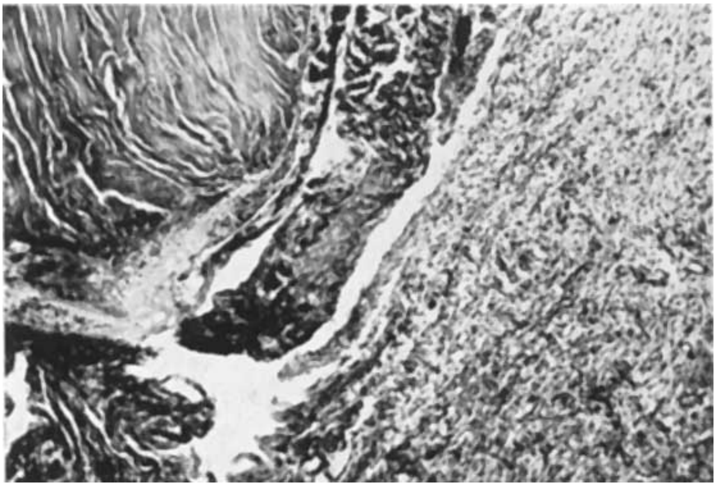

Fig. 22. Point of attachment between tendon and graft, at 5 days. The end of the tendon seen in left top corner, the graft below. Between them exudate with cells. A narrow region of degenerating tendon tissue, corresponding to the point of suturation, attaches to the tendon. The paratenon on the right is rich in cells and thickened. × 180.

in consequence of oedema. At the point of the suture small areas of tendon tissue are degenerating, since the nuclei do not stain. The most marked changes occur in the paratenon, which has thickened considerably, is rich in cells and presents several stages of mitotic figures. Columns of cells, moreover, are seen forcing their way from here into the intermediate tissue (Fig. 22).

At 7 Days

Cell proliferation has begun in the intermediate tissue, which contains fibroblasts with a number of mitotic processes going on. This tissue which is rich in cells seems to continue without any distinct border into the paratenon and in places invades the endotenon between the tendon bundles. A great number of lympho- and leucocytes occur around small necrotic areas. In the marginal part of the transplant the interstitial spaces between the fibril bundles have widened to some extent.

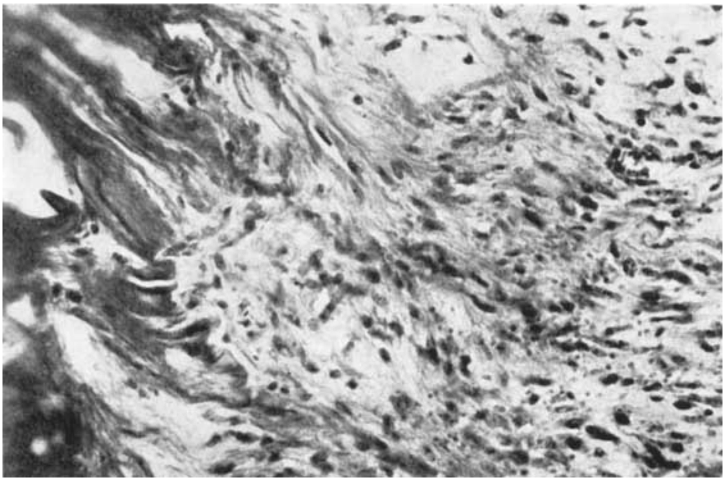

Fig. 23. Point of attachment in the tendon, at 10 days. At the end of tendon stump fibril bundles have broken up into strands and a loose new tissue with abundant cells seems to penetrate between the strands. The cells of the young tissue have arranged themselves in the direction of the tension. × 350.

At 10 Days

The fibroblasts in the intermediate tissue have lined up in the direction of tension. A considerable amount of capillary lumina are seen. The breaking up of the tendon bundles at the ends bordering on the intermediate tissue into thin fibrils is very noticeable, and the newly formed tissue which is rich in cells also invades between these fibrils. It likewise begins to extend to the small necrotic areas in the tendon causing the disappearance of the necrotic tissue (Fig. 23).

At 15 Days

The cell concentration of the intermediate tissue has decreased while thin fibrils running an undulating course in the direction of the tension have entered between the cells. The dispersed fibril bundles in the tendon tissue continue their course and gradually, without any distinct border, merge into this tissue. It is noteworthy that among the tendon cells those with stab form nuclei prevail and no signs of mitotic figures can be seen.

At 20 Days

The amount of cells has decreased further and that of fibril strands has correspondingly increased. In places they have packed into groups which pursue a parallel undulating course. These are obviously initial stages of fibril bundles. The necrotic areas have disappeared completely and the small groups of leucocytes that occur here and there are in all probability remnants of necrosis. The tendon cells themselves still display no reactions.

At 30—360 Days

The fibril bundles thicken continuously with the passing of time while the cell concentration in the intermediate tissue decreases correspondingly and stab form nuclei begin to preponderate. In a preparation of about 90 days' standing the structure has taken on the appearance of normal tendon structure to such a degree that under the microscope it is almost impossible to differentiate between the original tendon and the intermediate tissue, though the latter is progressively rather richer in cells than the normal tendon.

Synopsis of the Results

Both in the muscular and the tendon tissue some exudate first accumulates in the space between the graft and the tissue, where lymphocytes and leucocytes find their way at the same time. At the end of the first week the exudate is replaced by a loose young tissue rich in cells and capillaries, which as far as the muscular tissue is concerned seems to originate in the internal and external perimysium. At the same time, this tissue begins to penetrate into the interstices between the fibril bundles of the transplant which have widened evidently because of oedema. In the tendon tissue the granulation tissue seems to have its origin in the connective tissue covering the tendon, which proliferates considerably, and possibly to some extent in the connective tissue inside the tendon, the endotenon. Towards the second week, in both instances, but apparently somewhat earlier in the muscular tissue, fibril strands which adopt the course of the tension begin to form in this young tissue. During the third week these fibril strands group themselves into continuously thickening fibril bundles which follow the course of the tension. In the muscular tissue they proceed from the internal and especially the external perimysium, whose own fibril bundles have thickened. In the tendon tissue, on the other hand, the fibril bundles break up into strands at the stump end, and the new tissue penetrates between these strands apparently thus attaching this young tissue to the original tendon. Yet it should be noted that no division seems to take place in the tendon cells themselves, so that the tendon does not participate in the act of attachment. Clearly, too, the muscular cells do not take part in the formation of the new tissue but remain passive the whole time.

After 45 days, no margin is distinguishable in the muscular tissue between the new structure and the connective tissue of the muscle. In the tendon tissue complete merging does not take place until after 90 days. Nevertheless the cell concentration of the new tissue remained throughout the observation period somewhat higher than that of the normal structure.

Changes in the Connective Tissue of the Graft

I. In the Abdominal Wall Defect

At 3 Days

Only few changes are noted in the structure of the corium. The interstices between the collagenous fibril bundles have widened slightly only in a narrow region of both surfaces and around the hair follicles. Exudate has settled in these widened spaces and a certain number of lymphocytes and leucocytes have accumulated there. The connective tissue cells have survived well, the nuclei stain deeply and no mitotic figures occurs. The muscular cells in the transplant and the vascular lumina appear slightly contracted.

At 7 Days

The interspaces of the bundles of connective tissue have widened throughout and filled with exudation deposit and lympho- and leucocytes. Regions as yet displaying none of these cells occur only in the central parts of the transplant. The muscular cells and vascular lumina of the graft have contracted more and more and a considerable amount of lymphocytes and leucocytes have gathered around them (Fig. 8).

At 10 Days

A fairly thick layer of granulation tissue rich in vascular lumina is revealed on the upper and lower surface of the graft. The fibroblasts in this tissue tend to penetrate, accompanying the blood vessels, into the spaces between the fibril bundles, which correspondingly show less exudate and lympho- and leucocytes. Abundant mitotic figures are present in the fibroblasts, so that they reproduce fast.

At 15 Days

Fibroblasts fill the interstitial spaces of the fibril bundles. In places it seems as if the original fibril bundles of the transplant were dispersing into thinner strands while fibroblasts are penetrating into the spaces between. At some points in the new tissue some isolated thin fibril strands running a parallel course are revealed. The fibroblasts, too, lie parallel at certain levels.

At 25 Days

The number of fibroblasts has fallen considerably and that of the new fibril strands has correspondingly risen. The primary fibril bundles of the corium seem to have divided into thinner strands but they can yet be clearly differentiated from the new fibril strands which stain much lighter with the van Gieson method. Accumulations of lympho- and leucocytes are rather rare and occur mainly around the contracted remnants of muscular cells and the original vascular lumina of the graft.

At 30 Days

The number of fibrils has increased further and in places they have grouped themselves to form weak bundles which run a parallel slightly undulating course. Nearly everywhere the primary collagenous bundles have broken up into thin strands and joined the new fibril strands forming with them parallel bundles. Only here and there an isolated primary fibril bundle which has escaped division, is revealed. They stand out clearly because of their thickness, and they stain more vividly. The structure of the adjacent newly formed tissue resembles rather closely the structure in the site of the graft, for there too the fibril strands have increased and the number of the vascular lumina has decreased.

At 45 Days

The fibril bundles begin to tighten considerably and become thicker at certain points and their course is always parallel in the same areas. These fibril bundles proceed without any distinct margin from the intramuscular connective tissue and quite obviously their course is always determined by the effect of muscular tension. On the surface of the graft area which faces the abdominal cavity, an even, flattened smooth cellular layer is seen, underneath of which the connective tissue is somewhat looser than in the interior parts of the transplant. On the subcutaneous surface of the transplant, likewise, the connective tissue becomes looser when merging with the subcutaneous tissue.

At 60 Days

Part of the fibroblasts show stab form nuclei and follow closely the undulating course of the fibril bundles. The organization of the fibril bundles into layers proceeding at different levels has become clearer and the bundles have solidified further. Vascularity is decreasing in the interior parts of the transplant.

At 90 Days

The number of cells with stab form nuclei has increased somewhat though the cell amount has otherwise decreased, especially in the central parts of the transplant. It is now beautifully brought out how the fasciae covering the muscles continue their course on fibril bundles into the transplant and how the bundles in the transplant adopt a course conforming with that of the bundles of the muscular fasciae.

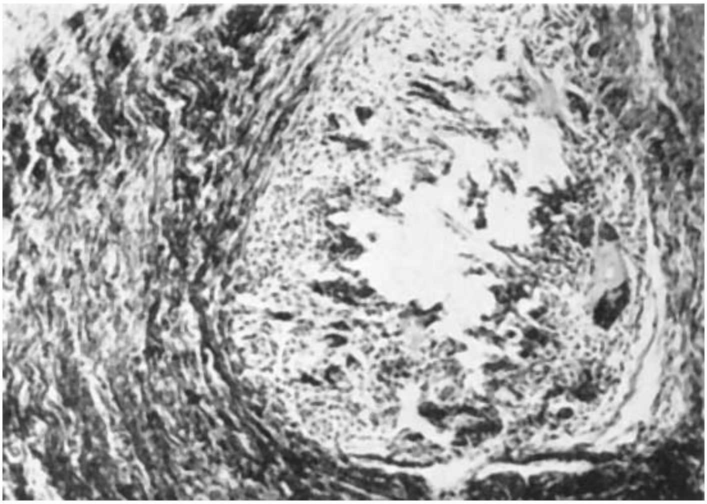

Fig. 24. Abdominal wall defect, at 80 days. Point of suturation with an abundance of epithelioid and giant cells. The fibril bundles run a circular course and their cell concentration does not exceed that of other regions in the graft. × 200.

A considerable accumulation of cells is revealed at the point of the suture, with an abundance of giant cells, epitheloid cells and lympho- and leucocytes. Around this area strong fibril bundles run a ring-like course (Fig. 24).

After 90 days no appreciable changes take place, though the cell concentration falls slightly, remaining nevertheless somewhat higher than that of a normal aponeurosis, to which in other respects it bears a close resemblance.

2. In the Tendon Defect

Here the skin graft is under a tension working in one direction, and though the changes resemble those occurring in the abdominal defect, the end result is slightly different.

At 5 Days

The transplant is surrounded by a layer of exudate containing lymphocytes and leucocytes. The paratenon and the adjacent connective tissue have grown rich in cells especially on the ventral side.

At 7 Days

The surrounding connective tissue has thickened and its vascularity increased considerably. This fact was brought out very clearly, because the aorta had been injected with Indian ink. From the connective tissue columns of fibroblasts invade the exudate layer. The interstices between the fibril bundles of the transplant have widened and are filled with exudate and lympho- and leucocytes.

At 10 Days

From the surrounding connective tissue some strong granulation tissue columns push up to the surface of the transplant and seem partly to penetrate into the widened interspaces of the fibril bundles, which are mainly filled with fibroblasts. In places the thick fibril bundles are seen to break up into thinner strands and fibroblasts appear between these strands.

At 15 Days

The division of the fibril bundles into strands has continued and the interstices are filled with fibroblasts which have grouped themselves in the direction of the tension.

At 20 Days

The graft is surrounded by a thick layer of newly-formed tissue with fibroblasts organized in the tensional direction and some thin fibril strands, likewise running in the direction of the tension, in the interstitial spaces. In the site of the graft thin new fibril strands have formed in the interstices of the fibroblasts, which stain much less deeply by the van Gieson method than the original fibril strands. The original fibril bundles are left, particularly in the tensional pirection, but those which proceeded in the other direc tions have apparently for the most part broken up into strands. The cells of these original fibril bundles whose course is parallel to the tension, also show oval nuclei and plentiful mitotic figures.

At 30 Days

The fibril strands run parallel and begin to unite into thick bundles. At several points it is difficult to differentiate clearly

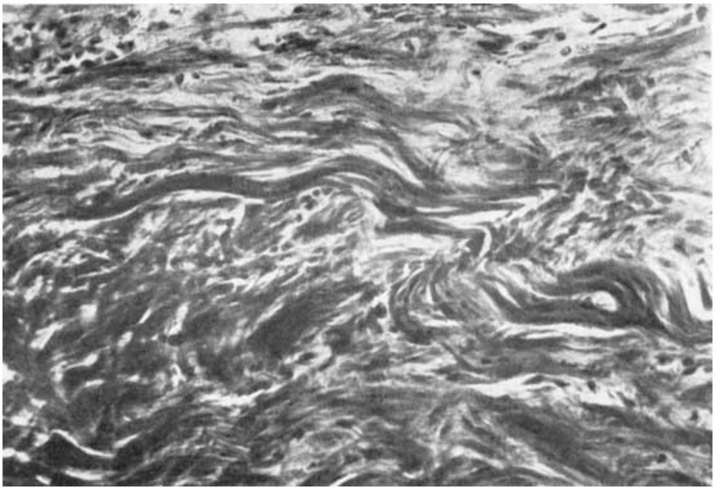

Fig. 25. Graft in tendon defect, at 30 days. The tissue is rich in cells. The original fibril bundles have been preserved in the tensional direction, but in the other directions they have broken up into thin strands. New fibril strands have formed, but so far they stain imperfectly. × 300.

between the newly formed tissue and that belonging to the graft. A certain amount of lympho- and leucocytes remain in both, and large blood vessels are quite plentiful (Fig. 25).

At 40 Days

The fibril bundles have thickened and vascularity has decreased.

At 45 Days

The fibril bundles run in fairly thick undulating bundles. The structure begins to take on a resemblance to the tendon tissue, although the fibroblasts still have spindle nuclei. It is now difficult to distinguish the original extant fibril bundles from the new ones.

At 60 Days

The fibril bundles have thickened and their cell concentration has decreased.

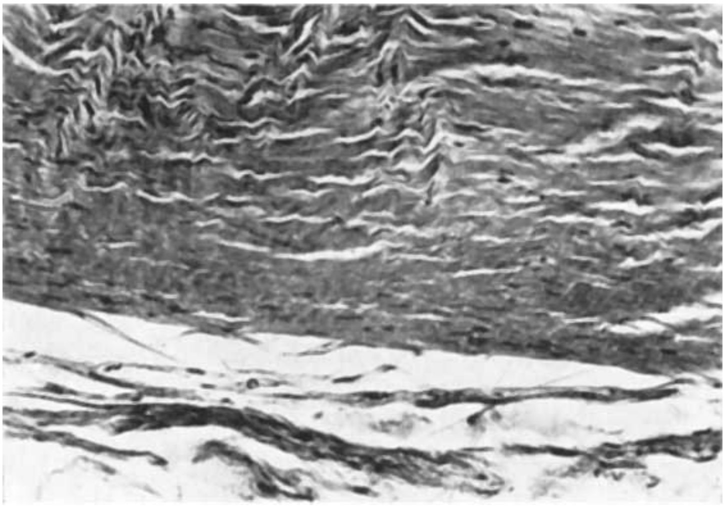

Fig. 26. Tendon repar at 6 months. The tissue resembles normal tendon tissue to such an extent that it is difficult to determine exactly the demarcation line between the graft and the original tendon, though the cell concentration of the site of implantation is somewhat higher. The tendon attaches to its surroundings with coarce-fibred connective tissue in mesh-like formation. × 350.

At 90—360 Days

The transplant completely resembles the normal tendon in structure, although the amount of cells still exceeds that of ordinary tendon tissue. The cell nuclei have now become stab forms, which implies a quiescent phase of the tissue. The site of implantation merges with its surroundings through the medium of loose tissue that has the appearance of network. As late as at 360 days hair fragments lying in the interstices of the fibril bundles are encountered (Fig. 26).

Synopsis of the Results

The changes in the connective tissue show an exactly similar pattern in the muscle and tendon tissue. During the first week the interstitial spaces between the fibril bundles of the transplant fill up with exudate and lympho- and leucocytes. During the second week this exudate is replaced by loose granulation tissue which penetrates into it from the surroundings, and in the marginal parts also begins to force its way into the fibril bundles breaking them up into fibril strands. This process continues in the third week while at the same time the fibril strands adopt the direction of the tension. Contemporaneously new thin fibril strands begin to form. In the fourth and fifth weeks, along with an increase in number, the fibril strands group themselves into parallel bundles, whose thickness and strength increase with time while the cell concentration decreases and the cell nuclei change into stab forms. In 90-day preparations, when a quiescent phase has set in, the graft closely resembles a normal fascia or tendon although the amount of cells remains somewhat above the normal. The effect of the tension becomes clearly apparent through the fact that in the tendon defect when the graft is under tension acting in one direction, all the fibril strands, both those which have formed through division and the new ones, and later the fibril bundles, organize themselves in the direction of the tension. In the muscle defect, on the other hand, when under tension from different directions, the fibril strands on the same level pursue a parallel course but those at different levels cross each other. This is because the direction of the muscular tension varies on the different levels and the fibril bundles follow the direction of the tension acting on each level.

Apparently in cases where the course of one of the fibril bundles of the original implant corresponds with the direction of the tension, this type of fibril bundle may escape division and as such become part of the new connective tissue.

Elastic Fibres

The changes in the elastic fibres of the graft by no means followed the same regular course as those of the collagenous ones. Originally, they form in the corium a network around the collagenous bundles, but their course changed and became parallel with the changed course of the collagenous fibrils in the tensional direction at 10—30 days. In some preparations the elastic fibres stayed in membraneous layers, in others they had dispersed evenly all over the site of the graft and no explanation could be obtained from the preparations themselves for this difference. Whether the number of the elastic fibres increases or remains what it was in the original graft, remained an open question in these experiments. Apparently however there is no appreciable increase, for the number of fibres did not seem to grow with time, though their thickness apparently increased somewhat. JACOBSON (1953) writes: "While collagen and reticular fibres can be regenerated through life, elastic fibres cannot be replaced to any extent in the adult human. Thus any scar contains an abundance of collagen, but not of elastic fibres". In the present experiments also no new formation of elastic fibres was noted in the area of the new tissue round the graft.

It seems as if the number of the original elastic fibres did not grow, their course becomes that of the muscular tension and possibly their thickness increases somewhat with time.

DISCUSSION

Material and Technique

Only adult rabbits were used for the experiments, so that there were no variations in age to affect the estimation of the results. No notice was taken of sex, but this could hardly influence the results as it has been shown that sex has no effect on the healing of wounds (HARVEY and HOWES 1930).

Although no antibiotics were used, infections were relatively rare in view of the difficulty of maintaining sterility in animal experiments. Infected cases were not taken into account in the present studies. Many surgeons who have used skin grafts in clinical work have noted that infections occur in the same ratio as in other corresponding operations (MAIR 1946, WEST and HICKS 1948). It has also been found that in cases of infection the skin or cutis graft has a good resisting power nor does the infection often lead to detachment of the graft or necrosis; the end results are mainly good (BLÜMER 1948, HEMPEL 1952, BARTHOLD and WEHRHEIM 1952). Apparently the skin graft tolerates X-rays well, too, SWANKER (1948) described a case in which a sarcoma of transverse colon had become attached to the abdominal wall and it became necessary to remove a large piece of the wall. The resulting gap had to be repaired by a free skin graft, and the patient was later given local X-ray treatment. He writes: "It is interesting to note that this therapy had no deleterious effect upon the graft so far as could be determined clinically".

In the present series it was found serviceable to obtain specimens in the first month at relatively short intervals, and often two experiments were made for equal lengths of time. The purpose was to ensure as accurate a picture as possible of this transformation, in the hope of eliminating all occasional and incidental factors.

As to technique, in the tendon defect the graft was inserted in the frontal plane, and when taking the specimen the implant area was split in the centre on the sagittal plane. The preparations were excised from this sectional surface. The advantage of this was that in all the experiments the specimens were actually obtained from the corresponding point, which makes them comparable. REHN and MIYAUCHI (1914) as well as SCHWARZ when making similar experiments used strips of cutis which they corded into twists. This makes it difficult to indentify corresponding skin layers in the different preparations and to compare their changes. In clinical work, too, it is obviously unpractical to use a twisted skin graft or one that has been rounded into a tube, for BUNNELL (1948) writes of the use of fascia in a tendon defect: "In grafting large tendons, it is best to use a flat piece of thick fascia lata and to refrain from tubularizing it, in order to give it nourishment through each surface".

Changes in the Graft

When studying the disappearance of the epithelium, the attachment of the graft, and changes in its connective tissue, three phases are noted in each process, as appeared from the previous detailed description:

1. The exudation phase, which is apparently a consequence of changes in the permeability of the blood vessel due to irritation caused by a foreign body. By means of the exudate the organism obviously tries to isolate this foreign body. The exudate shows a deposit of lympho- and leucocytes, which recognizedly are capable of resolution and resorption of exudate. This phase lasts till towards the end of the first week, when

2, the reparative phase, begins. In this phase proliferating fibroblasts and vascular capillaries invade the area of the exudate and form granulation tissue. Through this the organism attempts to convert the foreign body into an organic part of itself. The phase continues up till the end of the second week, and early in the third week

3, the maturation phase, begins. The granulation tissue becomes poorer in cells and forms fibril strands the number and thickness of which increase with time. The organism tends to change the newly formed tissue so as to make it conform with the requirements set to it by its function.

Disappearance of the Epithelium

In the exudate phase the epithelium becomes detached from the corium, which gives the granulation tissue room to surround the epithelium completely. It now rapidly loses its viability and its remnants disappear. Sometimes, however, the epithelium remains viable and keeps growing. This happens in the first place if the tension in the transplant disappears. STRAHAN explained the significance of the tension so that in a transplant under tension the exchange of electrolytes becomes hampered, epithelial nutrition suffers and the epithelium degenerates before the implant has had time to become revascularized from adjacent tissue. Secondly, the epithelium may survive and form cysts, if it has not disappeared in the reparative phase. It is obviously the granulation tissue that prevents the epithelium from growing; when the maturation phase sets in for this tissue after 14 days, the remaining epithelial cells can continue their growth and develop cysts. This may account for the fact that no cysts, not even in an initial stage, were yet met with in the exudate and reparative phases.

Cysts of a microscopic size seem to be fairly common, but they do not appreciably hamper the healing of the operative field or its use. Cysts of this kind do not occur only when whole-thickness skin is used; in a cutis graft also small sebaceous cysts with the appearance of atheroma are sometimes found. Their formation has been attributed to epithelial remnants (v. BRANDIS 1941). Yet HARKINS declared: "It is impossible to remove all of the epithelial elements from the cutis without excising such a thick layer of epidermis that no dermis is left behind".

KING (1933) put forward a theory according to which epithelial cysts have their origin in haematomata which come into touch with the epithelium or the glandular structure of the skin, so that epithelium begins growing to cover the wall of such a haematoma. In the present studies no signs of haematoma were noted even in the content of cysts in the first stages of development, so that this aetiology seems improbable, at least as far as the present experiments are concerned.

Those opposing skin grafts have also pointed to the possibility of malign degeneration. Nothing of the kind has been reported in the literature.

Attachment of the Graft

I have not found in the literature any descriptions of the attachment of a whole-thickness skin graft to the muscle tissue. GEEVER et. al (1952) did in fact experiment on a series of 32 dogs, repairing a defect they made in the diaphragm with a cutis graft. They found that it formed a strong enough partition between the thoracic and abdominal cavities. These workers also mention the use, without complications, of free cutis graft on human beings to repair a diaphragm defect which had occurred in connection with extirpation of stomach cancer. Yet they say nothing more definite about the fusion of the cutis graft and the muscle.

In the present experiments it was noteworthy that the attachment was first to the internal perimysium but later mainly to the external perimysium, the fibres of which continue without breaks into the site of implantation.

Three different tissues may participate in the repair of tendon defects, the tendon tissue itself, the connective tissue inside the tendon, or the connective tissue outside it. Opinions differ considerably as to the share of these tissues in the repair process. In the past, workers supposed that the tendon cells were the most important elements and that the connective tissue played only a subordinate part (ENDERLEN 1893, SEGGEL 1903). The majority of workers, however, consider the connective tissue a more important constituent and suggest that the tendon tissue hardly participates in the process at all (SCHWARZ, NÄRVI 1926, 1931). MASON and ALLEN (1941) consider all three elements important in the process of repair. SKOOG (1951) showed that it was possible to prevent, by means of a metal tube, the invasion of adjacent connective tissue into the point where the tendon is sutured. In these cases there was no healing. From his histological studies SKOOG concluded that endotenon and the tendon cells were of no significance in the regenerative process of the tendon and that the regeneration originated from the non-specific surrounding connective tissue only.

In the present studies no mitotic figures were noted in the tendon cells themselves, which apparently were in a quiescent state and therefore very probably did not participate in the formation of the tissue at the point of attachment. Extension could be noted in the endotenon area, which may have mainly been due to oedema.

There is moreover nothing that speaks against the theory that at these points the cells themselves proliferate, though there has been nothing to confirm it. The surrounding connective tissue increases forcibly, and in any case forms the main part of the junctural tissue which is gradually converted from an original tissue with plentiful cells into a tissue resembling the tendon.

Changes in the Connective Tissue

Functional changes in tissue appear most clearly in the musculature and the bones. ROUX (1913) was the first to declare that the processes called "hypertrophy of activity" and "atrophy of inactivity", which were known to occur in the muscular and bone tissues, pertained to connective tissue as well. Just as the interior structure of the bone changes under the influence of the force of tension and the force of gravitation that affect it, so the connective tissue also responds to such functional stimulus in a characteristic manner. Its fibres organize themselves under continuous tension in the direction of the tension. It is a now universally accepted view that the function substantially affects the regeneration and the transformation of the transplant and that its ultimate structure is determined by the functional requirements.

On the other hand it has been suggested that there are other forces that affect the fate of the transplant. BIER (1917) claimed that all tissular regeneration took place under the influence of irritants either promotive or preventative to regeneration, which occurred in the tissue in the form of hormones. SALOMON (1922, 1924) tried to obtain support for BIER's view from animal experiments pertaining to the growth of tendon tissue. REHN (1936), after previously considering function the only determinant of transplant transformation, now traced the growth of the implant to hormonal factors. Function, for its part, had an effect on the determination of the structure of the original tissue and the tissue merging in it through growth. He further suggested the existence of a special organizational centre, which regulates the development of the structure so as to make it into a harmonious whole.

The effect of the function on the form of the transplant has often been noted. In experiments on dogs SWENSON (1950) found when using the cutis graft on both abdominal wall and Achilles tendon defects, that after 152 days the site of implantation could no longer be differentiated from either the fascia or the tendon.

In these experiments the effect of the function on the transformation of the skin graft was established clearly. Under tension the fibres of the connective tissue group themselves in the tensional direction. The first changes are noted in the structure of the fibril bundles at 10 days, and after 20 days the fibres run a parallel course. The detailed course of events is not quite clear from the experiments, since for elucidating this it would apparently have been necessary to obtain specimens between the 10th and 30th days at much shorter intervals, obviously every day. Yet one gets the impression that the original collagenous fibres first break up into thin strands which then turn parallel to the tension. Later, again, these strands unite into thicker bundles. As such the fibril bundles originally running in the tensional direction do not divide and unite with the newly-formed fibril bundles.

It is clear that the graft tolerates tension poorly at the time when the original bundles of connective tissue have broken up into strands, and new fibril bundles have not yet formed. In the third week stretching in the tendon implants was visible to the naked eye. It was still doubtful why contraction of the implant was noted at the same time in the defect in the abdominal wall. Apparently the graft is not under equal tension in the abdominal wall, and the contraction peculiar to cicatrical tissue preponderates here.

SUMMARY AND CONCLUSIONS

The purpose of the present study is to elucidate, by means of animal experiments:

1. the fate of the epithelium of the whole-thickness skin graft both in the abdominal cavity and in subcutaneous tissue.
2. how the attachment of the whole-thickness skin graft to muscular tissue and to tendon tissue occurs, and
3. what changes take place in the whole-thickness skin graft under tension when embedded in tissue and subject to pull from different directions as in a muscular defect, and when subject to pull in one direction as is the case in a tendon defect.

The series consisted of 25 adult rabbits. Three operations were made on each of the rabbits by transferring a whole-thickness skin graft into a defect in the abdominal wall so shat the epithelium faced the abdominal cavity, and into two Achilles tendon continuity defects. In all 75 operations were made.

The changes in the whole skin graft were studied both with the naked eye and under the microscope after varying periods from the operation, ranging from 3 to 360 days.

First the transplant causes irritation in the surrounding tissue, to which the organism responds by developing exudate, apparently with the purpose of isolating this foreign body. This so-called exudate phase lasts till towards the end of the first week, when it changes into a reparative phase. Granulation tissue now replaces the exudate. In the third week the maturation phase begins, the granulation tissue grows poorer in cells and a greater number of fibril strands are produced. The three phases are apparent both in the disappearance of the epithelium and the attachment and transformation of the graft.

In cases which run a regular course the epithelium disappears during the reparative phase, so that in preparations at 15 days, when the maturation phase is beginning, there is no longer any epithelial tissue present. Yet if the epithelial cells have succeeded in surviving this phase, they tend to form small cysts in the course of proliferation, which do not hamper the healing of the site of implantation much, nor its function. One actual complication, though a rare one, is the appearance of large cysts of macroscopic size, which are due to the disappearance of tension in the graft, which with its epithelium then forms a part of the wall of the cyst.

The remnants of hair arrange themselves in the direction of the pull which acts on the graft, and do not seem to produce any appreciable reaction in the adjacent tissue. Such remnants may be encountered even in sites of implantation of one year's standing.

The disappearance of the epithelium occurs in approximately the same manner in the abdominal cavity and in subcutaneous tissue.

The attachment of the skin graft to the muscular tissue takes place as follows: the internal connective tissue, perimysium internum and above all the connective tissue covering the muscle, perimysium externum, proliferate and unite with the granulation tissue which surrounds the graft and penetrates into it. In the maturation phase the fibril strands and bundles of the muscular connective tissue force their way into this intermediate tissue and further into the graft. The muscle cells themselves remain completely passive.

In the attachment to the tendon tissue the main part is played by the surrounding connective tissue and possibly some small part by the internal connective tissue of the tendon, endotenon. The tendon tissue itself does not seem to participate in it nor does there seem to be any numerical increase of the tendon cells.

The interstitial spaces of the fibril bundles of the corium widen and primarily fill with exudate, which in the reparative phase is replaced by an abundance of connective tissue cells. When penetrating into the fibril bundles they break these up into fibril strands which reorganize themselves to take the course of the direction of the tension; in the maturation phase they increase in number and again unite into fibril bundles. Thus under a tension acting from different directions a tissue resembling aponeurosis is produced, and under a tension from one direction a structure similar to a tendon. Yet it does not macroscopically display the normal tendon-like gloss, and under the microscope, too, the tissue thus produced appears somewhat richer in cells than the normal tendon tissue.

To my mind the experiments have shown that when a whole-thickness skin graft is used the organism destroys or isolates in it the tissue which is ectodermal in origin, and transforms the tissue which has developed from the mesoderm into an organic part of itself.

REFERENCES

Barthold, G. and *Wehrheim, W.:* Theoretische Überlegungen und praktische Erfahrungen bei der verwendung der Cutistransplantation nach E. Rehn. — Zbl. Chir. 1952:77:705.

Behrend, M. and *Behrend, A.:* Full thickness skin graft in the repair of voluminous hernias. — J. int. Coll. Surg. 1950:13:41.

Benninghoff: Funktionelle Anpassung im Bereich des Bindegewebes. — Anat. Anz. Erg. H. 1931:72:95.

Bensley, B. A.: Practical anatomy of the rabbit. Philadelphia 1948.

Bier, A.: Beobachtungen über Regeneration beim Menschen. — Dtsch. med. Wschr. 1917:43:833.

Blond, K.: Zur Kenntnis der traumatischen Epitelcyste. — Arch. klin. Chir. 1922:120:695.

Blümer, G.: Freie Cutisplastik zum Verschluss des grossen Bauchdeckenbruches. — Chirurg 1948:19:71.

Born, S.: Zur Frage der epidermalen Basalmembran. — Derm. Z. 1921:34: 324.

v. Brandis, H. J.: Die Cutisplastik nach E. Rehn. — Chirurg 1941:13:418.

— Klinische Demonstrationen zur Behandlung grosser Bauchnarbenbrüche mit Kutisplastik nach Rehn. — Zbl. Chir. 1950:75:785.

Brockis, J. G.: The blood supply of the flexor and extensor tendons of the fingers in man. — J. Bone Jt Surg. 1953:35—B:131.

Broman, I. and *Häggqvist, G.:* Lärobok i histologi. Stockholm 1945.

Browne, H. R.: The dermograft — its versatility and viability. — Plast. reconstr. Surg. 1951:7:41. Ref. ZentOrg. ges. Chir. 1951:120:319.

Bunnell, S.: Surgery of the hand. — Philadelphia, London & Montreal 1948.

Bätzner, K.: Die Beseitigung grosser Narbenbrüche nach Operationen und Unfallverletzungen durch die freie autoplastische Cutistransplantation. — Bruns' Beitr. klin. Chir. 1949:178:481.

Cannaday, J. E.: The use of cutis graft in the repair of certain types of incisional herniae and other conditions. — Ann. Surg. 1942:115:775.

— Some of the uses of the cutis graft in surgery. — Amer. J. Surg. 1943: 59:409.

— Cutis graft in surgery: A review of results obtained, with comments on indications and technic and report of cases. — Arch. Surg. 1946:52:286.

Carstam, N.: The effect of cortisone on the formation of tendon adhesions and tendon healing. — Acta chir. scand. suppl. 1953:182.

Chodoff, R. J.: The use of full thickness skin graft in the repair of large herniae. — Ann. Surg. 1949:129:119.

Clarke, S. H. C.: The formation of inclusion dermoid cysts following whole-thickness skin-graft repair of hernia. — Brit. J. Surg. 1952:39:346.

Dantlo, R.: Transplantation de derme pour la cure des éventrations. — Presse méd. 1946:50:680.

Darrow, M.: Synthetic orcein as an elastic tissue stain. — Stain Technol. 1952:27:329.

Davis, J. S. and *Traut, H. F.:* The production of epithelial lined tubes and sacs. — J. Amer. med. Ass. 1926:86:339.

Dick, J. C.: Observations on the elastic tissue of the skin with a note on the reticular layer at the junction of the dermis and epidermis. — J. Anat. (Lond.) 1947:81:201.

Dumont, A. and *van der Ghinst, M.:* L'utilisation de la greffe de peau totale dans la cure des hernies et des éventrations. Résultats éloignés. Enseignements á tirer de deux réinterventions. — Acta chir. belg. 1949:48:456.

Edwards, D. A. W.: The blood supply and lymphatic drainage of tendons. — J. Anat. (Lond.) 1946:80:147.

Eisele, W. M. and *Starkloff, G. B.:* The use of skin grafts in hernia repair. — Ann. Surg. 1951:134:897.

Eitel, H.: Versuche zur Lebensenergie von Cutis. — Dtsch. Z. Chir. 1933: 242:806.

Eitner, E.: Über Unterpolsterung der Gesichtshaut. — Med. Klin. 1920: 16:93.

Enderlen: Ueber Sehnenregeneration. — Arch. klin. Chir. 1893:46:562.

Garrè, C.: Ueber traumatische Epithelcysten der Finger. — Bruns' Beitr. klin. Chir. 1894:11:524.

Geever, E. D. and *Merendino, K. A.:* The repair of diaphragmatic defects with cutis grafts. — Surg. Gynec. Obstet. 1952:95:308.

Gibbon, N. O. K. and *Lothian, K. R.:* Epithelial survival after cutis grafting. — Brit. J. Surg. 1952:39:501.

Giegerich, R. L.: Unsere Erfahrungen mit der freien Kutisplastik nach Rehn zum Verschluss grosser Bauchwandbrüche. — Zbl. Chir. 1951: 76:881.

Goodall, R. G. and *Guthrie, R. F.:* Repair of inguinal hernia with whole skin grafts. — Sth. Surg. 1947:13:135. Ref. Swenson 1950.

Gorni, D. L.: Plasticas con piel total en la reparación de grandes eventraciones y hernias. — Rev. méd. Rosario 1948:38:8. Ref. Excerpta med. (Amst.), Sect. IX 1949:3:772.

Gosset, J. and *Bonvallet, J. M.:* L'emploi des lanières de peau totale dans la réfection des ligaments articulaires. — Sem. Hôp. Paris 1951:27:2319.

Gray, D. B., Mansberger, A. R. jr. and Yeager, G. H.: The fate of buried full-thickness skin. — Ann. Surg. 1951:134:205.

Greene, L. W. jr. and *Wollgast, G. F.:* Full-thickness skin grafts in hernial repair. — Surgery 1949:25:902.

Harkins, H. N.: Cutis grafts: Clinical and experimental studies on their use as a reinforcing patch in the repair of large ventral and incisional herniae. — Ann. Surg. 1945:122:996.

Harvey, S. C. and *Howes, E. L.:* Effect of high protein diet on the velocity of growth of fibroblasts in the healing wound. — Ann. Surg. 1930:91: 641.

Hempel, E.: Die Versorgung übergrosser Bauchwandbrüche durch Kutisplastik. — Zbl. Chir. 1952:77:2228.

Herxheimer, K.: Ueber die epidermidale Basalmembran. — Derm. Z. 1916: 23:129.

Hesse, F. A.: Die Entstehung der traumatischen Epithelcysten. — Bruns' Beitr. klin. Chir. 1912:80:494.

Homb, A.: The treatment of large hernia with whole-skin grafts. — Acta chir. scand. 1952:104:171.

Jacobson, W.: Histological survey of the normal connective tissue and its derivatives. — *Randall, J. T.:* Nature and structure of collagen. London 1953.

Jolicoeur, A.: A propos des hernies et de leur réparation par des greffes intratissuraires de peau ou de derme. — Laval méd. 1949:14:720.

Junghanns, H. and *Juzbašić, M.:* Verschluss grosser Bruchpforten durch Cutislappenplastik. — Chirurg 1940:12:742.

Kallio, K. E.: Personal communication.

Kaufmann, E.: Ueber Enkatarrhaphie von Epithel. — Virchows Arch. path. Anat. 1884:97:236.

Kilian, V. Z. I.: Transplantace kuže u velkých brišních kýl. — Lék. Listy 1947:2:165. Ref. Excerpta med. (Amst.), Sect. IX 1948:2:387.

— Brně Naše zkušenosti s kožni plastkou pri operativním léčení kýl. — Rozhl. Chir. 1951:30:11. Ref. Excerpta med. (Amst.), Sect. IX 1951:6:245.

King, E. S. J.: Post-traumatic epidermoid cysts of hands and fingers. — Brit. J. Surg. 1933:21:29.

Krause, W.: Die Anatomie des Kaninchens. Leipzig 1884.

Lauber, H. J. and *Aresin, N.:* Zur Anwendung der Cutisplastik. — Chirurg 1947:17:211.

Limbosch, J.: Cure de hernie inguinale géante par greffe de peau. — Acta chir. belg. 1949:48:454.

Loewe, O.: Ueber Hautimplantation an Stelle der freien Faszienplastik. — Münch. med. Wschr. 1913:60:1320.

— Ueber Haut-Tiefenplastik. — Münch. med. Wschr. 1929:76:2125.

Mair, G. B.: Preliminary report on the use of whole skin-grafts as a substitute for fascial sutures in the treatment of herniae. — Brit. J. Surg. 1945:32:381.

— Use of whole skin grafts as a substitute for fascial sutures in the treatment of herniae: Preliminary report. — Amer. J. Surg. 1945:69:352.

— Analysis of a series of 454 inguinal herniae with special reference to morbidity and recurrence after the whole skin-graft method. — Brit. J. Surg. 1946:34:42.

Marsden, C. M.: Whole skin-graft repair of inguinal hernia. An account of 163 operations, with a follow-up of 136 operations at 12 months. — Brit. J. Surg. 1948:35:390.

Martini, R.: La nostra esperienza sull'uso di innesti di cute intera nella cura delle ernie recidive e degli sventramenti. — Boll. Soc. tosco-umbr. Chir. 1949:10:36. Ref. Excerpta med. (Amst.), Sect. IX 1949:3:1291.

Mason, M. L. and *Allen, H. S.:* The rate of healing of tendons. — Ann. Surg. 1941:113:424.

May, H. and *Spann, R. G.:* Cutis grafts for repair of incisional and recurrent hernias. — Surg. Clin. N. Amer. 1948:28:517.

Mustonen, M. and *Helve, Y.:* Kaniini. — Helsinki 1940.

v. Möllendorff, W.: Handbuch der Mikroskopischen Anatomie des Menschen. — Berlin 1930. Bd II.

Närvi, E. J.: Beiträge zur Kenntnis der Sehnenregeneration und Behandlung der Sehnenrupturen, insbesondere im Gebiete der synovialen Scheiden. — Acta chir. scand. 1926:60:1.

— Einiges zur Frage der Sehnenregeneration. — Acta chir. scand. 1931: 68:267.

Pataro, V. and *Zavaleta, D. E.:* El injerto de piel en la reparación de las hernias abdominales. — Rev. Asoc. méd. argent. 1947:61:666. Ref. Excerpta med. (Amst.), Sect. IX 1948:2:997.

Peer, L. A.: Types of buried grafts used to repair deep depressions in skull. — J. Amer. med. Ass. 1940:115:375.

Peer, L. A. and *Paddock, R.:* Histologic studies on the fate of deeply implanted dermal grafts. — Arch. Surg. 1937:34:268.

Pels-Leusden: Ueber abnorme Epithelisierung und traumatische Epithelcysten. — Dtsch. med. Wschr. 1905:31:1340.

Pone, J.: Behandlung der Narbenbrüche mit Interplantation des Narbengewebes. — Zbl. Chir. 1948:73:356.

Powell, T. and *Ewing, M. R.:* Post-operative implantation dermoid cyst. Brit. J. Surg. 1952:39:366.

Rehn, E.: Das kutane und subkutane Bindegewebe als plastisches Material. — Münch. med. Wschr. 1914:61:118.

— Zu den Fragen der Transplantation, Regeneration und ortseinsetzenden funktionellen Metaplasie. (Sehne- Faszie-Bindegewebe.) — Arch. klin. Chir. 1919:112:622.

— Über die funktionelle Anpassung des Bindegewebes im chirurgischen Geschehen. — Anat. Anz. Erg. H. 1931:72:133.

— Wiederherstellungschirurgie einschliesslich der Verwertung freier Transplantationen, Überblick und heutiger Stand. — Arch. klin. Chir. 1936:186:244.

Rehn, E. and *Miyauchi:* Das cutane und subcutane Bindegewebe in veränderter Funktion. — Arch. klin. Chir. 1914:105:1.

Reverdin, J. L.: Des kystes epidermiques des doigts. — Rev. méd. Suisse rom. 1887:7:121. Ref. Peer and Paddock 1937.

Romeis. B.: Mikroskopische Technik. München 1948.

Roux, W.: Terminologie der Entwicklungsmechanik der Tiere und Pflanzen. — Leipzig 1913. Ref. Peer and Paddock 1937.

Salomon, A.: Zur Prognose und Heilung der Sehnennähte. — Zbl. Chir. 1922:49:74.

Salomon, A.: Klinische und experimentelle Untersuchungen über Heilung von Sehnenverletzungen insbesondere innerhalb der Sehnenscheiden. — Arch. klin. Chir. 1924:129:397.

Schneider, E.: Leistungssteigerung durch regulatorische Zellstimulation. — Arch. klin. Chir. 1936:186:267.

Schulze, H.: Zur Erweiterung der Indikationsstellung der Rehnschen Cutislappenplastik. — Zbl. Chir. 1947:72:34. Ref. ZentOrg. ges. Chir. 1949:112:268.

Schwarz, E.: Über die anatomischen Vorgänge bei der Sehnenregeneration und dem plastischen Ersatz von Sehnendefekten durch Sehne, Fascie und Bindegewebe. — Dtsch. Z. Chir. 1922:173:301.

Scola, J. V.: Improved technic for preparing a buried dermal graft in hernial repair. — Amer. J. Surg. 1944:66:249.

Seggel, R.: Histologische Untersuchungen über die Heilung von Sehnenwunden und Sehnendefekten. — Bruns' Beitr. klin. Chir. 1903:37:342.

Skoog, T.: An experimental study on the healing of tendons. — Tr. of the 25th meeting of the North. surg. ass. in Copenhagen 1951. p. 81.

Straatsma, C. R.: Use of the dermal graft in the repair of small saddle defects of the nose. — Arch. Otolaryng. (Chicago) 1932:16:506.

Strahan, A. W. B.: Hernial repair by whole-skin graft with report on 413 cases. — Brit. J. Surg. 1951:38:276.

Swanker, W. A.: Repair of fascial defects with whole skin grafts. — Amer. J. Surg. 1948:75:677.

Swenson, S. A. jr.: Cutis grafts: Clinical and experimental observations. — Arch. Surg. 1950:61:881.

Swenson, S. A. jr. and *Harkins, H. N.:* Cutis grafts; Application of the Dermatome-flap method: Its use in a case of recurrent incisional hernia. — Arch. Surg. 1943:47:564.

Thorek, P.: Five years' experience with spool cotton as a suture material. — Amer. J. Surg. 1946:71:652.

Uihlein, A. jr.: Use of the cutis graft in plastic operations. — Arch. Surg. 1939:38:118.

Vainio, S.: Luun autotransplantaatin regeneraatio. Diss. Helsinki 1948.

West, W. T.: and *Hicks, E. S.:* Skin as a supporting graft in repair of Herniae. — Canad. med. Ass. J. 1948:58:178.

Wien, M. S. and *Caro, M. R.:* Traumatic epithelial cysts of the skin. — J. Amer. med. Ass. 1934:102:197.

Wörz, A.: Ueber traumatische Epithelcysten. — Bruns' Beitr. klin. Chir. 1897:18:753.

Zieler, K.: Lehrbuch und Atlas der Haut- und Geschlechtskrankheiten. — Textband. Berlin und Wien 1942.

Zimches, J. L.: Über das Schicksal des in die tieferen Gewebe frei transplantierten Deckepithels in Zusammenhang mit der Lehre von den Epithelcysten. — Frankfurt. Z. Path. 1931:42:203.

THE HIP JOINT IN LAPPS

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THE HIP JOINT IN LAPPS

AND ITS BEARING ON THE PROBLEM OF CONGENITAL DISLOCATION

BY

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CONTENTS

PREFACE

This investigation has been carried out in the Anthropological Department of the Anatomical Institute at the University of Oslo. I am deeply indepted to the head of the Institute, Professor Jan Jansen M.D., who has given me the opportunity to work at the Department and who has taken inspiring interest in the study.

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Oslo, November 1st 1954.

Bernhard Getz.

INTRODUCTION

The aim of the present paper is to investigate whether there are certain anatomical characteristics in the structure of the normal (i.e. non-dislocated) hip joint that may dispose to congenital dislocation of the same. As there is good evidence that this condition is hereditary, the investigation may also throw light on the developmental processes through which eventual genes manifest themselves in populations and individuals. If dislocation occurs especially frequently in particular groups, for instance in populations which are geographically isolated, the manifestation of the condition will provide a basis for the evaluation of the relative influence of environmental and hereditary factors. The skeletal material of the norwegian Lapps which is presented in this study is valuable in an attempt to elucidate these problems. The study is a morphological one. It is not meant as a contribution to the solution of the hereditary mechanism. Genetical problems are only discussed in so far as they have any bearing on the morphological problems.

From Wessel's (1918) investigation it is known that congenital dislocation of the hip occurs frequently in Lapps. It is, however, not evident from this study whether the condition is more frequent among Lapps than in the rest of the Norwegian population. It is also a fact that luxation of the hip has a high incidence in the present skeletal material of Lapps which is unselected in this respect. The investigation of Wessel provides a suitable basis for a discussion of the hereditary mechanism of congenital dislocation in Lapps in so far as this is necessary in the evaluation of the possible significance of hereditary and environmental factors in the manifestation of the deformity. We have to know whether dislocation in Lapps shows a genetical behaviour which differs significantly from the inheritance in other groups so far known. It is, for example, necessary to know whether sporadic cases are particularly frequent in Lapps, whether more cases are unilateral in particular families, or whether there are more cases among boys in Lapps than in other groups.

The present report is intended as a contribution partly to the anthropology of a group and partly to the anatomy of the hip joint. The large practical significance of congenital dislocation of the hip has conveyed that also orthopaedic problems will be discussed to some extent. The investigation does not, however, intend to penetrate into the field of clinical surgery.

A material of Lappic hip and thigh bones has been employed in the present investigation. Certain anatomical features are studied with respect to age, sex and geographical variations. As far as can be ascertained, an investigation of a corresponding material has not previously been carried out. It has therefore been expedient for the sake of comparison to employ a material consisting of other Norwegian hip and thigh bones, measured with the same methods and investigated with respect to the same problems as far as possible.

Since congenital dislocation of the hip was first given a thorough description by Paletta in 1820 and then a few years later by Dupuytren in 1826, there has been controversy about the etiology and pathogenesis of this deformity. Apart from these publications, which also treat the anatomical conditions of the dislocated hip joint, the literature of the last century with a few exceptions consists of etiological, pathogenetic, clinical and therapeutical considerations and reports. A series of publications has treated the question whether the condition is hereditary or caused by pre- or postnatal mechanical influences.

The majority of those who have recently studied the etiology and pathogenesis supports the importance of heredity (e. g. Bøhm 1935, Bauer 1936, Hilgenreiner 1936, 1939, Faber 1937, 1938, Hart 1942, Klopfer 1950, Cocchi 1951, Rohlederer 1951, Massie and Howorth 1951). Heredity has been demonstrated in 14.7 % of 1096 cases by Hayashi and Matsuoka (1913); 22.8 % of 69 cases by Wessel

(1918); 20.0 % of 1285 cases by Isigkeit (1928); 22.7 % by Scaglietti (quoted by Laurent 1953); and 26.3 % by Putti (1937). Idelberger in a material of 138 pair of twins among 22,004 dislocation cases demonstrated (1951) that congenital hip joint luxation occurs more frequently in uniovular than in binovular twins. Verschuer (1932) and Laurent (1953) state that the inheritance is irregularly dominant.

It is remarkable that congenital dislocation of the hip occurs mainly on the left side, namely in the ratio 1.5 : 1 (Verschuer), as do the majority of congenital anomalies and deformities. The condition occurs most frequently in women as opposed to most other malformations, the sex ratio being about 5 : 1. It is also stated (Hayashi and Matsuoka 1913, Wessel 1918, Bauer 1936, Korvin 1938, Müller 1939, Eckhardt 1943, Rohlederer 1943, Hass 1951) that congenital dislocation of the hip frequently occurs in conjunction with underdevelopment of the hip and thigh bones and with degenerative changes of the joint. According to Schreiner (1935), degenerative changes are very frequent also in non-dislocated hip joints in Lapps. Anomalies of the lumbar spine and the hip joint are apparently also rather frequent in Lapps, Schreiner reporting a frequency of spondylolysis of 12.8 % in 296 Lappic skeletons. In contrast Willis (1923) reports 4.3 % in 728 American whites and negroes. The frequent dislocation in Lapps is possibly an expression of a predisposition to underdevelopment of the lumbar spine and the hip joint.

It is, however, difficult to give a complete explanation of the congenital hip dislocation on the basis of heredity alone. The majority of authors who assume that the condition is primarily hereditary, therefore maintain that there are mechanical factors that are likely to play a role in the manifestation of the disease. Hilgenreiner (1936, 1939) maintains that mechanical forces taking effect during fetal life can provide an adequate explanation of hip joint luxation. He has been able to make the diagnosis at birth on several occasions. Like Waldenström (1932), Hart (1942) and Hass (1951), Hilgenreiner believes that dislocation of the hip develops from a state of subluxation. According to Müller (1929), the manifestation of the condition can occur so early in the fetal period that mechanical forces due to pressure of the uterine musculature can play no part in the dislocation.

It is a general opinion that the primary hereditary defect in congenital hip joint luxation is a deficient development of the upper rim of the acetabulum. Massie and Howorth (1951), however, point out that patients with a weakly developed acetabular roof, who have undergone successful replacement of the femoral head in the socket, later develop a normal acetabulum. This suggests that the shape and direction of the femoral head and neck may be a primary developmental factor, a suggestion previously made by Müller (1929).

The importance of defects in the capsular ligaments and the articular cartilage is stressed by Schneider (1943), Hart (1949), Klopfer (1950) and Hass (1951).

On the whole, the general opinion is that mechanical conditions play a large part in the manifestation of congenital dislocation of the hip. In fact this is the theoretical basis for orthopaedic treatment of the condition. Lorenz (1920) and Storck (1938, 1950) go to the extreme and maintain that the condition is not hereditary but caused by unfavourable mechanical forces taking effect during fetal life and later during adaptation to erect posture. Storck, however, does not completely reject the possibility that endogenous factors may play a part.

Le Damany (1908), Dega (quoted by Laurent 1953) and Lanz (1949) also point out that the erect posture lays claims on the hip joint which it can not always satisfy. During fetal life the joint affords maximal adjustment of the femoral head to the acetabulum (Wiberg 1939). This adjustment is challenged when extension takes place in the adaptation to erect posture. Dislocation occurs as a result of a deficient response to the new static conditions. In this connection it is interesting that Lappic children generally spend their first year in the Lappic cradle called «komse» («giethka») (Elgström 1922), in which the hip joint is forced into a position of extension and adduction at an age when its natural state is flexion and abduction. Thus the adaptational stress connected with the extension in the erect posture is precociously induced artificially, a factor which is worth considering on discussion of the frequent dislocation in this group.

The incidence of congenital dislocation of the hip varies to a large extent in different countries and among different races. The condition is relatively frequent in Italy, Germany, Japan and Czechoslovakia, but rare in China and among Negroes. Previous experience has also shown that the incidence among Lapps is relatively high. Wessel (1918) presents a frequency of 5 % in his material from South Varanger in Finnmark, Norway, among them 8.6 % in females. The incidence of the condition in the present skeletal material is 4.2 % of the total and 3.4 % of the adults. Among the latter the frequency is 6.8 % in females. In a material consisting of Finnish Lapps, Näätänen (1936) found an incidence of 5.2 %.

Laurent (1953) estimates that the occurrence of hip joint luxation in the Finnish population is 0.06 %. According to Kemp, the incidence is usually estimated at 0.15 % ± 0.06 % in the population and 0.10 % among newborn. To obtain corresponding figures for Norway, enquiries have been made of local medical officers in the counties of Opland, Sogn and Fjordane, Møre and Romsdal, Nordland, Troms and Finnmark regarding the number of cases of congenital dislocation of the hip in their districts. As it is not compulsory for the practitioner to report such cases to the medical officer, reliable information can only be acquired from districts in which the medical officer has a thorough knowledge of the population. In addition, information has been received from school doctors with respect to a series of elementary schools in Oslo. Information is obtained also regarding ailments in preschool years. Therefore most probably both cases which have been treated, eventually cured, in pre-school years, and manifest cases are included. The available data are stated in table 1. The information refers to an approximate population of 315,000. There is reason to believe that the data are on the whole reliable and that no essential number of dislocations are likely to have escaped notice in the relatively small districts with an average population of approximately 3,300, which have been chosen for this purpose.

Table 1.

Incidence of congenital dislocation of the hip in Norway, based on information from local medical officers.

County	Population included in information	No. of dislocations Males	Females	Unknown	Sex ratio	Frequency, percent
Opland	44.691	8	16		2.0 : 1	0.05
Sogn & Fjordane	77.599	9	49	38	5.4 : 1	0.12
Møre & Romsdal	43.410	4	30		7.5 : 1	0.08
Nordland	79.833	17	77		4.5 : 1	0.12
Troms	19.526	4	17		4.3 : 1	0.11
Oslo, schools..	10.069	1	11		11.0 : 1	0.12
Total	275.128	43	200	38	4.7 : 1	0.10
Finnmark ...	38.680	22	61	8	2.8 : 1	0.24
Total	313.808	65	261	46	4.0 : 1	0.12

The figures from Finnmark refer to both Norwegians and Lapps. No reliable basis has been found to enable determination of the number of pure Lapps among the cases. The incidence in Finnmark and in the Norwegian population in the other counties is 0.24 % ± 0.07 % and 0.10 % ± 0.02 % respectively. The number of Lapps in Finnmark is about 12,000 and of Norwegians and Finns about 47,000, people of mixed ancestry constituting a large percentage in both groups. Taking this fact into consideration, it seems probable that the relatively high incidence of luxation in this county is due to the Lappic influx. Information from several of the medical officers in Finnmark suggests, however, that this deformity is not so frequent today as it has previously been. If this is the case, it contradicts the general opinion that congenital dislocation of the hip is due to race mixture, an opinion which is apparently based on the peculiar idea that a Norwegian femoral head does not suit a Lappic acetabulum and vice versa.

It is a well known fact that the incidence of congenital hip dislocation is higher in women than in men. In Wessel's material the sex ratio (women : men) is 6 : 1. In a material including 326 cases Eckhardt (1943) found a sex ratio of 5.2 : 1, Schinz and coworkers (1951) report a ratio of 6 : 1 and Kemp a ratio of 5 : 1. In the Norwegian material (Finnmark excluded, see table 1) the ratio is 5 : 1 while in Finnmark it is 3 : 1. The difference between the sex ratios is not significant. However, it suggests that local differences exist in this respect and that the increased incidence of the deformity in Finnmark can be attributed to an increase of the number of affected men in some localities. A sex ratio of 6 : 1 in the population of South Varanger (Wessel) does not support any connection between ethnic groups and the sex ratio. In the present skeletal material the sex ratio is 4.5 : 1.

It has been mentioned above that congenital hip luxation most frequently occurs on the left side (1.5 : 1, Verschuer 1932). According to Isigkeit (1928) 65 % of all cases are unilateral. Of the 14 individuals with hip luxation in the skeletal material, 8 or 57 % are unilateral. Of these 8 cases, 7 are affected on the left side.

ANATOMICAL MATERIAL

The investigation includes:

1. The hips of 226 normal (i. e. non-dislocated) adult Lapps, including 130 males and 96 females. The total material collected by Schreiner comprehends 296 skeletons including 164 males and 132 females. (The percentage of dislocations is estimated in relation to this total number and the number of child skeletons.) A number of hip and thigh bones were so defective that they had to be discarded and therefore the number of skeletons investigated is somewhat smaller. The material dates from old Lappic grave-yards from recent time and was collected during the period 1913—29 in the localities Angsnes, Kistrand, Neiden, Pasvik, Karasjok and Kautokeino. A few skeletons were also collected from different other places. The determination of sex and age was carried out by Schreiner. The normal material was investigated with respect to variation in age, sex and geography. Several of the groups were thus small, a fact that must be taken into consideration on evaluation. The distribution of the normal material is presented in table 2.
2. The hips of 16 normal Lappic children, ages ranging from 5 to 14 years.
3. 17 dislocated hip joints of adult Lapps. Of the 11 individuals affected, 5 had unilateral and 6 bilateral dislocation. Of the 11 individuals 2 were men and 9 women. Some of the dislocated hips were too defective to allow any measurement.
4. 3 dislocated hip joints af Lappic children, all unilateral.
5. 64 thigh bones of adult men in an Oslo material.
6. 144 hip bones of adults in an Oslo material, including 84 men and 60 women.

Table 2.

Distribution of anatomical material.

Age	Males	Females	Locality	Males	Females
Juveniles	4	6	Angsnes	24	20
Adults	32	32	Kistrand	40	31
Adult-matures	22	13	Neiden & Pasvik	31	22
Matures	54	37	Karasjok & Kautokeino	25	19
Mature-seniles	18	8	Others	10	4
Total	130	96	Total	130	96

The available material from Oslo was received by the Department about 50 years ago and individual arrangement was not undertaken at that time. It is therefore only possible to present an average for this control material and measurement of the inclination of the acetabulum can not be made as this demands reconstruction of the pelvis.

METHODS

The following investigations of the hip and thigh bones were made:

1. The femoral antetorsion, i.e. the angle between the axes of the femoral collum and head and the condyles. In a skeletal material this angle is simply measured by means of a parallelograph (Martin 1914) or by means of Brøste's torsion goniometer. Two measurements are always made and the two needles which are fastened to represent the axes are removed and refixed between the readings. The mean of the two readings is employed; this also refers to the measurements mentioned below.

The deviation of the two readings was small, the largest deviations occurring with especially large angles and having maximal values of — 3° and + 3.5°. The arithmetical mean deviation was slightly under 1°, a value which is small in comparison to the standard deviation (see table 3). The algebraic mean deviation was approximately 0°. It can therefore be assumed that the method employed is reliable.

Methods for clinical and roentgenological determination of the degree of torsion have been prepared by Schultz (1924), Rogers (1934), Farrell and Howorth (1935), Edgren (1948), Kingsley and Olmstedt (1948), Richard (1950), Dunn (1952), Laurent (1953), Dunlap, Shands and coworkers (1953) and Ryder and Crane (1953).

2. The femoral neck-shaft-angle (often inadequately called the collo-diaphyseal angle) is measured on the ventral side of the femur by means of two threads, secured along the femoral neck and head and the shaft respectively as axes (Martin 1914). The angle can be read directly.

3. The depth of the acetabulum was measured both absolutely and relative to the diameter of the acetabulum, which according to the definition by S h i i n o (1915) is the distance from the point where the projection of the frontal ilium meets the upper acetabular roof to the furthest point on the lower acetabular rim. Depth is defined as the perpendicular distance from the axis joining these two points to the bottom of the acetabulum. A needle secured to the two points acted as axis. Depth is presented as a percentage of diameter. This relative depth gives a more useful basis for comparison than the absolute value, especially so when a comparison between the sexes is performed.

4. The inclination angle of the acetabulum to the sagittal plane. The pelvis must be reconstructed before the angle can be measured. This may be done by means of plastilin or by using a specially designed pincers on the symphysis and the iliosacral joints. Attention must be paid to the width of the symphysis which, according to B r a u s (1921), is on an average 5 mm, and to the somewhat smaller width of the iliosacral joints.. Reconstruction of the pelvis was always performed twice. The angle measured (L a n z 1949) is the angle between the sagittal plane and the axis joining the posterior and anterior acetabular rims. L a n z choses to adjust the pelvis so that the entrance plane, i.e. the plane through the linea terminalis and the promontory, is horizontally situated. This position may easily be obtained by means of a diagraph. By means of this instrument the acetabular axis and the sagittal plane can be marked on the underlying paper and the angle can be read directly. It should, however, be remembered that in the erect posture the entrance plane is inclined at about 60° to the horizontal plane.

Control experiments were performed to investigate the effect of deviation of the pelvis from the horizontal plane (entrance plane). A series of readings showed that an increased frontal inclination of the entrance plane of 5°, a deviation which can be said to be outside the probable error, only altered the inclination angle by 0.5°. With an increased inclination of the entrance plane, the change in the measured angle increases rapidly.

Determination of the inclination angle is not easily performed by roentgenological methods.

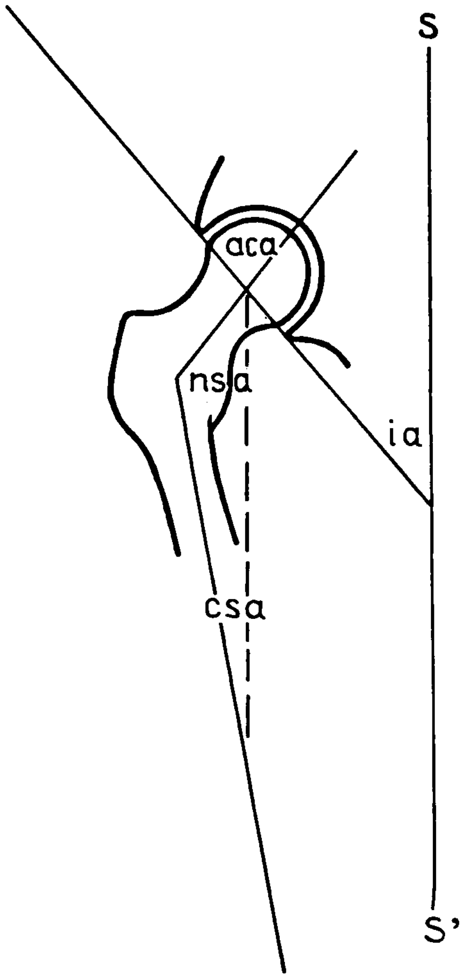

Figure 1.
Angle of incidence. Calculation: aca = 180° + ia — nsa — csa. The femoral shaft is in the same plane as the entrance plane of the pelvis. According to Lanz.

Even the inclination of the acetabulum to the horizontal plane has been measured in most of the normal material. The reconstructed pelvis is placed in the same position as described above and the angle is determined by means of a goniometer.

5. Under normal conditions (L a n z 1949), the femoral collum and the acetabular axis from the anterior to the posterior rim of the socket are nearly at right angles. To determine this angle, the angle of incidence, the axis of the femoral shaft must lie in the same plane as the entrance plane of the pelvis, i.e. the hip joint must be flexed at 30°. With this assumption, the angle can be calculated from the values for the neck-shaft angle, the angle of inclination to the sagittal plane and the condyle-shaft angle as illustrated in figure 1. For this calculation S c h r e i n e r's (1935) figures for the condyle-shaft angle were used, this angle being of rather small importance for the calculation as a difference of 10 % in this angle will only cause a difference of approximately 1 % in the size of the angle of incidence.

6. The platymeric index gives the relation between the sagittal and the transverse diameters in the proximal femoral diaphysis. The diameters were measured according to Martin's technique. This also applies to

7. The pilaster index, which gives the relation between the sagittal and the transverse diameters of the border between the middle and the distal thirds of the femoral diaphysis.

It has not been considered necessary to give a detailed description of the statistical methods employed in this paper. The standard deviation is calculated according to the formula

$$\sigma = \sqrt{\frac{\Sigma (x - M)^2}{n - 1}}$$

the standard error of the mean according to the formula

$$e = \frac{\sigma}{\sqrt{n}}$$

the standard error of the difference according to the formula

$$S = \sqrt{e_1{}^2 + e_2{}^2}$$

the correlation coefficient according to the method of grouped series, based upon all single readings.

Finally the standard error of a percentage is calculated according to the formula

$$\sqrt{\frac{(p \cdot q)}{n}}$$

where the sum of p and q comprises 100 (%).

Regularly the measurements are presented in tables. With a few exceptions, diagrams are not made, as differences and coefficients of correlation have been employed to demonstrate the essential facts.

RESULTS

1. Antetorsion

As previously mentioned, femoral antetorsion is defined as the angle between the axes through the femoral neck and head and the condyles, provided that the neck is frontally directed with respect to the condylar axis. Antetorsion varies considerably from individual to individual as well as bilaterally. Moderate retrotorsion is considered a normal condition. Examples of mean values for antetorsion in normal samples can be given: 11.6° (Mikulicz 1878); 8.0° (Martin 1914); 11.9° (Durham 1915); 8.0° (Kingsley and Olmstedt 1948) and 8.7° (Dunlap, Shands and coworkers 1953). The mean values for several samples are slightly higher for men than for women, although Dunlap, Shands et al. find no significant variation. Antetorsion varies in all samples within fairly wide limits, thus between 0° and 50° (Soutter and Bradford 1903); — 17° and 40° (Parsons 1914); 0° and 35° (Durham 1915); — 18° and 41° (Pick, Stack and Anson 1941) and — 20° and 38° (Kingsley and Olmstedt 1948).

Schreiner (1935) found in the Lappic skeletal material a mean antetorsion of 16.5°, namely 17.9° for women and 15.4° for men. Both the total value and the values for each sex in the present investigation are approximately 1.5° lower. This variation can be considered relatively unimportant since the standard deviation for men is 9.3 and for women 9.5 with ranges from 0°—45.5° and 0°—41.0° respectively. No case of retrotorsion was found in the material. The readings for antetorsion in the sample are presented in tables 3—8. Figure 6 shows a photograph of a typical Lappic femur with large degree of antetorsion.

Table 3.

Femoral antetorsion. Different age groups, both sexes. Normal material, Lapps.

Age	Males				Females			
	M°	n	σ	e	M°	n	σ	e
Juv-Ad	14.1	6	9.0	3.7	18.2	11	12.7	3.8
Ad	15.1	56	10.4	1.4	16.9	62	9.0	1.2
Ad-Mat	11.7	37	9.3	1.5	14.2	24	8.2	1.7
Mat	14.4	101	8.9	0.9	16.2	62	9.5	1.2
Mat-Sen	13.8	32	8.0	1.4	16.3	12	11.0	3.2
Total	14.0	232	9.3	0.6	16.3	171	9.5	0.7
Var°	0 — 45.5				0 — 41.0			

Table 3 demonstrates that the femoral antetorsion is on the average 2.3° larger for women than for men. The standard error of this difference, which is calculated from the standard errors of the two means, is 0.92. This difference comprises 2½ times the standard error and would therefore arise by chance only once in 80 times. The difference thus can be considered significant. This applies to all the age groups and most of the geographical local groups (table 7). The femoral antetorsion in children in the normal sample is larger than that of adults (table 4). As the skeletons of children are of undetermined sex, the standard error of the difference in antetorsion between adults and children can only be calculated for the average of both sexes. The average antetorsion in adults comprises 15.0°, the difference thus being 8.0°. The standard error for this difference is 2.06 and the difference is

Table 4.

Femoral antetorsion. Children. Normal material, Lapps.

Age	M°	n	σ	e	var°
5—9	20.5	16	10.8	2.7	8—50
10—14	25.5	16	11.2	2.8	5—41
Total	23.0	32	11.3	2.0	5—50

therefore significant. There is, however, within the adult groups no regular change in the antetorsion with increasing age.

The angle of antetorsion in adult and mature male Lapps was compared with that of adult and mature men in an Oslo sample (table 5). The angle is on an average 4.0° larger in the Lappic

Table 5.

Femoral antetorsion. Adult and mature men. Normal material, Oslo. Comparison with the same age groups in normal material, Lapps.

	M°	n	σ	e	var°	d°	S
Lapps	14.1	194	9.4	0.7	0—45.5		
Oslo	10.1	64	7.1	0.9	—2—25.0	4.0	1.14

groups than in the Oslo sample. The standard error of this difference is 1.14, thus the difference is significant. (When the difference comprises 3 times the standard error, it is likely to arise by chance only once in 370 times.) In addition, the Oslo sample has a smaller range, the largest angle being 25° while the largest angle in the Lappic group is 45.5°. In the Lappic male sample 22.4 % of all femurs showed an antetorsion angle of more than 20°, while only 10.9 % of the Oslo male sample had an angle of that size.

Table 6.

Femoral antetorsion. Bilateral comparison, both sexes. Normal material, Lapps.

	Right				Left						
	M°	n	σ	e	M°	n	σ	e	d°	S	var°
Males	13.6	117	8.8	0.8	14.3	115	9.6	0.9	0.7	1.20	38.0
Females	16.5	80	10.5	1.1	16.2	91	9.0	1.0	0.3	1.49	25.5

Table 6 demonstrates that there is no bilateral difference with respect to antetorsion. The interesting fact that the angle is small in the local groups of Neiden and Pasvik will be discussed later. (Cfr. table 7.)

Table 7.

Femoral antetorsion. Comparison of different localities. Normal material, Lapps.

Locality	Males				Females			
	M°	n	σ	e	M°	n	σ	e
Angsnes	18.4	46	10.2	1.5	17.0	39	8.7	1.4
Kistrand	14.7	69	8.4	1.0	17.0	51	9.8	1.4
Neiden & Pasvik .	10.4	53	7.8	1.1	13.0	39	7.8	1.2
Karasjok & Kautokeino	13.2	47	9.0	1.3	18.1	34	10.7	1.8

Table 8.

Femoral antetorsion. Dislocated hips.

Age	ata°	n
Children	40.0	3
Adults	25.0	11

The mean angles of antetorsion for 3 dislocated child hips and 11 dislocated adult hips were 40.0° and 25.0° respectively (table 8). Investigation of a series of other samples has proved that there is a large degree of antetorsion in cases of congenital hip joint dislocation. Thus Farrell, Lackum and Smith (1926) found that 47 % of such cases had an antetorsion angle of more than 20° and that 24 % had an angle of more than 50°. Fairbank (1930), in a sample of 26 thigh bones from dislocated hips found a mean antetorsion of 30.6° with a range from 0°—75°; Rogers (1934) in 6 unilateral dislocations found 48° and in 4 bilateral cases 67.5°; Farrell and Howorth (1935) in 11 cases found 63°; Massie and Howorth (1951) found that the angle in 80 % of the dislocated cases was between 30° and 70°; Platou (1953) in a material of 406 treated cases found an angle of more than 30° in 15 %; Dunlap, Shands and coworkers (1953) found 51° with a range from 29°—85°; and finally Laurent (1953) in 111 treated cases found a mean angle of 37° with a range from 0°—80°. Rogers, Farrell and

Table 9.

Femoral antetorsion. Variation at different ages as given by other authors.

Age	Le Damany 1908, 1914	Dega 1933	Rogers 1934	Bøhm 1935	Lanz 1951	Dunlap 1953
2. fetalmonth				— 15		
4. »	0		— 2	0	10	
6. »					21	
8. »					22	
Birth	35	30	22	30	31	
2. year			39		34	24
4. year			28		26	
Adults	12			12	12	9

H o w o r t h and D u n l a p, S h a n d s et al. report that in unilateral dislocations antetorsion was as a rule large also in the unaffected side. The antetorsion angle in the dislocated Lappic hips ranges from 8°—45° in adults and from 30°—51° in children. Even in this material antetorsion is large also in the unaffected hip joint in unilateral cases.

It is a recognized fact that the degree of antetorsion of the femur varies considerably during fetal life and the first years of life. A review of the observations presented by a few authors with this respect is shown in table 9.

Summary: The femoral antetorsion in normal Lapps is larger than in a normal Norwegian sample of femurs, larger in women than in men and larger in children than in adults. There is no bilateral difference but the individual range is considerable. The angle is especially large in dislocation cases and in local groups where this condition most often occurs.

2. Neck-shaft angle

The neck-shaft angle is defined as the angle between the axis through the neck and head and the axis through the shaft of the femur. Various observations have been made with respect to the size of this angle. Thus M a r t i n (1914) states that the angle for contemporary Europeans ranges from 126° to 133° and that it is slightly larger for men than for women. Telkkä (1949) supports the latter observation and reports that the angle in a Finnish sample on an average comprises 125°—126°. Also Lanz (1949) presents an average of 126° in adults while Schinz and coworkers (1951) assume that the angle ranges from 120° to 130°. According to Telkkä no significant bilateral difference is found.

The mean neck-shaft angle in the Lappic skeletal material was 129.4° for men and 128.8° for women as measured by Schreiner (1935). The values in the present investigation are very nearly the same, namely 129.0° for men and 128.0° for women, the differences from Schreiner's figures being insignificant. The values for the neck-shaft angle are presented in tables 10—15. See also figure 3.

Table 10.

Femoral neck-shaft angle. Different age groups, both sexes. Normal material, Lapps.

Age	Males				Females			
	M°	n	σ	e	M°	n	σ	e
Juv-Ad	133.4	7	2.1	0.8	129.0	12	3.4	0.9
Ad	130.7	59	4.1	0.5	128.6	63	3.2	0.4
Ad-Mat	129.2	40	2.6	0.4	129.1	25	4.3	0.9
Mat	128.6	104	3.6	0.4	126.9	67	3.6	0.4
Mat-Sen	125.9	32	3.9	0.7	128.0	15	3.3	0.8
Total	129.0	242	3.9	0.3	128.0	182	4.5	0.3
Var°	119.5—140.0				118.5—139.0			

Table 10 shows that the neck-shaft angle is on an average 1.0° larger for men than for women. The standard error of the difference is 0.42, the difference thus being nearly significant. (When the difference comprises twice the standard error, it is likely to arise by chance once in 20 times.) A difference obviously exists in all the lower age groups of the adult sample and in the majority of the local groups (table 14). In addition, table 10 illustrates that the neck-shaft angle decreases with age. This decrease, which is ascribed purely to mechanical factors (Lanz and Wachsmuth

Table 11.

Femoral neck-shaft angle. Children. Normal material, Lapps.

Age	M°	n	σ	e	var°
5—9	129.4	16	3.5	0.9	124—135
10—14	130.9	16	3.0	0.8	126—135
Total	130.0	32	4.7	0.8	124—135

1938), is more apparent in the male sample, where the decrease from group to group is on the whole significant.

A comparison of tables 10 and 11 shows that the neck-shaft angle is slightly larger for children than for adults. The mean angle of the adult samples, regarded as one sample, is 128.6° which differs from the mean angle for children by 1.4°. Despite the limited number of child femurs, the difference approaches significance, the standard error being 0.84.

Table 12.

Femoral neck-shaft angle. Adult and mature men. Normal material, Oslo. Comparison with the same age groups in normal material, Lapps.

	M°	n	σ	e	var°	d°	S
Lapps	129.3	203	3.8	0.3	120—140		
Oslo	125.1	64	3.5	0.8	118—135	4.2	0.85

As in the case of antetorsion, tests were made to control whether the neck-shaft angle for Lapps differs from that of an Oslo sample. Table 12 shows that adult and mature men in the Oslo sample have a considerably smaller angle than adult and mature Lapps, the difference being 4.2°. With a standard error of 0.85 the difference is significant. The average value for the Oslo material, 125.1°, is approximately the same as that presented by Lanz for adults.

Table 13 confirms the non-existence of a bilateral difference as regards size of the neck-shaft angle. The values presented in table 14 regarding the local groups will be discussed below.

Table 13.

Femoral neck-shaft angle. Bilateral comparison, both sexes. Normal material, Lapps.

	Right				Left						
	M°	n	σ	e	M°	n	σ	e	d°	S	var°
Males	129.1	122	4.0	0.4	128.9	120	3.7	0.3	0.2	0.50	5.5
Females	128.0	88	3.8	0.4	127.9	94	3.6	0.4	0.1	0.57	6.0

The mean neck-shaft angle for 11 dislocated hips in the adult sample was 116.0° with a range from 105.0° to 125.0°. The mean for the 3 dislocated child hips was 127.0°, the values ranging from 124.0° til 130.0° (table 15). The varus position of the dislocated adult femurs is shown in the photograph in figure 8 b.

The neck-shaft angle, as does the antetorsion angle, varies during fetal life and infancy. According to Lanz (1949, 1951), it decreases from 137° in the 4th month to 128° in the 9th month and thereafter increases up to 144° in the 2nd year of life. Then

Table 14.

Femoral neck-shaft angle. Comparison of different localities. Normal material, Lapps.

Locality	Males				Females			
	M°	n	σ	e	M°	n	σ	e
Angsnes	129.0	46	4.2	0.6	128.2	40	4.3	0.7
Kistrand	129.5	75	3.9	0.5	128.1	53	3.9	0.5
Neiden & Pasvik ..	129.1	57	3.3	0.4	127.4	42	2.8	0.4
Karasjok & Kautokeino	127.3	47	4.2	0.6	129.1	38	2.6	0.4

Table 15.

Femoral neck-shaft angle. Dislocated hips.

Age	nsa°	n
Children	127.0	3
Adults	116.0	11

it diminishes to 134° at the age of ten, 128° at the age of sixteen, 126° in adults and 120° in the aged. Compared with this report, the angle for Lapps is relatively large. A typical Lappic femur is shown in the photograph in figure 8 a.

Summary: The femoral neck-shaft angle in normal Lapps is somewhat larger in men than in women, larger in children than in adults and decreases with age. The angle is larger in Lapps than in a normal Oslo sample. There is no bilateral difference. The angle is small in old dislocation cases, but no reliable difference is found with regard to the local groups.

3. Acetabular depth

The majority of authors maintain that the normal acetabulum approaches a hemispherical form and that, with the exclusion of the cartilage, its depth comprises about half its diameter. Le Damany (1908) found that the acetabulum of adults normally constitutes 60 % of a sphere, while, according to Shiino (1915), the value is slightly over 50 %. For the calculation Shiino makes use of the diameter through the upper and lower rims of the socket. According to the same author, this diameter is 1—2 mm longer than the diameter through the anterior and posterior rims.

Readings of the acetabular depths were taken of 322 hip bones in the normal Lappic sample. Both the absolute and the relative depths are presented. Comparison of the relative values is presumably more reliable as the absolute readings are dependent on the size of the pelvis as well. The values of the acetabular depth are presented in tables 16—19. It is impossible to obtain reliable depth readings for child samples and for dislocated hips, but it is evident that the sockets of the latter are rather shallow.

Table 16 shows that the acetabulum, both absolutely and relatively, has a greater depth in men than in women. The difference of the means of the absolute depth is 2.5 mm with a standard error of 0.28 and difference of the means of the relative depth is 1.2 with a standard error of 0.42. Both differences are signifi-

Table 16.

Acetabular depth. Different age groups, both sexes. Normal material, Lapps.

Age	Males							Females						
	Ma	Mr	n	σa	σr	ea	er	Ma	Mr	n	σa	σr	ea	er
Juv-Ad	22.8	45.7	6	1.2	1.3	0.5	0.5	20.0	44.0	10	0.8	1.6	0.3	0.5
Ad	23.7	46.7	52	1.9	4.3	0.3	0.6	22.3	46.9	49	1.7	3.1	0.2	0.4
Ad-Mat	24.2	48.0	32	1.6	2.3	0.3	0.4	21.7	46.6	18	1.8	3.2	0.4	0.8
Mat	25.1	48.5	81	2.2	3.6	0.2	0.4	22.5	47.4	37	2.4	4.2	0.4	0.7
Mat-Sen	25.6	48.7	28	2.2	2.9	0.4	0.5	22.9	45.9	9	1.2	2.2	0.4	0.7
Total	24.6	47.9	199	2.3	3.5	0.2	0.3	22.1	46.7	123	2.1	3.1	0.2	0.3
Var°	18—29, 34.6—54.9							17—27, 37.8—55.1						

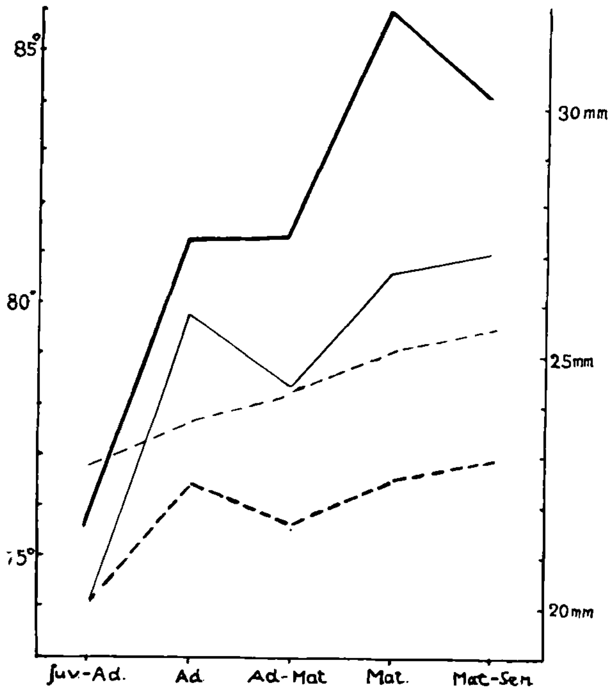

Figure 2.

Diagram showing the variation of acetabular depth and angle of incidence with age. Both sexes. Light lines indicate men, heavy lines women. Continous lines indicate angle of incidence, dotted lines absolute acetabular depth.

cant. It was to be expected that the larger hip bones of men have a larger absolute acetabular depth. The depth varies in the different age groups — table 16 suggests that it increases with age (figure 2). In addition, the depth is remarkably constant within the single groups, a fact which is obvious from the small standard errors of the means.

The measurements of Shiino are employed for comparison. His sample comprises 51 normal male and 44 normal female hip bones. The absolute depth for men is on an average 31.1 mm and for women 28.0 mm; the relative depth being 53.1 % and 51.5 % respectively. Compared with the Lappic sample, Shiino finds a mean depth which is 6.5 mm and 5.2 (%) larger for men and 5.9 mm and 4.8 (%) larger for women. The corresponding stan-

Table 17.

Acetabular depth. Adult and mature men and women. Normal material, Oslo. Comparison with the same age groups in normal material, Lapps.

	Males							Females						
	Ma	Mr	n	σa	σr	ea	er	Ma	Mr	n	σa	σr	ea	er
Lapps	24.5	47.8	165	2.0	3.4	0.2	0.3	22.3	47.0	104	2.2	3.7	0.2	0.4
Oslo	27.3	50.7	84	2.0	2.9	0.2	0.3	24.5	50.5	60	1.1	2.3	0.2	0.3
d	2.8	2.9						2.2	3.5					
S	0.28	0.42						0.28	0.50					
var°	Lapps: 18—29, 34.6—54.9 Oslo: 21—32, 44.2—57.7							17—27, 37.8—55.1 22—28, 44.0—57.1						

dard errors all lie under 1.0 and the differences are significant. Shiino, too, reports that the socket is relatively deeper for men than for women, in fact a difference (1.6) close to significance, the standard error being 0.80.

For further comparison, the readings of 144 hip bones in the Oslo sample are employed (table 17). The table demonstrates that the socket of those hip bones is significantly deeper, both absolutely and relatively, than those of Lapps. There is thus no doubt that the normal acetabulum in Lapps is shallow. Table 18 shows that a bilateral difference does not exist with respect to acetabular depth. The geographical distribution is shown in table 19. There were no criteria to show that the depth varied from locality to locality, although some reservation has to be taken.

Table 18.

Acetabular depth. Bilateral comparison, both sexes. Normal material, Lapps.

	Right				Left						
	M	n	σ	e	M	n	σ	e	d	S	var
Males, a	24.7	101	2.1	0.2	24.5	98	2.2	0.2	0.2	0.28	7
Males, r	48.1	101	3.4	0.3	47.6	98	3.8	0.4	0.5	0.50	13.2
Females, a	22.1	61	2.3	0.3	22.3	62	2.1	0.3	0.2	0.42	3.
Females, r	46.4	61	3.8	0.5	46.9	62	3.7	0.5	0.5	0.71	7.3

Summary: The acetabular depth in normal Lapps is both absolutely and relatively larger in men than in women and larger in the normal Norwegian sample from Oslo than in Lapps. The depth seems to increase with age. There is no bilateral difference and no reliable difference with regard to the local groups.

4. Inclination of the acetabulum

The inclination of the acetabulum to the sagittal plane indicates the degree of frontal orientation of the socket, i.e. a large angle indicates a more frontal direction and a small angle a more sagittal direction of the socket (see figure 1). Different values have been

Table 19.

Acetabular depth. Comparison of different localities. Normal material, Lapps.

Locality	Males							Females						
	Ma	Mr	n	σa	σr	ea	er	Ma	Mr	n	σa	σr	ea	er
Angsnes	23.9	47.2	46	2.6	4.4	0.4	0.7	22.0	46.8	36	1.7	2.8	0.3	0.5
Kistrand	24.9	48.3	59	2.0	3.8	0.3	0.5	23.1	48.3	32	1.7	2.8	0.3	0.5
Neiden & Pasvik	24.9	48.5	39	1.4	3.6	0.2	0.6	21.8	46.3	26	2.3	3.9	0.5	0.8
Karasjok & Kautokeino	24.9	47.2	39	2.1	3.6	0.3	0.6	21.3	44.6	21	2.1	3.9	0.4	0.8

reported with regard to the size of this angle in normal adults, thus 40° (Le Damany 1908, Steindler 1935); 42° (Lanz 1949, 1951); and 30° (Donovan and Campbell, quoted by Badgley 1949). By means of the same technique as presented by Lanz, a mean angle of 37.2° for men and 40.0° for women was found in the normal Lappic sample (table 20). The more frontal direction of the female acetabulum was also observed by Dega (quoted by Laurent 1953) and Laurent (1953) and is probably due to the broader female pelvis. The readings for the inclination angle are presented in tables 20—22. It was impossible to undertake reconstruction of the child and dislocated hips. The angle could therefore not be measured in these samples.

Table 20 shows that there is no definite increase with age in the acetabular inclination to the sagittal plane as Lange and Pitzen (1921) observed in another normal sample. It is apparent that the direction of the acetabulum is more frontal in women than in men, the difference being 2.8° and the standard error 0.64. The range of the values is large, both individually and bilaterally, but it is seen from table 21 that there is no significant bilateral difference. The geographical distribution is presented in table 22.

The inclination of the acetabulum to the sagittal plane also varies considerably during fetal life and infancy. A review of the different reports on this respect is presented in table 23. It is evident that the reported values are very much at variance.

Table 20.

Inclination angle of acetabulum to the sagittal plane. Different age groups, both sexes. Normal material, Lapps.

Age	Males				Females			
	M°	n	σ	e	M°	n	σ	e
Juv-Ad	38.5	2	0.5	0.4	35.8	6	3.9	1.6
Ad	38.3	32	3.8	0.7	40.3	40	4.0	0.6
Ad-Mat	36.2	34	4.6	0.8	39.1	14	4.4	1.2
Mat	37.4	54	5.3	0.7	41.0	18	4.6	1.1
Mat-Sen	36.5	15	3.6	0.9	41.8	6	3.0	1.2
Total	37.2	137	4.6	0.4	40.0	84	4.5	0.5
Var°	27—50				30—50			

Table 21.

Inclination angle of acetabulum to the sagittal plane. Bilateral comparison, both sexes. Normal material, Lapps.

	Right M°	Right n	Right σ	Right e	Left M°	Left n	Left σ	Left e	d°	S	var°
Males	37.3	69	4.6	0.6	37.2	68	4.7	0.6	0.1	0.85	10.0
Females	39.9	42	4.4	0.7	40.1	42	4.4	0.7	0.2	0.99	15.0

Table 22.

Inclination angle of acetabulum to the sagittal plane. Comparison of different localities. Normal material, Lapps.

Locality	Males M°	Males n	Males σ	Males e	Females M°	Females n	Females σ	Females e
Angsnes	36.9	41	4.3	0.7	40.5	30	4.4	0.8
Kistrand	37.5	42	4.6	0.7	39.4	24	2.6	0.6
Neiden & Pasvik	38.6	26	5.0	1.0	41.0	12	5.9	1.7
Karasjok & Kautokeino	36.2	18	5.6	1.3	38.2	14	4.0	1.1

Table 23.

Inclination angle of acetabulum to the sagittal plane. Variation at different age as given by other authors.

Age		Dega 1933	Mayet 1950	Lanz 1951	Laurent 1953
3. fetalmnth.	m	27—30	39	32	
	f	33—37			
8. fetalmnth.			51	38	15—20
Birth	m	22—27	31	38	10—25
	f	28—30			
1.—3. year				35	20—25
Adults				42	

Table 24.

Inclination angle of acetabulum to the horizontal plane. Both sexes. Normal material, Lapps.

	M°	n	σ	e
Males	59.8	138	5.8	0.5
Females	57.0	86	5.6	0.6

The inclination of the acetabulum to the horizontal plane has also been the object of investigation. This angle indicates to some, obviously restricted, extent the development of the upper acetabular rim. The following mean values have been obtained for this angle: 52.5° (Shiino 1915); 62.8° (Dega, quoted by Laurent 1953); 60.0° (Steindler 1935, Donovan and Campbell, quoted by Badgley 1949). There are also other factors in the structure of the bone that affect the degree of this angle and the present observations are not intended to give an indication of the state of development of the socket. The angle in 224 hip bones was measured and was on an average 59.8° for men and 57.0° for women (table 24).

Summary: The inclination of the acetabulum to the sagittal plane in normal Lapps is more frontally directed in women than in men. There is no bilateral difference. The direction of the acetabulum is slightly more frontal in the local groups where the highest incidence of dislocation is found. The inclination of the acetabulum to the horizontal plane obviously could not serve as a reliable indication of the development of the upper rim of the socket.

5. Angle of incidence

According to Lanz (1949), the axis through the femoral neck and head in normal adults is approximately at right angles to the axis through the posterior and anterior acetabular rims (see figure 1), namely 90° for men and 92° for women. The same sex difference is found in normal Lapps, but the absolute figures lie approximately 10° lower than those of Lanz.

The calculation of this angle has been discussed previously. It must be stressed that neither the femoral antetorsion nor the acetabular depth is taken into consideration in this calculation. Allowance must be made for this fact when the stability of the joint is evaluated. (Table 32 demonstrates that the lowest values for this angle occur in groups with large antetorsion.)

Table 25 shows that the angle of incidence increases with age. Even if this increase is insignificant, it cannot be rejected. It also

Table 25.

Angle of incidence. Different age groups, both sexes. Normal material, Lapps.

	Males				Females			
	M°	n	σ	e	M°	n	σ	e
Juv-Ad	74.0	2	2.0	1.4	75.4	6	2.8	1.1
Ad	79.8	32	5.2	0.9	81.1	39	5.6	0.9
Ad-Mat	78.3	33	5.7	1.0	81.2	14	6.1	1.6
Mat	80.5	54	6.3	0.9	85.8	18	6.3	1.5
Mat-Sen	80.8	15	3.9	1.0	84.0	6	4.2	1.7
Total	79.8	136	5.2	0.5	81.9	83	6.6	0.7
Var°	66.7—95.6				60.7—97.8			

appears that the angle is larger in women than in men in all groups. The mean angle for women is 2.1° larger than that for men and the standard error is 0.86, i.e. the difference is significant. The geographical variation, presented in table 26, is discussed below.

Summary: The angle of incidence is larger in women than in men, although for both sexes it is about 10° smaller than the normal averages given for other samples. The angle increases with age (figure 2).

Table 26.

Angle of incidence. Comparison of different localities. Normal material, Lapps.

Locality	Males				Females			
	M°	n	σ	e	M°	n	σ	e
Angsnes	78.6	40	5.5	0.9	82.0	30	6.3	1.2
Kistrand	80.7	42	5.7	0.9	82.1	23	4.1	0.9
Neiden & Pasvik	82.1	26	5.2	1.0	84.1	12	6.6	1.9
Karasjok & Kautokeino	79.0	18	6.8	1.6	79.6	14	6.7	1.8

6 and 7. Platymery and pilaster

The percentage ratio of the sagittal to the transverse diameter of the proximal femoral diaphysis, the platymeric index, is, according to Martin (1914), approximately 85 % for modern Europeans. Women regularly show a more pronounced platymery than men, the difference being but a few percents. An index of less than 75 % indicates a condition of hyperplatymery which is considered to be a primitive trait demonstrating the occurrence of a lateral enlargement of the insertion of the Gluteus maximus. Hyperplatymery often occurs in conjunction with a large degree of femoral antetorsion.

A specially developed linea aspera is called pilaster and the pilaster index indicates the ratio of the sagittal to the transverse diameter at the border between the lower and middle thirds of the femoral shaft. The index is often moderate even when a pronounced pilaster can be seen at inspection. According to Martin, the average values for the pilaster index in modern Europeans vary between 100 % and 103 %, the individual range, however, being considerable. The index is usually a few percents larger in women than in men. The development of pilaster is ascribed primarily to the development of especially strong insertions of the medial and lateral portions of the Quadriceps femoris.

The figures for the platymeric and pilaster indices in the normal Lappic sample are presented in tables 27—28. It is evident from table 27 that platymery is more pronounced in women, the index being 2.7 % larger for men. This difference is significant with a standard error of 0.64. The same applies to the pilaster index where the difference is 3.4 % and the standard error 0.78. Thus pilaster is more pronounced in men in the Lappic sample. Table 28 shows the geographical variation and shall be discussed later.

There is a correlation between the neck-shaft angle and age as well as between platymery and age (figure 3). In both sexes the neck-shaft angle decreases, and the platymeric index increases, with age. In the male sample the regression line is rather straight and the correlation is fair. There is, however, no correlation between the neck-shaft angle and the platymeric index, both being depen-

Table 27.

Platymeric and pilaster indices. Different age groups, both sexes. Normal material, Lapps.

Age	Platymeric index								Pilaster index					
	Males				Females				Males			Females		
	M	n	σ	e	M	n	σ	e	M	σ	e	M	σ	e
Juv-Ad	78.1	7	4.9	1.8	77.0	12	5.9	1.7	99.3	5.8	2.2	98.4	6.5	1.9
Ad	78.5	57	4.7	0.6	77.9	64	6.4	0.8	101.3	8.1	1.0	99.9	6.4	0.8
Ad-Mat	79.1	42	6.5	1.0	76.5	25	9.5	1.9	101.0	7.1	1.1	98.3	6.9	1.4
Mat	80.4	107	7.9	0.8	76.7	73	7.0	0.8	104.2	9.4	0.9	98.6	7.2	0.8
Mat-Sen	81.0	33	7.6	1.3	76.4	16	4.2	1.1	99.7	9.1	1.6	97.0	6.5	1.6
Total	79.8	246	6.5	0.4	77.1	190	7.0	0.5	102.2	9.3	0.6	98.8	7.2	0.5
Var	64.5—100.0				59.4—96.2				80.8—122.2			80.0—114.3		

Table 28.

Platymeric and pilaster indices. Comparison of different localities. Normal material, Lapps.

Locality	Platymeric index								Pilaster index					
	Males				Females				Males			Females		
	M	n	σ	e	M	n	σ	e	M	σ	e	M	σ	e
Angsnes	78.2	46	4.8	0.7	79.7	40	7.0	1.1	99.3	6.9	1.0	97.8	7.3	1.1
Kistrand	80.0	78	7.0	0.8	75.9	59	6.9	0.9	102.6	7.5	0.9	97.8	9.3	1.2
Neiden & Pasvik	79.4	60	8.7	1.1	73.3	44	6.0	0.9	102.2	10.4	1.3	100.1	6.9	1.0
Karasjok & Kautokeino	81.6	49	7.0	0.9	80.0	38	4.9	0.8	102.6	6.9	1.0	97.8	6.8	1.0

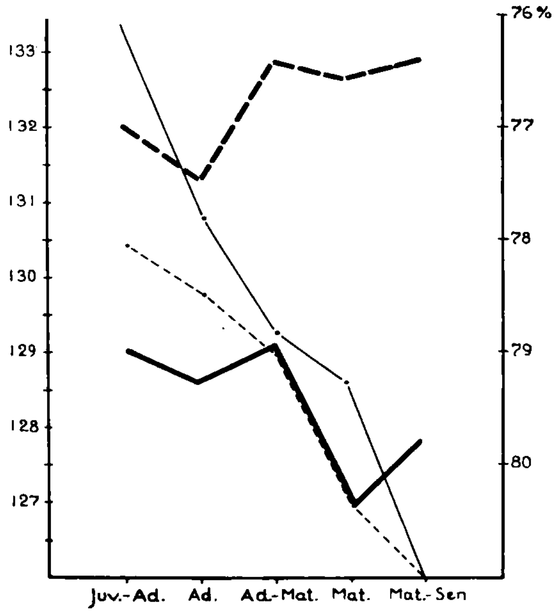

Figure 3.
Relation between neck-shaft angle and platymeric index. Different age groups, both sexes. Light lines indicate men, heavy lines women. Continous lines indicate neck-shaft angle, dotted lines platymeric index.

dent upon the increase in age. Neither is correlation between these two traits found within the separate age groups or within the total male or female samples. There is no correlation between platymery and pilaster, the correlation coefficients for men and women being + 0.25 and + 0.17 respectively.

Summary: The femurs of normal Lapps are relatively platymeric and most so in women. The pilaster index is larger in men than in women. Platymery decreases with age.

8. Some reciprocal relations

It is appropriate to give a short account of the correlation between certain of the investigated traits, followed by a short summary of the observed age, sex and geographical variations in the normal material of Lapps. The average values are presented in

Table 29.

Relation between femoral antetorsion and inclination angle of acetabulum to the sagittal plane. Normal material, Lapps. (The number is smaller than in table 20 because the inclination angle could not be measured in all the hip bones where the antetorsion angle could be measured in the corresponding femurs.)

ata°	ia° males				ia° females			
	M	n	σ	e	M	n	σ	e
0— 9.5	37.2	57	3.2	0.4	40.2	18	4.0	0.9
10—19.5	37.0	47	4.7	0.7	40.5	26	4.0	0.8
20—29.5	37.6	22	5.1	1.1	39.9	27	2.1	0.4
30—39.5	37.0	6	3.8	1.5	40.3	4	0.9	0.5
40—49.5	40.0	3	1.7	1.0	(36.0)	1	—	—

tables 29—32, the correlation coefficients, however, being calculated from all single readings and not from these averages.

In table 29 the relation between the femoral antetorsion and the inclination angle of the acetabulum to the sagittal plane is shown. The correlation coefficients are less than 0.1 in both sexes demonstrating that there is no correlation between these angles. The inclination angle is also independent of the acetabular depth (table 30). A comparison of the relative depth and the antetorsion angle (table 31) shows that there is no correlation between these values either. No significant correlation is found with respect to the relation between the antetorsion angle and the angle of incidence (table 32). Even if it is not presented in any table, it should be mentioned here that a calculation of the relation between the neck-shaft angle and the acetabular depth reveals that no true correlation exists between these traits either. The coefficients of correlation are in none of these cases outside $0.2 > r > \div\, 0.2$. A calculation of the coefficients within the age and geographical groups on the whole corroborates the findings within the total sample.

The findings demonstrate that a large degree of antetorsion on the average is not compensated for by alterations in the position or the depth of the socket. On the whole it may be said that the characteristics of the femur are apparently independent of the characteristics of the acetabulum.

Table 30.

Relation between the relative acetabular depth and the inclination angle of acetabulum to the sagittal plane. Normal material, Lapps. (The number is smaller than in table 20 because the inclinatin angle could not be measured in all the hip bones where the acetabular depth could be measured.)

Depth %	ia° males				ia° females			
	M	n	σ	e	M	n	σ	e
36—40.9	36.5	6	5.5	2.2	(32.0)	1	—	—
41—45.9	38.4	23	4.3	0.9	40.0	31	2.2	0.4
46—50.9	36.2	66	4.2	0.5	40.3	38	4.3	0.7
51—55.9	37.7	29	4.6	0.9	40.4	8	2.3	0.8

Table 31.

Relation between femoral antetorsion and the relative acetabular depth. Normal material, Lapps. (The number is smaller than in tables 3 and 16 because antetorsion and acetabular depth could not always be measured in the same skeleton.)

	Depth, males				Depth, females			
	M	n	σ	e	M	n	σ	e
0— 9.5	47.6	76	2.9	0.3	46.9	34	3.7	0.6
10—19.5	48.4	72	3.8	0.4	46.8	40	3.7	0.6
20—29.5	47.8	25	4.8	1.0	46.2	34	3.3	0.6
30—39.5	49.1	9	3.9	1.3	45.3	5	3.2	1.4
40—49.5	38.5	3	3.9	2.3	(40.0)	1	—	—

Table 32.

Relation between femoral antetorsion and the angle of incidence. Normal material, Lapps. (The number is smaller than in table 25 because antetorsion and the angle of incidence could not always be measured in the same skeleton.)

ata°	aca°, males				aca°, females			
	M	n	σ	e	M	n	σ	e
0— 9.5	80.9	50	4.5	0.6	81.3	18	4.3	1.0
10—19.5	80.0	45	5.0	0.6	83.1	26	5.2	1.0
20—29.5	79.1	20	6.3	1.4	82.0	28	7.6	1.4
30—39.5	79.9	6	6.9	2.8	79.7	3	5.3	3.0
40—49.5	79.0	3	5.5	3.2	(79.3)	1	—	—

9. Age differences

The variations within the age groups are presented in tables 3, 10, 16, 20, 25 and 27. They have been discussed in separate chapters and only a short summary is given here. Antetorsion does not vary with age within the adult groups (table 3). On the other hand, there is a significant difference in antetorsion between the adult sample and the child sample (table 4), antetorsion being most pronounced in the latter. Despite the relatively small samples, a decrease of the neck-shaft angle with age is observed (table 10). A graph of these values (figure 3) demonstrates that the decrease runs parallel with diminishing platymery of the femur (table 27). Comparison of tables 10 and 11 shows that the neck-shaft angle is slightly larger for children than for adults.

The acetabular depth, both relatively and absolutely, appears to increase with age (figure 2 and table 16). This increase in depth, similar to the decrease of the neck-shaft angle, may be ascribed to mechanical forces. The inclination angle does not show any variation with age that may suggest a regular change (table 20), while the angle of incidence seems to increase slightly with age (figure 2 and table 25).

10. Sex differences

The sex differences are presented in the same tables as the age differences. Antetorsion angle is on an average larger for women than for men, a difference which can be considered significant. It can also be mentioned that a larger percentage (34.5) of the female femurs than of the male femurs (22.4) have an antetorsion angle of more than 20°. Table 10 demonstrates that the neck-shaft angle is on an average 1° larger for men than for women, a difference which is close to significance. The acetabular depth (table 16), both absolutely and relatively, is larger for men than for women. Table 20 shows that the acetabulum is more frontally directed in women than in men. There is also a significant difference with respect to the angle of incidence which is larger in women than in men (table 25). The female femur shows a more marked platymery than the male (table 27) while the latter has the most developed pilaster.

11. Geographical variations

The geographical variations are presented in tables 7, 14, 19, 22, 28, 33 and 34. The readings have been arranged in two ways, partly placed in 4 head groups (Agnsnes, Kistrand, Neiden and Pasvik, Karasjok and Kautokeino), partly in 2 groups (namely Angsnes and Kistrand, which show a very high incidence of hip luxation, on the one side and the other groups on the other.) A few very small local groups were only included in the total sample.

Table 33.

Comparison of different localities. Normal material, Lapps.

		ata°	nsa°	depth	ia°	aca°	platy-meric-index
Angsnes & Kistrand	m	16.2	129.3	47.8	37.2	79.7	79.3
	f	17.0	128.1	47.5	40.0	82.0	77.6
Others	m	11.7	128.3	47.8	37.6	80.8	80.4
	f	15.4	128.3	45.5	39.5	81.6	76.5
d	m	4.5	1.0	0.	—0.4	—1.1	—1.1
S	m	1.27	0.57	—	0.94	1.08	1.00
d	f	1.6	—0.2	2.0	0.5	0.4	1.1
S	f	1.49	0.51	0.72	1.12	1.61	1.13

It is apparent from consideration of table 33 that the deviations between the two main groups are on the whole insignificant. The most obvious fact is the larger degree of antetorsion in the Angsnes—Kistrand group. The neck-shaft angle is also slightly larger for men in this group.

Comparison of the sex indices (values for women as a percentage of corresponding values for men) of the different measurements for the two main groups (table 34), shows that there is no difference with this respect within the groups, the index for antetorsion excluded. There is a less pronounced difference between the

Table 34.

Comparison of different localities by means of the sex ratio. Normal material, Lapps.

	ata°	nsa°	depth	ia°	aca°	platymeric & pilaster indices	
Angsnes & Kistrand	1.05	0.99	0.99	1.08	1.03	0.98	0.97
Others	1.32	1.00	0.95	1.05	1.01	0.95	0.97

sexes with regard to antetorsion in the Angsnes—Kistrand group than in the others. A smaller difference in this group with respect to acetabular depth can also be traced.

12. Description of the hip joint in Lapps

A short description of the hip joint in Lapps, with special reference to the normal adult and the dislocated joints, is given as a supplement to the biometric presentation of the material.

The hip bone as well as the thigh bone of both sexes is regularly of a relatively gracile structure. The acetabulum is of primary interest. This is as a rule shallow (figure 4) with an upper support that is often underdeveloped. The socket is more open than in the Oslo sample where it is rather deep with a solid upper rim (figure 5).

The large degree of femoral antetorsion which is often present (figure 6) is most striking. Platymery and pilaster are also often rather pronouced. A third trochanter is well developed in a considerable number of femurs (figures 6 and 8 a). This is in accordance with Martin (1914) who assumes that this is found in about 65 % of Lapps while it is found in about 35 % of contemporary Europeans. The femur is often slightly inclined to the sagittal plane. The neck-shaft angle is large (figure 8 a).

The most characteristic feature of the hip bone in skeletons with dislocation is the flat and deformed acetabulum. A new socket has been formed cranially to the deformed one in 3 cases (figure 7). Both the original and the new socket lack support in the form of a developed upper rim. The acetabulum is small in dislocated

Figure 4.
Photograph of the left hip bone of normal male Lapp, lateral view. Note the open socket and the underdeveloped upper rim.

Figure 5.

Photograph of the left hip bone of normal male from Oslo, lateral view. Note the deep socket and the solid upper rim.

Figure 6.
Photograph of the left femur of normal male Lapp. Note the considerable antetorsion angle.

Figure 7.
Photograph of the left hip bone from a dislocated Lappic hip joint. Note the new socket. Lateral view.

a b

Figure 8.

a. Photograph of the left femur presented in figure 6, posterior view. Note the large neck-shaft angle and the third trochanter.

b. Photograph of the left femur from a dislocated Lappic hip joint. Note the varus position, the deformed head and neck and the stenomery. Anterolateral view.

cases, its diameter being 25—30 mm as opposed to the normal 45—50 mm, and the depth is only 15 mm approximately, i.e. as much as 10 mm less than for normal Lapps. The socket seems to be frontally directed.

In cases of dislocation, the femur is very deformed with attendant atrophy of the collum and caput, partly resulting from the increased pressure of this part of the bone against the ilium (figure 8 b). In the majority of cases the femur shows a large degree of stenomery and a small neck-shaft angle (figure 8 b). Stenomery is especially developed in cases where a new socket has developed. The femoral antetorsion is as a rule larger than in the normal sample. Figure 8 b shows a typical adult femur in a case of dislocation; it should, however, be remembered that in the sample of adult dislocation cases only old, untreated luxations are included.

ABBREVIATIONS

a = absolute
aca = angle of incidence (collum — acetabulum)
ad = adult
ata = antetorsion angle
csa = complementary condyle-shaft angle
d = difference
e = standard error of the mean
f = female
g = Gluteus maximus muscle
i = Ileopsoas muscle
ia = inclination angle
juv = juvenile
m = male
M = mean
mat = mature
n = number
nsa = neck-shaft angle
r = relative
S = standard error of the difference
SS' = sagittal plane
sen = senile
σ = standard deviation
var = maximal variation (range)

DISCUSSION

1. Anatomical aspects

It is necessary to consider two main groups of factors with regard to the hip joint, those concerning the femoral neck and head and those concerning the acetabulum.

The considerable degree of antetorsion in fetal life (table 9) is compensated by the flexion of the joint. In this position with equilibrium between the muscles and ligaments of the joint, the outward rotatores possess a greater potential strength than the inward rotatores (Schneider 1943). If the normal decrease of the antetorsion angle does not take place during infancy, dislocation is apt to occur. There seems to be a connection between antetorsion and luxation, a problem which has been discussed by several authors (e.g. Hibbs 1915, Gaugele 1918, Lorenz 1920, Lange and Pitzen 1921, Pitzen 1923, Krida 1928, Murk Jansen 1929, Bøhm 1935, Schneider 1943, Badgley 1949, Bernbeck 1949, Storck 1950, Hass 1951).

The Gluteus maximus is the most important outward rotator in the hip joint, assisted in a flexed joint by the adductores, and in the presence of large antetorsion even by the Ileopsoas (figure 9). The overweight of outward rotatores during fetal life and infancy favours a modelling of the femoral neck in a direction which predisposes to dislocation. On the other hand, antetorsion will normally be compensated for before transition to erect posture takes place (Preiser 1908, Brandt 1928, Leveuf and Bertrand 1946).

Also the neck-shaft angle is large during fetal life and infancy. The angle decreases with age, presumably mostly due to the effect

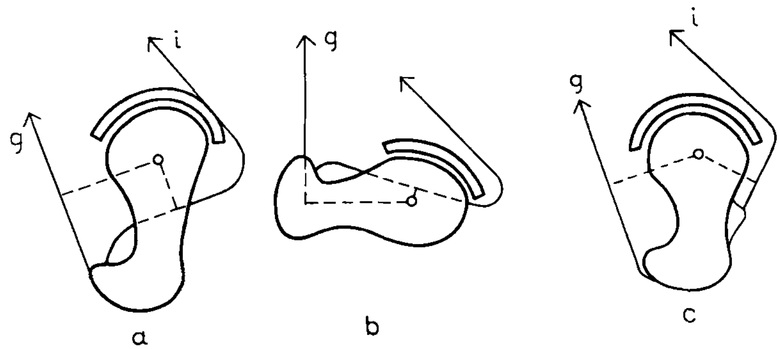

Figure 9.

a. Normal rotational balance. The Ileopsoas muscle rotates medially and acts at a point lateral to the axis of rotation. The Gluteus maximus muscle rotates laterally.
b. Dislocated hip with functional lateral rotational balance due to the lateral rotation of the Ileopsoas muscle acting at a point medial to the axis of rotation.
c. Conditions following operation. Antetorsion angle is diminished, the Ileopsoas muscle rotates medially and acts at a point lateral to the axis of rotation. According to Bernbeck.

of the body-weight on the femoral head and neck. The effect of the muscles with regard to this angle is obscure. The neck may be considered as a level with the body weight acting on the medial and the trochanter muscles on the lateral end, the net result being a decrease of the neck-shaft angle. The Gluteus medius is one of the most important muscles that favour a decrease of the angle, the same muscle being an important stabilizing muscle in the joint. On the other hand, the proximal part of the Gluteus maximus (L a n z 1949) tends to increase the angle. This part of the muscle inserts into the upper part of the lateral lip and occasionally to a third trochanter. The latter is a sign of great stress on the muscle. In contrast to the other outward rotatores, the Gluteus maximus is an important extensor in the hip joint. For this reason it is of particular interest with regard to the erect posture.

Besides a third trochanter, platymery is the most reliable sign of stress on the Gluteus maximus. It shall be stated here that no correlation can be found between platymery and antetorsion.

In the normal Lappic sample the neck-shaft angle as well as platymery decreases with age (figure 3). There is, however, no correlation between these characteristics. (If the material is arranged according to age, the correlation between the neck-shaft angle and the platymeric index seems to be negative, and if it is arranged according to sex and geographical localities as shown in tables 14 and 28 there seems to be a positive correlation.) A large neck-shaft angle and considerable platymery is met with in neolithic people and in several modern groups (Martin 1914). The fact that platymery is common in pathological coxa vara may seem surprising. This condition, however, is a primary maldevelopment of the femoral neck, presumably due to epiphyseal disturbances and irrelevant to the present problems.

Even though the femoral neck and head are considered to be the primary formative factors in the hip joint (Falk 1913, Müller 1929, Putti 1937, Badgley 1949, Richard 1950, Rohlederer 1951), the structure of the acetabulum plays an essential part in its stability. The normal relative depth of the socket in adults was stated by Le Damany (1908) and Shiino (1915) to lie between 50 and 60 %. Special interest was paid to the development of the upper acetabular rim. If this part of the socket is underdeveloped, the normal decrease of the neck-shaft angle will not take place due to a deficient fixation and accordingly lack of strength of the trochanter muscles. It is of interest in this connection that this angle is considerable in Lapps and that it, even if it decreases with age, even in the aged is larger than the normal values usually given for this age group. That an underdeveloped upper acetabular rim plays an important role in the development of dislocation, is seen from the fact that the anterior and superior luxation type of this most common of all congenital malformations, is the most typical one.

Great importance has been ascribed to the inclination of the acetabulum to the sagittal (Lanz 1949) and the horizontal (Leveuf and Bertrand 1946) planes. The anteversion of the pelvis taken into consideration, one should perhaps believe that a frontally directed acetabulum would afford better adjustment than a sagittally directed one. If this were true, one should expect that dislocation would most often occur in men. The opposite, however, is the fact. Even Gaugele (1918), Lanz (1949) and Hass (1951) maintain that dislocation is more apt to occur when

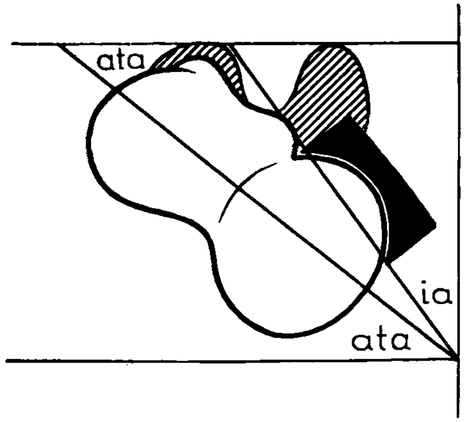

Figure 10.

Relation between antetorsion and inclination angles. Poor adjustment when antetorsion is large and the socket is frontally directed. Full extension in the joint, i.e. maximal effect of the Gluteus maximus.

the socket is frontally directed. It might therefore be of interest to employ another view and to consider also the femoral antetorsion in the evaluation of the stability. In order to maintain the possibility of a comparison with the angle of incidence as measured by previous authors, even the inclination angle is measured in relation to the entrance plane.

A frontally directed socket gives poor adjustment to a femur with large antetorsion. The adjustment is less if the socket is shallow. This is especially so during maximal extension, i.e. in a position when the outward rotator Gluteus maximus takes its greatest effect. According to Lanz (1951), a decrease in antetorsion takes place with age while the socket is more and more frontally directed (table 23).

If antetorsion is as large, as or larger than, the inclination angle of the acetabulum to the frontal plane (i.e. the complementary angle of the inclination to the sagittal plane), the axes through the femoral head and neck on the one side and the acetabulum on the other will be close to parallel and the adjustment accordingly small. This comparison of the angles should, strictly speaking, only be employed if the femoral shaft lies in a plane vertical to the entrance plane in which the inclination angle was measured. As maximal extension in the joint, however, only comprises about 20° in relation to the normal erect position, and 45° during abduction, this will be impossible because the entrance plane is inclined at 60° to the horizontal plane. In spite of this, the inclination angle measured in the entrance plane is employed for a comparison with the antetorsion angle because the interest is concentrated upon the difference in the relation between the two sexes and not so much upon the absolute values. (See figure 10.)

Turning now to the Lapps, antetorsion has been found to be more pronounced than in Norwegians (table 5). Further, it is more pronounced in women than in men (tables 3 and 6), larger in children than in adults (table 4) and especially large in cases with dislocation (table 8). Within the normal sample, antetorsion is largest in the local groups in which the highest incidence of dislocation is found (table 7).

The neck-shaft angle is significantly larger in Lapps than in Norwegians (tables 10, 12 and 13). A large angle, according to Hass (1951); is often seen in dysplastic hips.

Several authors (Preiser 1908, Bernbeck 1949, Massie and Howorth 1951) maintain that congenital dislocation is connected with a valgus position of the femur. On the other hand, Harrenstein (1928), Bøhm (1935) and Näätänen (1936) generally found a varus position in this condition. Rogers (1934) has pointed out that a large antetorsion angle may produce an apparent coxa valga in roentgenograms if the antetorsion is not compensated for by the positioning of the patient.

The neck-shaft angle of dislocated hips in the Lappic sample is small, especially in adults (table 15). Even normally the angle is larger in children than in adults (table 11). In adults with dislocation stenomery (the opposite of platymery) is also found, i. e. an increased sagittal diameter of the upper femoral diaphysis. This is surprising if one assumes that dislocation is partly due to an increased effect of the outward rotatores which tend to produce platymery. Due to the shrinking of the femoral head and neck in dislocation (figure 8 b) the body weight is transmitted directly to the shaft which is exposed to increased static tension. On motion the femur glides upwards and is exposed to a tension which also requires increased strength in the sagittal plane. The dislocation upwards shortens the Gluteus maximus. Its strength is impaired and as a result a coxa vara with stenomery is produced. It should be remembered that the neck-shaft angle normally decreases with age and that this is followed by a decrease also in platymery (table 27).

Regarding the acetabular depth there is a general agreement that a shallow socket predisposes to dislocation (Le Damany 1908, Preiser 1908, Müller 1929, Bøhm 1935, Hilgenreiner 1936, Faber 1937, Putti 1937, Korvin 1938, Lanz and Wachsmuth 1938, Schneider 1943, Mayr 1944, Haberler 1945, Bernbeck 1949). It is universally reported that especially the upper acetabular rim is underdeveloped in congenital dislocation. Throughout the whole of the Lappic material there is a marked underdevelopment of this part of the socket (figure 4). The relative depth of the Lappic acetabulum comprises only 47—48 % (tables 16—19) and is even less in dislocation cases.

The direction of the acetabulum in Lapps is not especially frontal (tables 20—22) and is most frontal in the sample from Neiden and Pasvik where no cases of dislocation were found. Table 23 shows the inclination angle in different groups as given by previous authors. It is seen that there is a considerable disagreement in this respect.

In the present material the inclination of acetabulum to the horizontal plane (table 24) apparently reveals no information of the acetabular depth and the upper acetabular rim.

It is stated above that a frontally directed socket gives poor adjustment to a femur with a large antetorsion angle. In the Lapps there is no correlation between the inclination of the acetabulum to the sagittal plane and its depth (table 30) nor between the antetorsion and the depth (table 31) or the antetorsion and the sagittal inclination (table 29). It is therefore likely that a more frontally directed socket will give poor adjustment (figure 10). A large degree of antetorsion tends to decrease the stability of the joint if it is not compensated by an increased sagittal direction of the acetabulum. The normal Lappic sample shows to some extent such a compensation as compared with other normal materials. If, however, one compares the different local groups within the Lappic sample, the larger antetorsion in the group form Angsnes and Kistrand is not compensated by a more sagittal orientation of the socket (table 33).

With the reservation taken above considering the inclination of the entrance plane, the inclination of the acetabulum to the frontal plane in normal adults is on the average 52.8° for men and 50.0° for women while the average antetorsion angles are 14.0° and 16.3° respectively. The larger the difference between the two angles, the better is the adjustment in the joint between the femoral head and the socket. It is seen that the adjustment is best in the male joint.

Judged by previous publications (Putti 1937, Laurent 1953), conclusions based on the inclination of the acetabulum to the sagittal (and the frontal) plane should be treated with reservation. The question of the relation between this angle and anterior and posterior dislocation will not be treated here.

Comparison of the two groups where dislocation was frequent (Angsnes and Kistrand) with the remaining groups (table 33) may provide information regarding the geographical differences within the normal Lappic sample. The difference between antetorsion and the inclination of the acetabulum to the frontal plane indicates the extent of adjustment and stability of the joint, provided a position of maximal extension. The difference in the Angsnes—Kistrand group is 36.6° for men and 33.0° for women, while in the other groups the differences are 40.7° and 35.1° respectively. The adjustment is least in women and in the groups where dislocation is most frequent. The sex ratio with respect to the angle calculated above is 0.90 in Angsnes—Kistrand and 0.86 in the remaining groups, indicating a smaller sex difference in the groups where dislocation is frequent. No definite difference was, however, found with regard to the angle of incidence (table 34).

The antetorsion angle is not considered in the calculation of the angle of incidence, and the degree of correlation between these angles is poor. It is evident that the occurrence of a small angle of incidence in conjunction with a large degree of antetorsion will cause an increased instability of the joint. From table 34 it is evident that the sex difference regarding antetorsion is small in the groups where dislocation most often occurs.

2. Genetical aspects

In extensive samples of dislocation cases several authors (e. g. Hayashi and Matsuoka 1913, Isigkeit 1928) have proved heredity of the condition. These and other authors (e. g. Verschuer 1932, Faber 1937, Hart 1942, Hass 1951, Laurent 1953) have discussed different hereditary mechanisms. The present investigation does not pretend to give a solution to this problem. It is, however, appropriate to discuss the anatomical findings also from this point of view. It is of interest to know whether there are special genetical and anatomical conditions in the Lappic material which may explain the high frequency of dislocation in this group. The only available pedigrees are those of Wessel (1918), although they are insufficient to allow any certain conclusions. They are, however, also of interest with regard to the frequency of the disease among Lapps, the sex ratio and the bilaterality.

An account has been given of the measurements made in a sample of non-dislocated Lappic hip joints, and how these measurements compare with corresponding readings from a control sample and a sample of dislocated hip joints in Lapps. The normal Lappic sample can on the whole be regarded as non-mixed and unselected. In addition, it is a distinct group comprising individuals from a population which differs from the Norwegian one. The sample dates from the 18th century, a time when the Lappic population was more isolated than it is today.

As mentioned above the frequency of congenital hip dislocation in this material, adults and children included, is 4.2 %, i. e. more than 30 times the incidence of this condition in other Scandinavian populations. This figure was corroborated by Wessel (1918) who found a frequency of 5 % in South Varanger and who presented 54 Lappic families with at least one individual affected, the families including 278 individuals. It is natural to raise the question whether the normal hip joint in Lapps is characterized by traits which deviate from those found in other populations and whether such a deviation can provide a basis for the determination of the factors which are of importance for the manifestation of congenital dislocation.

If one takes a closer look at Wessel's Lapp families from South Varanger, there are 69 affected individuals; 10 males and 59 females, and 209 non-affected; 105 males and 104 females. The sex ratio is 6 : 1 for the affected and 1 : 1 for the non-affected individuals. The pedigrees where congenital dislocation occurred in two generations show that there are 12 females and one male whose mother had dislocation and 2 females and one male whose father had dislocation. The frequency in the brothers and sisters of the affected individuals is about 22 %; 6 % in males and 38 % in females. The evidence so far does not indicate that dislocation is different in Lapps from other populations concerning hereditary behaviour.

Cocchi (1951) reports that different pedigrees may show a varying incidence among relatives, particularly regarding unilateral versus bilateral cases. He quotes Scaglietti who found both joints affected in 54 % of the cases. In the present skeletal material there are 6 bilateral cases in 14 individuals, i. e. 43 %; of the 8 unilateral cases, one was affected on the right while 7 were affected on the left side. Among 47 individuals Wessel found 22 bilateral cases. Of the 25 unilateral cases 15 were affected on the right and 10 on the left side. Even admitting that the data by Cocchi from the era of modern roentgenology can not be compared with the data by Wessel, the evidence so far is not suggestive of any different frequency of unilateral versus bilateral cases between Lappic and other populations. If both hips are considered, Wessel's material of cases with known site of manifestation comprises in all 94 hips with 69 (22 bilateral and 25 unilateral) or about 73 % affected. The frequency is about 47 % in the other hip in individuals in whom one hip is affected against 22 % in sibs of affected individuals. If the condition is supposed to be due to a dominant gene as most authors maintain, the expected frequency in sibs is 50 %. The observed frequency is 22 % and the probability of manifestation accordingly about 50 %, an assumption which is confirmed by the observed frequency of 47 % in the other hip in individuals with one hip affected.

Roentgenological examination of pedigrees have, according to Faber (1937) and Cocchi (1951), shown that a dysplastic hip joint must not necessarily produce a dislocation; this is said to occur only in 25 % (Cocchi) of individuals showing such underdevelopment of the joint. These authors report that the sex ratio in maldeveloped joints without dislocation is 1.74 : 1 (Faber) and 1.25 : 1 (Cocchi), whereas in dislocation the corresponding ratios are 5 : 1 and 6 : 1 respectively. Females with subluxation are thus more disposed to dislocation than males, a fact indicating an influence of different static conditions in the sexes.

The sex differences in the structure of the pelvis appear as early as in the third fetal month. The girls are precociously developed as regards ossification. They also begin to stand up and walk earlier than the boys, just in the critical stage for the development of a dislocation from a dysplastic hip joint. There is a connection between ossification rate and dislocation, a good diagnostic criterion in this condition being the delayed ossification of the femoral head and the ischiopubic synchondrosis. However, orthopaedic treatment has clearly shown the interplay of hereditary growth potentialities and function in dislocation as in bone morphology generally.

The incidence of dislocation in the first or second child in Wessel's sample is 42 %; 21 % in the third or fourth child and 9 % in later children. These differences suggest a more frequent occurrence in early children or in children of young mothers.

Abnormal developmental potentialities of an hereditary origin may be counteracted by environmental factors or manifest themselves as a dislocation. However, also in the first case the individual may show pathological changes of the joint, i. e. a subluxation, on roentgen examination. The common occurrence of deformative arthritis in the joint in Lapps is of interest in this connection

(Schreiner 1935). There is good evidence that arthritis of the joint is an expression of congenital abnormalities in the static conditions in the joint.

A frequency of dislocation of about 5 % as in some Lappic populations corresponds to a frequency of about 20 % of maldeveloped hips without dislocation as judged from roentgenological studies of other populations. Considering the close developmental relationship between the lower spine and the hip, the high frequency of spondylolysis in Lapps (Schreiner 1935) may also have a hereditary relationship to dislocation.

The peculiarities of the hip joint in Lapps are no conclusive evidence that the normal anatomy of the joint in Lapps predisposes to dislocation in these populations. They may as well be due to the 20 % of the population in which the abnormal genes have manifested themselves as maldevelopment without dislocation. In some families, genes may be present conditioning the manifestation of the hypothetical main gene referred to in genetical literature, the female genotype and pattern of development, growth and maturation being particularly maladjusted to the functional stress put upon the joint in the erect posture. The observations from the Lappic skeletal material may serve as an illustration how pathological genes may express themselves in normal individuals in such a way that the traits involved may appear as racial ones.

The great range and standard deviation regarding antetorsion in Lapps compared with Norwegians (tables 3—7), and particularly the extreme values in the localities Kistrand and Angsnes (table 7) where dislocation is most frequent may be due to the latent subluxation cases in these populations. Of the males 22 % and of the females 34 % show an antetorsion angle of more than 20°. The corresponding value in the Oslo sample is 11 %. These percentages are in fair agreement with the supposition that about 25 % of the Lapps have the genotype predisposing to dislocation.

Also the relative depth of the acetabulum (tables 16—19) shows a greater range and standard deviation in Lapps than in the Oslo sample. However, a relationship between the morphology of the acetabulum and the femoral neck and head is not favoured by the lack of correlation between the depth and antetorsion (table

31). The frequent coincidence of an extreme antetorsion and a shallow acetabulum in dislocation cases is perhaps not due to functional factors only, even though the favourable effect of reposition on the depth of the socket may be considered as proving a secondary influence of function in this respect (Massie and Howorth 1951). The surprising lack of correlation between antetorsion and acetabular depth is explainable on the hypothesis that the development of the femur and the acetabulum is influenced by different genes. Dislocation may be the result of a coincidence of both in the same individual. It is of interest in this respect that extreme antetorsion and an extremely shallow acetabulum is as a rule not met with in the same joint in the normal material although these traits are rather common in the sample.

This hypothesis may be tested by calculating the expected frequency of dislocation concerning the antetorsion and the depth. Judged by tables 3 and 4 and by previous authors is it reasonable to consider an antetorsion angle of more than 20° as extremely large. Judged by table 16 it is also reasonable to consider an acetabular depth of less than 40 % as extremely small ($47.9 - 2 \times 3.5$ in men and $46.7 - 2 \times 3.1$ in women; $\pm$ twice the standard deviation will cover 95.5 % of all readings). This will correspond to an absolute acetabular depth of 20 mm or less in men and 19 mm or less in women. Due to the large standard deviations the same calculation could not serve as a basis for the evaluation of the antetorsion angle. For the same reason the same upper limit was chosen in both sexes with regard to this angle.

If only those skeletons are chosen for this calculation, in which both joints could be measured, the expected frequencies of luxation in the adult sample are calculated at 1.9 % in men, 6.1 % in women and 3.3 % on the average. Of the expected number, about 60 % are unilateral and 55 % on the left side. The sex ratio is about 3 : 1. The actual frequencies in the material are 1.2 % in men, 6.8 % in women and 3.4 % on the average, the total material taken into account. There are 57 % unilateral cases, mostly on the left side. In the normal sample extreme antetorsion and extreme shallowness are very rare in the same individual while this is a common trait in dislocation cases. A corresponding calculation of the data from Oslo gives an expected frequency of 0.13 %, the actual incidence in the Norwegian population (table 1) being 0.12 % on the average. The conformity of the actual numbers and the expected numbers according to the hypothesis suggests that a chance occurrence of large antetorsion and a shallow acetabulum in the same individual is a primary factor in dislocation. These anatomical factors confirm the supposition of two independent groups of hereditary factors in the disease, one affecting the acetabulum, the other the femoral neck and head.

According to Bauer and Bode (1940), individuals with dislocation of the hip are small and lightly built. No data have been available that could confirm or discard this statement. It is worth noting that the Lapps generally show the same body-build. One may indeed raise the question, to what degree the low stature in Lapps is a racial character or an effect of the hereditary factors in dislocation. The variability of the stature in different Lappic populations is of interest in this respect.

How these genes accumulated in the genotype of these isolated, in many cases nomadic groups, is a matter of speculation. An increase in the frequency of a gene may be due to mutation, selection, a selective immigration of people with the gene or an emmigration of people without it, or to a random fixation. Nothing is known about the mutation rate. An eventual selection may concern the gait which is of particular importance to people living on subarctic plains. The joints, and particularly the hip joint, are essential to the efficiency of the gait. What manifests itself as a dislocation in one case may appear as a particularly mobile and efficient joint in another. The Lapps may have gained in mobility what they have lost in stability, the predisposition to dislocation being an expression of a genotype in a particular stage of evolution as far as the hip is concerned. One has to consider that dislocation of the hip is by far the most frequent malformation of the locomotor apparatus. This is what is to be expected in traits which are recent from an evolutionary point of view. The high frequency of orthopaedic ailments of the lower back and extremity may be due to developmental patterns which are still not sufficiently stabilized in the genotypes of the species.

There is no evidence of changes in the fertility in Lapps, the average number of children in Wessel's families being 5.1. An increase due to a positive selective value of the trait is therefore improbable. The Lapps are spread over a vast area and are distributed in many isolates which to a large extent have been endogamous for centuries. Such groups are apt to develop different gene frequencies by random fixation. However, random fixation, which is of great importance in single gene characters as blood groups, is of less influence in traits which are due to many genes.

The racial affinities of the Lapps are obscure. It is a rather peculiar fact that the ancestor of the largest Lappic pedigree or tribe in Kautokeino is of Finnish extraction. Wessel (1918) also reports that several of the families in his material had intermixed with Finns. The problem of congenital dislocation is no racial problem, but a problem of population genetics. Remarkable differences between the isolates have been established both regarding the skeletons (Schreiner 1935) and the teeth (Selmer-Olsen 1949). Particularly the Skolts in Neiden and Pasvik show many osteological peculiarities. The remarkably small antetorsion angle in this group (table 7) is therefore not surprising.

Most of the authors who maintain that the condition is hereditary, point out that functional factors are of importance in its manifestation. The mode of action of these factors during fetal life and infancy has been discussed with special reference to transition to erect posture. As mentioned above, it is noteworthy that Lappic children, even in our days, are placed in the «komse» inmmediately after birth. In this cradle they spend their first year interrupted only by care. In the «komse» the hip is forced into a position of maximal extension and adduction, a position coming close to an attempt to produce dislocation.

One has to consider the possibility that the characteristics of the hip joint in Lapps may be due to causes other than an influence of a dislocation genotype. Platymery, which is rather common in palaeolithic man, and also in Lapps, has been attributed to a particular gait such as mountain climbing. The gait of the Lapps has been described by several authors, among them keen observers like W e s s e l and, according to him L i n n é. According to W e s s e l the women have a gait which may be described by saying that most of them seem to have dislocated hips. By contrast the men are easy walkers, this sex difference being due (W e s- s e l) to the fact that the men follow the reindeer while the women stay at home. Such environmental factors may influence the use of the muscles and thereby the morphology of the joint.

It appears that the anatomy of the hip joint in the Lapps is closely related to the problem of dislocation. It is a question of what may be called population morphology; i. e. the influence of the gene frequencies in a population and its environment in determining the developmental pattern and relative growth of the traits constituting the joint which, of course, has to be considered as an integrative part of the individual.

SUMMARY

I. In the introduction the question is raised whether the high incidence of congenital dislocation of the hip in Lapps is due to a particular morphology of the hip joint in Lapps and eventually which these peculiarities are and what environmental and hereditary factors underly them. The investigation is primarily concentrated upon measurements of certain anatomical characteristics in the structure of the hip joint in a non-mixed and unselected sample of Lappic skeletons. In this sample congenital dislocation of the hip is frequent.

II. In addition to the anatomical investigation, the pedigrees of 54 Lappic families in which congenital dislocation occurred and which were presented by W e s s e l, are employed as a basis for genetic considerations.

III. Enquiries of local medical officers in different counties of Norway have confirmed that congenital dislocation of the hip is significantly more frequent in the material investigated than in the Norwegian population. The more frequent occurrence of the condition in women and on the left side is confirmed.

IV. The anatomical investigations include measurements of the femoral antetorsion and neck-shaft angle, the acetabular depth and inclination to the sagittal and horizontal planes, the angle of incidence, and finally the femoral platymeric and pilaster indices.

V. The femoral antetorsion is large in Lapps and larger in women than in men. Also the femoral neck-shaft angle is large in Lapps. The acetabulum is shallow and relatively sagittally directed. The angle of incidence of the femoral head and neck to the acetabulum is small. There is a considerable degree of platymery of the femur. The pilaster index is relatively small.

VI. In dislocated hips the femoral antetorsion is on the average more pronounced than in the normal sample. In these hips the femoral neck-shaft angle is small. The acetabulum is extremely shallow.

VII. In families where dislocation occurs, the probability of manifestation of the condition in sibs of affected individuals is about 50 % and the probability of manifestation on the other side when one hip is affected, about the same.

VIII. The significance of the anatomical characteristics is discussed. A large antetorsion angle, a shallow acetabulum and a relatively frontal orientation of the acetabulum seem to predispose to instability of the joint. These traits are most pronounced in women and for women even more frequent and more pronounced in the local groups where dislocation most often occurs. This is especially evident when the relation between the antetorsion angle and the inclination of the acetabulum to the sagittal plane is considered. The sex differences are on the whole less in groups where dislocation is most often found.

IX. The frequencies of extreme antetorsion and shallowness of the acetabulum are in conformity with the hypothesis that dislocation is caused by a coincidence of extreme antetorsion and a shallow acetabulum. The peculiarities of the hip joint in Lapps are not a racial trait but a manifestation on the population level of the hereditary factors involved.

RESUMÉ

I. Dans le préface, on pose la question à quel point l'occurence frequente de luxations congénitales de la hanche chez les Lapons est due a des traits morphologiques spéciaux, lesquels ceci sont et quels facteurs de milieu et d'héritage sont leur cause. Les recherches se concentrent primairement aux mesurages de caractéristiques spéciaux anatomiques concernant la structure du joint d'un matérial homogène et non sélecté de squelettes de Lapons. Dans ce matérial, la luxation ocngénitale de la hanche est fréquente.

II. En plus des recherches anatomiques, les tables généalogiques de 54 familles Laponnes, où la luxation congénitale de la hanche s'est montrée, ont été utilisés comme base d'une discussion de circonstances génétiques.

III. Les mèdicins régionaux de divers départements norvégiens ont confirmé que la luxation congénitale de la hanche se montre plus souvent dans le matérial éxaminé que parmi la population norvégienne. De même façon l'occurence plus fréquente de la maladie s'est confirmée chez les femmes et du côté gauche.

IV. Les recherches anatomiques comprennent des mesurages de l'antétorsion et de l'angle collo-diaphysique du fémur, la profondeur et le penchant de l'acétabulum en relation avec le plan sagittal et le plan horizontal, de l'angle incident entre le fémur et l'acétabulum, et enfin de l'index platymerique et pilastrique.

V. L'antètorsion du fémur est plus grande chez les Lapons que chez les norvégiens et plus grande chez les femmes que chez les hommes. De même façon, l'angle collo-diaphysique est plus grand chez les Lapons. L'acétabulum est peu profond et relativement

sagittalement placé. L'angle incident est petit. Il y a assez de cas de platymerie, tandis que le pilastre est point fréquent.

VI. L'antètorsion de joints de hanches disloqués est en moyenne plus grande que parmi le matériel normal. Dans ces cas-ci l'angle collo-diaphysique est plus petit et l'acétabulum est très peu profond.

VII. Dans les familles, où la luxation congénitale de la hanche se montre, la probabilité est d'environ 50 % que l'état se manifeste chez des frères et soeurs. De l'autre côté, la même probabilité existe quand un de hanche est attaquée.

VIII. L'importance de caractéristiques anatomiques est discutée. Une grande antètorsion, un acétabulum peu profond et une position relativement frontale de celui-ci semble prédisposer l'instabilité du joint. Ceci est plus prononcé chez les femmes et chez le même sexe dans les cas où la luxation est la plus fréquente. Cela se manifeste spécialement bien si l'on considère la relation entre l'antètorsion et le penchant de l'acétabulum relatif au plan sagittal. La différence entre les sexes est la moins parmi les groupes où la luxation est le plus fréquent.

IX. La fréquence d'antètorsion extrème et d'un acétabulum spécialement peu profond correspond à l'hypothese que la luxation est due à l'occurence simultane de ces traits. Les traits caractéristiques du joint de la hanche chez les Lapons ne sont pas conditionnés par la rasse, mais sont l'expression de facteurs d'héritage de toute une partie de population.

ZUSAMMENFASSUNG

I. In der Einleitung wird die Frage gestellt inwiefern das häufige Vorkommen von angeborenen Hüftverrenkung bei Lappländern spezielle morphologische Züge zu Grunde liegen, welche diese sind und welche Milieu- und Erbfaktoren die Ursachen bilden. Die Untersuchung ist hauptsächlich auf Messungen spezieller anatomischer Charakteristika der Glied-struktur in einem homogenen und nicht ausgewählten Material von Lappländer-skeletten konzentriert. In diesem Material kommt angeborene Hüftverrenkung oft vor.

II. Zusätzlich der anatomischen Untersuchungen sind die Stammtafeln 54 Lappländerfamilien (W e s s e l), in welchen angeborene Hüftverrenkung vorkam, als Grundlage eiener Diskussion der genetische Verhältnisse verwendet.

III. Anfragen bei Kreisärzten in verschiedenen norwegischen Provinzen hagen bestätigt, dass angeborene Hüftverrenkung häufiger in dem untersuchten Material als in der übrigen norwegischen Bevölkerung vorkommt. Ebenso wurde das häufigere Vorkommen des Leidens bei Frauen und auf der Linken Seite bestätigt.

IV. Die anatomische Untersuchung umfasst Messungen von Antetorsion und Hals-schaft-winkel des Femurs, Tiefe und Neigung des Acetabulums im Verhältnis zu den Sagittal- und Horisontalpläne, Einfallswinkel zwischen Femur und Acetabulum und schliesslich des Platymerischen Index und Pilasterindex.

V. Die Antetorsion des Femurs ist grösser bei Lappländern als bei den übrigen Norwegern und grösser bei Frauen als bei Männern. Auch der Hals-schaft-winkel ist grösser bei Lappländern. Das Acetabulum ist untief und verhältnismässig sagittal gestellt. Der

Einfallwinkel ist klein. Es gibt ziemlich ausgesprochen Platymerie, während dem Pilaster geringfügig ist.

VI. In dislosierten Hüftgelenken ist die Antetorsion durchschnittlich grösser als in dem Normalmaterial. In diesen Fällen ist der Hals-schaft-winkel klein und das Acetabulum ist sehr untief.

VII. In Familien wo angeborene Hüftverrenkung vorkommt, ist die Wahrscheinlichkeit, dass der Zustand bei Geschwistern auftritt ca. 50 %. Derselbe ist der Fall hinsichtlich des Manifestasions der Leiden auf der anderen Seite falls eine Hüfte schon angegriffen ist.

VIII. Die Bedeutung der anatomischen Merkmale wird diskutiert. Eine grosse Antetorsion, ein untiefes Acetabulum und eine relative Frontalstellung desselben scheint eine Unstabilität des Gelenkes zu prädisponieren. Diese Züge sind bei Frauen am meisten ausgeprägt, und bei diesen besonders so in den Lokalgruppen wo Luxationen am häufigsten ist. Dies tritt besonders deutlich hervor, wenn man auf das Verhältnis zwischen Antetorsion und Neigung des Acetabulums in Beziehung zum Sagittalplan betrachtet. Der Geschlechtsunterschied ist am geringsten in denjenigen Gruppen, wo Luxation am Häufigsten vorkommt.

IX. Die Häufigkeit extremer Antetorsion und besonders untiefem Acetabulums stimmt mit der Hypothese überein, dass die Luxation einem gleichseitigen Vorkommen dieser Züge zuzuschreiben ist. Die charakteristischen Züge des Hüftgelenkes bei Lappländern sind nicht rassemässig bedingt, sondern sind Ausdruck erbmässiger Faktoren einer ganzen Bevölkerungsgruppe.

LITERATURE

Badgley, C. E.: Etiology of congenital dislocation of the hip. J. Bone & Joint Surg., *31 A:* 341—356, 1949.

Bauer, E.: Die Entstehung der angeborenen Hüftverrenkung durch Zwangshaltung. Z. Orthop., *65:* 318—340, 1936.

Bauer, H. K. and *Bode, W.:* Erbpathologie der Stützgewebe beim Menschen. Handbuch der Erbbiologie des Menschen. III: 105—334, 1940.

Bernbeck, R.: Die pathologische Femurtorsion und Coxa Valga. Z. Orthop., *78:* 303—313, 1949.

Brandt, G.: Die Torsion der unteren Extremität und ihre Bedeutung für die Deformitätentstehung. Z. Orthop., *49:* 481—542, 1928.

Braus, H.: Anatomie des Menschen. I: Bewegungsapparat. J. Springer, Berlin 1921.

Brøste, K.: Et Torsionsgoniometer til Maaling af de lange Rørknoglers Torsionvinkel. Pers. comm.

Bøhm, M.: Das menschliche Bein. F. Enke, Stuttgart 1935.

Cocchi, U.: Erbleiden der Gelenke. In Schinz et al. Lehrbuch der Röntgendiagnostik. III: 1356—1391, G. Thieme, Stuttgart 1951.

Dega, W.: Quoted by Laurent 1953.

Donovan, M. M. and *Cambell, C. W.:* Quoted by Badgley 1949.

Dunlap, K., Shands, A. R. Jr., and *coll:* A. new method for determination of torsion of the femur. J. Bone & Joint Surg., *35 A:* 289—311, 1953.

Dunn, D. M.: Anteversion of the neck of the femur. J. Bone & Joint Surg., *34 B:* 181—186, 1951.

Durham, H. A.: Anteversion of the femoral neck in the normal femur and its relation to congenital dislocation of the hip. J. Am. Med. Ass., *65:* 223—224, 1915.

Eckhardt, H.: Statistische Bearbeitung von Meldungen über angeborene Missbildungen. Z. Orthop., *74:* 1—15, 1943.

Edgren, W.: Metod för bestämning av femurhalsens antetorsionsvinkel vid kongenital höftledsluxation. Nord. Radiol. Congress 1948.

Elgström, O.: Karesuando Lapparna. Åhlen & Åkerlund, Stockholm 1922.

Faber, A.: Erbbiologische Untersuchungen über die Anlage zur «angeborenen» Hüftverrenkung. Z. Orthop., *66:* 140—166, 1937.

— Untersuchungen über die Ätiologie und Pathogenese der angeborenen Hüftverrenkung. G. Thieme, Leipzig 1938.

Fairbank, H. A. T.: Congenital dislocation of the hip: With special reference to the anatomy. Brit. J. Surg., *17:* 380—416, 1930.

Falk, E.: Fötale Entwicklungsstörungen am Becken und an der Wirbelsäule als Ursache von Deformitäten, insbesondere von Skoliosen und angeborener Hüftluxation. Z. Orthop., *31:* 545—566, 1913.

Farrell, B. P. and *Howorth, M. P.*: Open reduction in congenital dislocation of the hip. J. Bone & Joint Surg., *17:* 35—42, 1935.

Farrell, B. P., v. Lackum, H. L. and *Smith, A. de F.*: Congenital dislocation of the hip. A report of three hundred and ten cases treated at the New York orthopaedic Dispensary and Hospital. J. Bone & Joint Surg., *8:* 551—561, 1926.

Gaugele, K.: Zur Anatomie und Röntgenologie des oberen Femurendes bei der angeborenen Hüftgelenkverrenkung. Z. Orthop., *38:* 35—79, 1918.

Haberler, G. v.: Neue Erkenntnisse der angeborenen Hüftverrenkung und ihrer Behandlung. Z. Orthop., *75:* 38—59, 1945.

Harrenstein, R. J.: Ein neuer Gedankengang über das Entstehen der angeborenen Hüftluxation. Z. Orthop., *49:* 388—409, 1928.

Hart, V. L.: Primary genetic dysplasia of the hip with and without classical dislocation. J. Bone & Joint Surg., *24:* 753—771, 1942.

— Congenital dysplasia of the hip joint. J. Bone & Joint Surg., *31 A:* 357—371, 1949.

Hass, J.: Congenital dislocation of the hip. C. Thomas, Springfield, Illinois 1951.

Hayashi, K. and *Matsuoka, M.*: Angeborene Missbildungen kombiniert mit der kongenitalen Hüftverrenkung. Z. Orthop., *31:* 369—399, 1913.

— Über die Erblichkeit der angeborenen Hüftgelenksverrenkung. Z. Orthop., *31:* 400—423, 1913.

Hibbs, R. A.: Anteversion of the neck of the femur. In connection with congenital dislocation of the hip. Trans. Sect. Orthop. Surg., Am. Med. Ass., 48—51, 1915.

Hilgenreiner, H.: Zum angeborenen Charakter der sogenannten angeborenen Hüftverrenkung. Z. Orthop., *65:* 58—78, 1936.

— Zur angeborenen Dysplasie der Hüfte. Z. Orthop., *69:* 30—51, 1939.

Idelberger, K.: Die Erbpathologie der sogenannten angeborenen Hüftverrenkung. Bruns Beitr. z. klin. Chir., *183*, Sonderband, 1951.

Isigkeit, E.: Untersuchungen über die Heredität der orthopädischen leiden. Die angeborene Hüftverrenkung. Arch. f. Orthop., *26:* 659—718, 1928.

Kemp, T.: Pers. comm.

Kingsley, P. C. and *Olmstedt, K. L.:* A study to determine the angle of anteversion of the neck of the femur. J. Bone & Joint Surg., *30 A:* 745—751, 1948.

Klopfer, F.: Zur Problematik der Sofortbehandlung bei der angeborener Hüftgelenksdysplasie. Z. Orthop., *79:* 1—60, 1950.

Korvin, H.: Über die echte und teratologische angeborenen Hüftluxation. Z. Orthop., *68:* 33—66, 1938.

Krida, A.: Congenital dislocation of the hip: The effect of anterior distortion; a procedure for its correction. J. Bone & Joint Surg., *10:* 594—604, 1928.

Lange, F. and *Pitzen, P.:* Zur Anatomie des oberen Femurendes. Z. Orthop., *41:* 105—134, 1921.

Lanz, T. v.: Anatomische und entwicklungsgeschichtliche Probleme am Hüftgelenk. Verhandl. Deutsch. Orthop. Gesellsch., 37th Congr., 7—40, 1949.

— Über umwegige Entwicklungen am menschlichen Hüftgelenk. Schw. Med. Wochenschr., *81:* 1053—1064, 1951.

Lanz, T. v. and *Wachsmuth, W.:* Praktische Anatomie. J. Springer, Berlin 1938.

Laurent, L. E.: Congenital dislocation of the hip. Acta Chir. Scand., Suppl. *179,* 1953.

Le Damany, P.: Die angeborene Hüftverrenkung. Ihre Ursache. Ihr Mechanismus. Z. Orthop., *21:* 129—169, 1908.

— Congenital luxation of the hip. Am. J. Orthop. Surg., *11:* 541—567, 1914.

Leveuf, J. and *Bertrand, P.:* Luxations et subluxations congénitales de la hanche. G. Doin, Paris 1946.

Lorenz, A.: Die sogenannte angeborene Hüftverrenkung. Ihre Pathologie und Therapie. F. Enke, Stuttgart 1920.

Martin, R.: Lehrbuch der Anthropologie. G. Fischer, Jena 1914.

Massie, W. K. and *Howorth, M. B.:* Congenital dislocation of the hip. II. J. Bone & Joint Surg., *33 A:* 171—190, 1951.

— Ibid. III. J. Bone & Joint Surg., *33 A:* 190—198, 1951.

Mayet, A.: Quoted by Lanz 1951.

Mayr, O.: Die angeborene ungenügende Hüftkopfüberdachung. Z. Orthop., *75:* 177—182, 1944.

Miculicz, J.: Über individuelle Formdifferenzen am Femur und an der Tibia des Menschen. Arch. Anat. & Physiol. (Anat. Abt.), *1:* 351—404, 1878.

Murk Jansen, O. B. E.: The large brain, the wide pelvis girdle and the outstanding number of hip anomalities in man. J. Bone & Joint Surg., *11*: 461—531, 1929.

Müller, W.: Biologie der Gelenke. J. A. Barth, Leipzig 1929.

— Die mit anderen Missbildungen kombinierte Hüftluxation in ihrer Bedeutung für das Luxationsproblem. Z. Orthop., *69*: 293—326, 1939.

Näätänen, E.: Über die Anthropologie der Lappen. Ann. Acad. Scient. Fennia, *47*, 1936.

Parsons, F. G.: The characters of the Englisch thigh-bone. J. Anat. & Physiol., *48*: 238—267, 1914.

Pick, J. W., *Stack, J. K.* and *Anson, B. J.*: Measurements on the human femur. I. Lengths, diameters and angles. Quart. Bull. Northwestern Univ. Med. School, *15*: 281—290, 1941.

Pitzen, P.: Das menschliche Femur während seiner Entwicklung. Arch. Anthropol. (N. F.), *19*: 57—81, 1923.

Platou, E.: Luxatio coxae congenita. J. Bone & Joint Surg., *35 A*: 843—866, 1953.

Preiser, G.: Die Coxa valga congenita — die Vorstufe der kongenitalen Hüftverrenkung. Z. Orthop., *21*: 177—196, 1908.

Putti, V.: Die Anatomie der angeborenen Hüftverrenkung. F. Enke, Stuttgart 1937.

Richard, G.: Methodik der Torsionsbestimmung mit Hilfe der Röntgenstrahlen. Z. Orthop., *79*: 636—644, 1950.

Rogers, P.: Observations on torsion of the femur. J. Bone & Joint Surg., *16*: 284—289, 1934.

Rohlederer, O.: Zur Ätiologie der angeborenen Hüftverrenkung. Z. Orthop., *74*: 120—130, 1943.

— Über den Stand der Luxationsforschung. Z. Orthop., *80*: 278—288, 1951.

Ryder, C. T. and *Crane, L.*: Measuring femoral anteversion: The problem and a method. J. Bone & Joint Surg., *35 A*: 321—328, 1953.

Scaglietti, O.: Quoted by Cocchi 1951 and by Laurent 1953.

Schinz, H. R., *Baensch, W. E.*, *Friedl, E.* and *Uehlinger, E.*: Lehrbuch der Röntgendiagnostik. G. Thieme, Stuttgart 1951.

Schneider, H.: Die Pathogenese der angeborenen Hüftverrenkung, vom Standpunkt der funktionellen Anatomie gesehen. Z. Orthop., *74*: 201—235, 1943.

Schreiner, K. E.: Zur Osteologie der Lappen. I—II. Inst. Sammenl. Kulturforskn., Oslo 1931—1935.

Schultz, J.: Die Darstellung der Torsionswinkel von Femur mit Hilfe von Röntgenstrahlen. Z. Orthop., *44*: 325—334, 1924.

Selmer-Olsen, R.: An odontometrical study on the Norwegian Lapps. Skr. N. Vid. Akad. I No. 3, J. Dybwad, Oslo 1949.

Shiino, K.: Über die Hüftpfanne. Z. Mohprol. & Anthropol., *17:* 325—356, 1915.

Soutter, R. and *Bradford, E. H.:* Twists in normal and in congenitally dislocated femora. N. Y. Med. J., *78:* 1071—1077, 1903.

Steindler, A.: Mechanics of normal and pathological locomotion in man. C. Thomas, Springfield, Illinois 1935.

Storck, H.: Zur Pathogenese der Hüftluxation. Z. Orthop., *68:* 308—336, 1938.

— Antetorsion, Retroversion und Entstehungsmechanismus der Hüftverrenkung. Z. Orthop., *79:* 282—294, 1950.

Telkkä, A.: Über die Asymmetrien der langen Gliedmassenknochen bei den Finnen. Ann. Acad. Scient. Fennia, 1949.

Verschuer, O. v.: Allgemeine Erbpathologie des Menschen. Erg. Allg. Path & Path. Anat., *26:* 1—58, 1932.

Waldenström, H.: On subluxatio coxae congenita in adults and its treatment. Acta Chir. Scand., *72:* 548—553, 1932.

Wessel, A. B.: Laaghalte slegter i Finmarken. Tidsskr. n. lægefor., *38:* 337—368, 1918.

Wiberg, G.: Studies on dysplastic acetabula and congenital subluxation of the hip joint. Acta Chri. Scand., Suppl. *58,* 1939.

Willis, T. A.: The lumbosacral column in man, its stability of form and function. Am. J. Anat., *32:* 95—123, 1923.