ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM No. XXXVI

FROM THE CLINIC FOR ORTHOPEDICS AND TRAUMATOLOGY, UNIVERSITY CENTRAL HOSPITAL, HELSINKI
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TENSILE STRENGTH OF THE WHOLE-THICKNESS SKIN GRAFT USED AS REPLACEMENT OF TENDON AND LIGAMENT DEFECTS

AN EXPERIMENTAL STUDY

BY

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COPENHAGEN 1958

PREFACE

The subject for the present study was suggested by my esteemed teacher, Professor K. E. Kallio, Chief of the Clinic for Orthopedics and Traumatology, University Central Hospital, Helsinki. He has followed the progress of my work with untiring interest and has always been ready to help me with valuable advice over problematic phases and to encourage me in the work. I am glad to have this opportunity to express my warm gratitude to my greatly admired teacher and principal.

My sincere thanks are due to Professor Unto Uotila, Chief of the Institute of Forensic Medicine, University of Helsinki, who kindly allowed me to use the laboratory of the Institute for the preparation of histologic specimens.

Likewise I express my gratitude to Professor Erkki Häyrinen, Director of the Textile Laboratory of the Institute for Technical Research, who permitted me to make use of the dynamometer of the Institute for the measurements of tensile strength. In this connection I offer my sincere thanks to Assistant, Mr. Muisto Kuusela, who so perseveringly and unsparingly gave up his time to helping me to carry out the measurements.

The material of this study has been statistically analysed in the Statistical Section of the Institute of Occupational Health. There Mrs. Sisko Asp, M. A., has taken a great deal of trouble on my behalf and I beg to thank her.

The English text has been corrected by Mrs. Jean Margaret Perttunen, B. Sc., whom I should also like to thank.

My sincerest thanks are due to Miss Etti Kinosmaa, Miss Pirkko Nyberg, Miss Marianne Ejder and Miss Anja Virtama, who have always been available, when needed, to assist me in the animal experiments. I also wish to thank Mrs. Lisbeth Schwanck, who gave me technical assistance in the preparation of the histologic specimens.

Helsinki, October, 1958.

Tuula Jokinen.

CONTENTS

I. INTRODUCTION

At the Orthopedic Clinic of the University of Helsinki, great interest has been attached to the use of skin in reconstructive surgery. In 1952 Professor Kallio assigned to Dr. Kivilaakso the task of explaining systematically the changes occurring in the whole-thickness skin graft used to replace tendon and muscle tissues in animals. These experiments showed that the skin graft developed into a tissue resembling the tendon both macroscopically and histologically.

Since 1954, a total of 186 operations performed at the Clinic have involved the use of the whole-thickness autogenous skin graft as a free transplant in reparative orthopedic surgery. The majority (119) of these cases have been arthroplasties of various joints, mainly of the hip, the skin graft being used as interposition material according to the method developed by Professor Kallio. No infection has occurred in these consecutive cases.

During the year 1958, two major works dealing with the use of the skin graft in arthroplasty have been published from the Clinic. The first is an experimental study by Dr. Kauko Kettunen on the use of the whole-thickness skin graft as interposition material in arthroplasty of the hip joint. He has performed operations on cats and established that a functional metaplasia takes place in the skin graft up to the stage of formation of hyaline cartilage, the presense of which he has been able to verify macroscopically, histologically, histochemically and historadiographically. The second work is a clinical study by Dr. Erkki Kallio on the value of the whole-thickness skin graft as interposition material in arthroplasty of the hip joint as compared with alloplastic material. It is concluded that the skin arthroplasty may be ranked with the other methods. Moreover, by far the smallest number of complications occurred in this group.

Professor Kallio has likewise used skin to replace various tendon defects. The surprisingly frequent discovery, during operations for prolapse of a lumbar disc, of tears in the interspinal ligaments has led him to use free skin transplants for their reconstruction.

Thus skin grafting has become a routine procedure at the Clinic, and a need has been felt for further investigations into the qualities of the material used. Since it appeared that no systematic study has hitherto been made on the tensile strength of skin grafts, particularly when used to replace tendon and ligament defects, Professor Kallio proposed that I should make an experimental investigation of this subject.

II. GENERAL SURVEY OF THE LITERATURE

CLINICAL USE OF THE SKIN GRAFT AS REPLACEMENT OF TENDON AND LIGAMENT DEFECTS

So far as is known, OTTO LÖEWE, of Germany, was the first to introduce skin grafts to any great extent as replacement of tissue defects. In 1913, he published an article dealing with the use of skin in plastic operations, mainly in hernial repair. Among the nine cases he published at that date there was one in which the tendon of the extensor pollicis was replaced with a strip of skin 0.5 cm wide and 3 cm. long. It is in this case that the use of skin in actual reconstructive surgery has its origin. LEXER was the first to refer to the replacement of tissue defects located deeper in the body as »Wiederherstellungschirurgie» (reconstructive surgery), a term which has come into general use. KIRSCHER was responsible for the concept of »Flickmaterial» (patch material), when he introduced the free fascia transplant and LOEWE modified this method, using a free skin transplant in stead of fascia. In 1929, LOEWE already had a series of 100 patients on whom he had performed a reconstructive operation by means of skin grafting. To his mind skin was applicable in the following cases: tendon surgery, strengthening of the abdominal wall (as in hernial repair), operations in the region of the alimentary canal (in connection with GEA, for intestinal fistular repair and prolapse of the rectum), in duraplasty, for encircling neural sutures, in reconstructive operations on various joints and possibly also in deep plastic operations with a pedicle flap, e.g. for fixation of organs (in connection with gastroptosis, etc.). In 1914, REHN reported that he had used skin to replace an extensor tendon of the finger. He noted that within six weeks the skin transplant changed into a tissue resembling tendon. He likewise employed skin for the replacement of knee ligaments.

Early in the 20th century, additional articles on the use of skin grafting in reconstructive surgery were published: EITNER (1920), STRAATSMA (1932) and CANNADAY (1942, 1943 and 1946) published extensive series. PEER

(1940), SCHULZE (1947), v. BRANDIS (1950), BROWNE (1951) and BAUMGART (1955) also discussed the question.

All these authors employed the tissue known as the cutis plastic, i.e., both the epithelium and in general also the subcutaneous fat being removed and only the connective tissue of the corium utilized. LOEWE removed the epithelium by simply scraping with a scalpel, but REHN began to use a Tiersh knife for this purpose. With this he removed the epithelial layer down to the stratum papillare until bleeding points appeared on the surface. SWENSON and HARKINS (1943) used the dermatome, the epithelium so removed being stored and used to cover the defect in the donor area. SCOLA (1944) also developed a method of his own, in which a dermatome was used.

MAIR (1940) was the first to use whole-thickness skin grafts in plastic operations for hernias. He noted that it was impossible to remove all the epithelium, because it was present in the deeper layers, too, in the hair follicles and glandular elements. He did not consider the quantity of epithelium important. He considered it essential that the transplant was placed under tension.

The following authors have also used whole-thickness skin grafts: GOODALL and GUTHRIE (1947), PATARO and ZAVALETA (1947), GORNI (1948), MARSDEN (1948), CHODOFF (1949), MARTINI (1949), LIMBOSCH (1949), REES (1957).

In 1930 KELLER developed the tunnel graft, in which the skin transplant was carried to the new site through two small incisions, and SKINNER (1941) reported that in this way he had replaced the palmar fascia in patients with Dupuytren's contracture. GOSSET (1951) reported the use of whole thickness skin grafts for the replacement of various ligaments.

Beside fresh autogenous skin, homogenous cadaver bank skin has nowadays come into use. SANCHIS-OLMOS (1954), of Spain, published his experiences with skin preserved in merthiolate solution. When using such skin he first removed the epithelium and fat. He replaced tendons and ligaments with this banked skin. Of recent years, additional articles about the use and storage of cadaver skin have been published: DOGO (1952), HEMPHILL-BROWN (1954), SKOOG (1954), TAYLOR et al. (1956).

VIRENQUE et al. (1949) reported that they had replaced the Achilles tendon with skin. SWENSON (1950) has done the same. SVART (1952) claimed that he had used skin to replace various ligaments, including the lateral ligaments of the knee. MIYAKAWA (1954) published a case in which he had used pinch-graft skin to repair the flexor tendons of the hand. The skin was first transplanted directly to the defect surface and only in the second phase was it united with the tendon stumps and covered with a new pedicle flap. In a follow-up study seven years after the operation the function of these tendons was noted to be perfect. SIROT (1954) reported that he had also succeeded in replacing the flexors of the hand with a skin graft. HUC, TEISSIER and BRISARD (1954) used a transplant taken from the abdominal skin to repair paralyzed abdominal muscles. SCHMIDT (1955) used skin for the replacement of the lateral ligaments of the knee. BEIER (1955) used skin for repairing subcutaneous rupture of the biceps muscle. LOEFFLER, in an article published in 1956, reported that since 1946 he had been using skin for the repair of tendon injuries, including rupture of the Achilles tendon. He had also used skin for reconstruction of ligaments in the ankle and shoulder regions. GRUCA (1956) reported that he had used dermodesis in place of active fasciodesis, the transplanted m. tensor fasciae latae being used for repairing idiopathic scoliosis. He considered living material better than the alloplastic spiral bow, which he had also used. JANIK (1957) wrote that he had in general used skin grafts denuded of epithelium, but he also had one case in which he had forgotten to remove the epithelium in spite of which healing had been uneventful. In one case the knee, in which a ligament had been replaced by skin, had to be reoperated on after a further accident 3 months later and it was noted that there was a well-shaped new skin ligament.

EARLIER EXPERIMENTAL STUDIES

HISTOLOGIC STUDIES ON THE SKIN GRAFT USED FOR RECONSTRUCTIVE PURPOSES.

At one time it was feared that complications would arise if skin, and particularly its epithelial elements, entered the deeper layers. REVERDIN (1887) wrote about traumatic epithelial cysts. KAUFMAN (1884), GARRE (1894), PELS-LEUSDEN (1905), HESSE (1912) and WIEN and CARO (1934) each studied the production of epithelial cysts from his own point of view.

DAVIS and TRAUT (1926) produced tubes and sacs lined with epithelium by transplanting whole-thickness skin grafts on the abdominal muscles of dogs and they forecast that this method would be of importance in clinical surgery, too. RIGANO, ISURA and SASUDOTE (1927) transplanted auto- and homogenous skin into the subcutaneous tissue of the rabbit embryo. YANO (1940) implanted homogenous skin into the bone marrow of the rabbit embryo.

ZIMCHES (1931) transplanted whole-thickness skin graft, skin from the nose tip and urethral mucous membrane into the muscles of dogs without fixing the graft to the surrounding tissues. He noted that the epidermis of transplant bends like a horseshoe and after 25 days the two edges unite to form a cylinder or closed cavity filled with epithelial debris and remnants of hair. This is a consequence of the general law of growth of the epithelium. Nothing indicated alteration of the quality of the epithelium or its malignification. The skin healed well in its new surroundings, becoming attached by granulation tissue, which later organized to connective tissue. In the connective tissue of the urethra he noted heteroplastic metaplasia, osseous tissue being formed.

PEER and PADDOCK (1937) carried out interesting experiments on human beings. In connection with plastic operations for saddle nose, the remaining costal cartilage used for correction was stored under the skin of the chest wall and at the same time skin from which the epithelium had been removed was implanted. An essential observation was that in spite of the macroscopic removal of the epithelium, epithelium was present in all specimens. Sweat glands were also found in all specimens and they were only slowly replaced by fibrous tissue. Hair follicles were encountered up to the third week and formed microscopic cysts. Sebaceous glands were found only during the first week. There was no malignification of the epithelium. UIHLEIN (1939) took histologic specimens from two patients, on whom four years earlier a plastic operation had been performed and found no remnants of epithelium, but only normal connective tissue. He regarded the metamorphosis as complete.

As long ago as 1914 REHN had replaced the Achilles tendon by skin in dogs. He removed the epithelium from the transplant. He noted that skin regenerated more rapidly than fascia used for the same purpose. SCHWARZ (1922) also used the Achilles tendon of the dog and noted that in conseguence of the functional irritation, the skin changed within 10 weeks to a tissue resembling tendon. He found, however, that the skin transplant frequently necrotized and therefore he relied more upon the fascia. MAIR (1945) was of the opinion that if the transplant was put under strong tension, fewer epithelial cysts occurred. He replaced a piece of the fascia lumbodorsalis with skin in the rabbit and noted, after 5 months, that the epithelium had disappeared. Under the microscope only degenerating papillae of the skin were seen. Around the hair follicles some kind of capsule had formed owing to the irritation of the foreign body. SWENSON (1950) made experiments with the Achilles tendons of dog and could no longer find the original tissue of the transplant after 152 days. GEEVER et al. (1952) replaced a diaphragmal defect in dogs by skin transplants without epithelium. These workers have also used this method on human beings in connection with operation for carcinoma of the stomach. BOGETTI et al. (1954) also studied replacement of the Achilles tendon of the dog with skin in functional, anatomic and histologic respects. KIVILAAKSO (1955) has noted that the whole-thickness skin graft transplanted to a defect of the abdominal wall of the rabbit became naturally attached to the new surroundings within two months. When he replaced part of the Achilles tendon by a skin graft, there was no difference from the tendon tissue after 90 days. This was the first systematic study on the histologic changes occurring in the whole-thickness skin graft used as replacement of tendon and muscle tissue. As regards the original tissue he noted that the internal perimysium reacts first and then the external perimysium also participates in the reparative process. The tendon cells themselves remain passive. The same observations had also been made by MASON and ALLEN (1941) and by SKOOG (1951). The latter isolated the tendon suture from the surroundings with a metallic tube and was able completely to prevent the regeneration process.

EARLIER EXPERIMENTAL STUDIES ON TENSILE STRENGTH

The tensile strength of the healing wound.

Chlumsky (1899) reported that he had studied the tensile strength of intestinal anastomoses by measuring the pressure of water injected into the intestine. He noted that the strength decreased during the first four days, after which an increase took place up to the tenth day, when the strength was almost normal. Carrel (1910) examined superficial wounds, measuring the variation of areas by planimetric methods. The wound area remained the same size for 2—5 days, after which there was a contraction and finally epithelization. Howes, Sooy and Harvey (1929) determined the rate of healing of wounds by measuring their tensile strength. Wounds made in the abdominal wall were excised and their strengths measured with an apparatus for measuring the strength of thread. This was the Howes method also used by later investigators .The same method has also been used in the present work. In the same year, Harvey developed a method of his own. He distended the stomach with air and measured the pressure necessary to rupture wounds in the abdominal wall. The values obtained with the two methods were comparable with each other and with those of Carrel, too: after 4—6 days of latency the tensile strength was found to increase rapidly, the maximum being reached after about 10—14 days. Harvey considered that this curve follows the general growth curve. Burr, Harvey and Taffel (1938) developed a method by which it was possible to distinguish between cell proliferation and maturation by means of the electric potential generated by rapidly dividing cells. Up to the 7th day the growth of the cells predominates, after which their maturation begins to have a greater significance. Hartzell and Stone (1942), using guinea-pigs, examined the correlation between the concentrations of ascorbic acid in the blood and the tensile strength of wounds. In C-avitaminosis the strength about the 6th post-operative day was only one-half of the normal and 8—14 days after operation only one-fourth of the normal. Increasing the vitamin C in the diet of healthy animals did not cause any rise in the tensile strength.

SANDBLOM (1944) studied the tensile strength of healing wounds with a tensiometer according to HOWES' method. He made wounds on the backs of white rabbits, excised them after a definite interval and measured the strength. The difference between the wounds on the right and left sides was not significant, but wounds located laterally were 22.8 % stronger than those located medially. The second wound made on the same animal was 28.7 % stronger than the first one. He also examined the influence of general factors on the healing of wounds and noted that anemia decreased the strength by 40%, anemia and dehydration by 30% and acidosis by 20 %. In association with hypoprothrombinemia the wound was only 13 % weaker than in normal animals. In view of his experiences, SANDBLOM considered an operation in two stages more advisable than two operations at one session. MAJAUCHI (1956) noted that somatotropin increased the tensile strength of wounds.

SAIKKU, of Finland (1956), studied the tensile strength of granulation tissue and the influence of somato- and thyrotropin upon it. Experiments were performed on rats, in which the tensile strength of wounds were measured by the method of HOWES. SAIKKU noted that the tensile strength was greater in those animals which had received either somato- or thyrotropin than in those which received both substances simultaneously.

LOEFFLER (1956) mentioned experiments performed by his assistant MÜLLER-STEPHANN on the tensile strength of skin taken from the thigh. It was noted that at the beginning of the test the skin stretched by 30—60 % and even after this considerable force was needed to tear the skin. To his mind no stress would be met with in practice which would be capable of breaking the skin. LOEFFLER emphasized particularly that skin used in plastic operation should be placed under strong tension.

Observations on the tensile strength of the human skin have been made in connection with postoperative wound ruptures caused by abdominal distention, coughing or vomiting. (MADELUNG 1905, SOKOLOFF 1932, COLP 1934, GLENN and MOORE 1937, HARTZELL and WINFIELD 1939).

The tensile strength of tendons.

PAGET (1853) was the first to measure the tensile strength of the severed Achilles tendon. NICOLA (1934) found the average tensile strength of human tendons to be 645 kg/cm². CRONKITE (1936) also published data on the tensile strength of human tendons. According to the studies carried out by him, the tensile strength varies between the limits 611—1 265 kg/cm².

In his opinion no absolute values can be given for individual tendons owing to physiologic variations. ALTSCHAFFEL (1937) examined the tensile strength of individual tendons of a Persian community.

MASON and ALLEN (1941) studied the tensile strength of healing tendons in dogs. They considered 9.39 kg/mm^2 to be the normal mean. They carried out measurements 2—68 days after suturing tendons and noted that the tensile strength was at a minimum 3—5 days after operation and was then practically dependent upon the sutures alone. By the 5th—7th postoperative day the strength begins to rise fairly rapidly and about the 10th day the enclosing tissue has formed a cuff, the »tendon callus», around the point of suture. This is at a maximum about the 14th day and then begins to decrease in size. They also examined the effect of immobilization on the healing of tendon and noted that a splint preventing movement only in one direction caused less reaction at the site of suture than occurs with the usual complete immobilization for a period of three weeks. The reaction was greater, however, than after a full-length immobilization time of 4—6 weeks. These tendons were at first stronger than those immobilized for longer, but a levelling took place within two weeks after mobilization. They found that early exercise accelerates the healing. In the healing of tendons there are three phases: 1) an exudation phase, during the first five days, in which there is a rapid decrease in the tensile strength of the tendon, 2) a fibroblastic phase lasting to the 6—16th day; during this phase there is a rapid increase in the tensile strength. 3) a maturation phase beginning about the 19th day and continuing for a long time, during which there is still a moderate increase in the tensile strength.

STUCKE (1951) examined loading and rupture of tendons on anesthesized dogs and noted that a normal tendon in situ never ruptured. CARSTAM (1953) examined the effect of cortisone on tendon adhesions and tendon healing. The latter was examined on the Achilles tendon of the rabbit and cortisone was noted not to hamper the healing of the tendon, but largely to prevent the formation of adhesions around a traumatized tendon.

DAVIDSSON, of Finland (1954), studied the tensile strength of the Achilles tendon in cats. The experiments were performed on anesthetized animals, the Achilles tendon still being in situ. The tendon itself never ruptured under the influence of either a dynamic or a static force, but it loosened from either its origin or its insertion. In some cases fracture of the femur occurred as a result of the pull. He carried out experiments on partly severed tendons and noted that rupture only took place after half the diameter was cut through. In a further experiment necrosis was caused in the tendon by two tight silk ligatures. Up to the fourth week rupture took place between these ligatures but not later. According to DAVIDSSON, a regenerating tendon regains its normal strength within six weeks.

KIVILAAKSO (1955) carried out some experiments on the strength of whole-thickness skin graft replacements of the Achilles tendon in rabbits. He used split tendons and noted that they broke at the point of juncture or in the region of the transplant. He considered that the strength of the skin graft replacement was not to be compared with that of the normal tendon.

III. THE PROBLEMS

The purpose of the present study was

1) to measure the tensile strength of the normal rabbit skin in different directions,
2) to measure the tensile strength of tendons and ligaments replaced by whole-thickness skin graft,
3) to study whether it is possible to transfer muscle power by means of a long-distance tendon made of whole-thickness skin graft between two points located far from each other,
4) to study whether the direction of the fibrous structure of the skin graft has an influence upon the strength of the transplant,
5) to discover the optimal immobilization time for skin tendons.

IV. THE STRUCTURE OF THE CONNECTIVE TISSUE OF THE RABBIT SKIN

It seems advisable first to describe the structure of the normal rabbit skin, which forms the basis of the following experiments. The following account is mainly after BENSLEY and BENNINGHOFF.

Two layers are histologically recognisable in the skin: the epidermis, which is ectodermal in origin and is composed of stratified squamous epithelium — and the cutis or corium, which is mesodermal in origin. The glands of the skin and hair follicles are also epithelial in origin. Sebaceous glands are located at the roots of the hair follicles and occur everywhere in the skin of the rabbit. Sweat glands, on the contrary, occur only in the groins and some atrophic ones also on the lips.

The corium can further be divided into two layers: the stratum papillare and beneath it the stratum reticulare. The latter is bounded by the loose subcutaneous tissue.

In the corium there are three kinds of fibrils: collagenous, elastic and reticular fibrils. The fibrils are already orientated in definite directions in the embryo and the skin folds follow the same directions. The direction of the fibrils corresponds to the maximal tension of the skin. The fibrils are orientated girdlewise around the trunk, round the region of the joints, etc. In the course of development, the direction of tension changes and later this system of fibrils is replaced by a new one, which then fuses with the former to give a rhombic figure. The fibrils are prone to react to all tensile stresses and to reorientate themselves. The great modifiability of the skin depends on this phenomenon. The fibrils themselves do not lie in the direction of maximal tension, which corresponds to the long axis of the rhombic figure. Stretching is at a minimum in this direction and wounds whose long axis is in the same direction gape least. The fibrous structure of the corium forms a stereoscopic system of nets, in which the angles formed by the fibrils alternate and so the connective tissue glides easily.

In the corium there is smooth musculatur which is attached to the hair follicles and from there extends to the stratum papillare. The m. cutaneus maximus is also attached to the subcutaneous connective tissue in the rabbit and is used by the animal for shaking its coat. The linea alba is the origin of this muscle and its insertion the skin of the trunk, mainly of the flanks, but some fibrils reach the midline of the back, forming an uniform network with the fibrils interlacing. The direction of the fibrils is obliquely caudad and dorsad.

V. MATERIAL AND TECHNIC

EXPERIMENTAL ANIMALS

Only purebred white rabbits, 5—7 months old and weighing 1.8—2.2 kg were used for the experiments. No attention was paid to the sex since it has been shown to have no significance in this connection (HARVEY and HOWES 1930, KIVILAAKSO 1955).

The rabbits were kept in dry roomy hutches at room temperature, one rabbit in each. They received a normal mixed diet, which included hay and dry bread, but in the summer they were given fresh grass, too, as far as possible. Drinking water was always available from a bottle hanging on the door of the hutch, furnished with a glass tube leading to within the rabbit's reach. All the experiments were performed during one year. When sacrificed, the rabbits were on an average one year old, but the age range was 7—18 months.

The rabbits were kept in their hutches 1—2 weeks before operation so that they would have an opportunity to grow accustomed to their surroundings and the possible change in diet. Before the operations the animals were kept fasting for 6 hours. Every rabbit has been operated on twice, the interval between the operations being 3—4 weeks at least.

Five different kinds of operations were performed on the rabbits:

1) A part of a) the Achilles tendon and b) the extensor hallucis longus tendon was replaced by a whole-thickness skin graft. In the following, such a tendon has also been called a »skin tendon» (comparable with »skin arthroplasty», a general term introduced by Professor Kallio).
2) Long-distance tendons were constructed on the hind leg of the animal by uniting the end of the sartorious muscle with a whole-thickness skin graft to the tendon of the extensor digitorum longus, which was severed immediately below the cruciate ligaments of the ankle joint. Professor Kallio has been especially interested in the use of skin as a long-distance tendon and when the work was at the planning stage he suggested such an experiment. In the following text the term »long- distance skin tendon» has been used.

3) Interspinal ligaments were replaced by whole-thickness skin graft in the region of the lumbar column. The term »skin ligament» has also been used in the text.
4) Dermodesis was carried out on the hind leg of the rabbit on the same principle as the tenodesis.
5) Whole-thickness skin grafts were buried in the biceps brachii muscle as functionless transplants, which were not fixed to the surrounding tissue.

The two last-mentioned operations were carried out only as controls, above all to note the possibility of epithelial cyst formation. Their tensile strength was not measured owing to the technical difficulty involved.

The operations performed on the animals and the length of the observation time appear from table 1. The following abbreviations are used:

A—t = Achilles tendon replaced by a skin transplant.
A—s = Sutured Achilles tendon.
A—n = Normal Achilles tendon.
A—b = Achilles tendon replaced by bank skin.
E—t = Extensor hallucis longus tendon replaced by skin transplant.
E—s = Sutured extensor hallucis longus tendon.
E—n = Normal extensor hallucis longus tendon.
L—d—t = Long-distance skin tendon.
L—l = Skin ligament.
D—d = Dermodesis.
I.m.s. = Intramuscular skin graft.

TABLE 1.

R a b b i t s grouped according to the o p e r a t i o n and the length of the o b s e r v a t i o n time.

N:o	Age in months	Observ. time in days	Nature of operation	N:o	Age in months	Observ. time in days	Nature of operation
1	18	360 300	A-t A-s	21	12	190 120	A-t A-s
2	18	360 300	A-t E-t	22	12	180 240	A-s L-d-t
3	18	360 300	A-t A-s	23	12	180 120	A-s A-b
4	18	360 300	A-t E-t	24	12	180 120	A-s A-b
5	16	300 180	A-s D-d	25	12	180 120	A-s L-d-t
6	16	300 180	A-s E-t	26	12	180 300	A-s D-d
7	16	300 180	A-s E-t	27	11	180 120	A-s D-d
8	16	300 180	D-d E-t	28	11	180 120	L-l I.m.s.
9	14	240 300	A-t A-s	29	11	180 120	L-l I.m.s.
10	14	240 180	A-t L-d-t	30	11	180 120	L-l E-t
11	14	240 180	A-t A-s	31	11	180 60	D-d E-s
12	14	240 180	A-t L-d-t	32	11	180 120	D-d A-s
13	14	240 300	A-t A-s	33	10	120 180	A-t A-s
14	14	240 180	A-t L-d-t	34	10	120 180	A-t L-l
15	14	240 120	L-d-t E-t	35	10	120 180	A-t E-s
16	12	180 240	A-t L-d-t	36	10	120 180	A-t A-s
17	12	180 120	A-t A-s	37	10	120 180	A-t A-s
18	12	180 240	A-t L-d-t	38	10	120 60	A-t A-s
19	12	180 120	A-t A-s	39	10	120 180	A-t E-s
20	12	180 120	A-t L-l	40	10	120 180	A-t E-s

N:o	Age in months	Observ. time in days	Nature of operation
41	10	180	A-b
		120	A-s
42	10	180	A-b
		120	A-s
43	10	120	L-d-t
		60	E-s
44	10	60	L-l
		—	—
45	10	180	L-d-t
		120	E-s
46	10	120	L-d-t
		60	E-s
47	10	120	L-d-t
		60	E-s
48	10	180	L-l
		30	E-s
49	10	120	L-l
		30	E-s
50	10	120	L-l
		180	A-b
51	10	120	L-l
		180	I.m.s.
52	9	90	A-t
		120	A-s
53	9	90	A-t
		120	D-d
54	9	90	A-t
		120	A-s
55	9	90	A-t
		120	D-d
56	9	90	A-t
		120	A-s
57	9	90	A-t
		120	A-b
58	9	90	A-t
		120	A-s
59	9	90	A-t
		180	I.m.s.
60	9	90	A-t
		60	A-s
61	8	60	A-t
		30	L-l
62	8	50	A-t
		30	A-s
63	8	60	A-t
		30	L-l
64	8	60	A-t
		30	A-s
65	8	60	A-t
		30	L-l
66	8	60	A-t
		30	A-s
67	8	60	A-t
		30	A-s
68	8	60	A-t
		30	I.m.s.
69	8	60	A-t
		30	I.m.s.
70	8	60	A-t
		30	A-s
71	8	30	A-t
		60	I.m.s.
72	8	30	A-t
		60	A-s
73	8	30	A-t
		60	E-t
74	8	30	A-t
		60	A-s
75	8	30	A-t
		60	A-s
76	8	30	A-t
		60	E-t
77	8	30	A-t
		60	A-s
78	8	30	A-t
		60	E-t
79	8	30	A-t
		60	A-s
80	8	30	A-t
		120	I.m.s.
81	8	14	A-s
		120	L-l.
82	8	60	A-b
		30	L-d-t

N:o	Age in months	Observ. time in days	Nature of operation
83	8	60 30	A-b L-d-t
84	8	60 30	A-b L-d-t
85	8	60 30	A-b L-d-t
86	8	60 30	L-l I.m.s.
87	7	14 60	A-t I.m.s.
88	7	14 60	A-t A-s
89	7	14 60	A-t D-d
90	7	14 60	A-t L-d-t
91	7	14 60	A-t L-d-t
92	7	14 60	A-t A-s
93	7	14 60	A-t A-s
94	7	14 60	A-t L-d-t
95	7	14 60	A-t L-d-t

N:o	Age in months	Observ. time in days	Nature of operation
96	7	14 60	A-t D-d
97	7	7 30	A-t A-s
98	7	7 30	A-t A-s
99	7	7 60	A-t L-l
100	7	7 30	A-t A-s
101	7	7 60	A-t L-l
102	7	7 30	A-t A-s
103	7	3 60	A-t L-l
104	7	3 30	A-t A-s
105	7	3 30	A-t L-l
106	7	3 30	A-t A-s
107	7	3 30	A-t L-l
108	7	3 30	A-t A-s

Two specimens were further taken from each rabbit for measuring the tensile strength of the skin. Skin strips both for measurement of tensile strength and for transplantation were always taken from corresponding sites on the flanks caudally of the line passing through the costal margins (Fig. 1). When reconstructing the interspinal ligaments, on the other

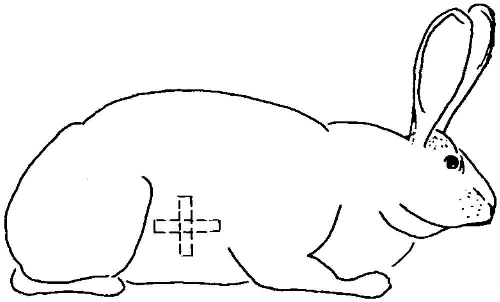


Fig. 1. Skin has been taken from the flank of the rabbit.

hand, skin was taken longitudinally from the wound edge because it was difficult to change the position of the rabbit during the operation without jeopardizing the sterility. The flank was chosen as the donor site, because it is easy to determine the direction of the collagenous fibrils here. Additional skin from ten rabbits was further removed when the rabbit was sacrificed and stored for use as bank skin in the tendon replacement operations. For preserving this, a method reported by SANCHIS-OLMOS (1954) was used. The skin was stored in a refrigerator in merthiolate solution, the concentration of which was 1: 1 000. Strips 1 cm in width and 1,5 cm in length were prepared and used as replacement of tendon defects of definite lengths. SANCHIS-OLMOS reported that he washed the skin with serum and penicillin solution before use. In the present study, the washing was carried out with penicillin solution alone, the strips being moistened with it and wiped with a tupfer. This method appeared to be satisfactory, for no irritation reactions were noted in the surroundings of the transplant.

Measurement of the tensile strength was carried out in 511 cases in all. A total of 236 measurements were made on the skin and 275 measurements on the skin tendons, ligaments and their controls:

	Cases
Replacement of the Achilles tendon by a whole-thickness skin graft	85
Suturing of the Achilles tendon	50
Replacement of the extensor hallucis longus tendon by a whole-thickness skin graft	10
Suturing of the extensor hallucis longus tendon	10
Long-distance skin tendons	20
Skin ligaments	20
Dermodesies	10
Intramuscular skin grafts	10
Measurements on normal tendons	60

Different operations, such as skin transplantation and tendon suturing, carried out on the same individuals were performed in different order, because it is known that the second wound heals more rapidly than the first (SANDBLOM 1944).

OPERATIVE TECHNIC

Anesthesia was induced by a preliminary injection of 0.5—1.5 cc of 2.5 per cent Intraval sodium into the auricular vein, when the rabbit rapidly and quietly fell asleep, and the narcosis was then continued with ether from a drop mask such as is generally used for children. Immediately after falling asleep the animal received 0.25 mg of atropine sulfate to eliminate the mucous secretion occurring later during the narcosis and especially during the waking of the animals. When necessary, the rabbits also received oxygen gas through a nasal catheter.

In preparing the operative field the hair was first cut with scissors and then shaved with a razor. S. VAINIO (1948), CARSTAM (1953) and KIVILAAKSO (1955) did not recommend chemical depilatories. The skin was cleansed first with a 70 per cent alcohol solution and then with tincture of iodine. The animals were covered with sterile cloths and the operations were performed under strictly aseptic conditions. 4/0 atraumatic black silk was used for the tendon sutures. For closure of fascia and skin 4/0 Ethicon catgut was used. Catgut was chosen for the skin sutures as well, because it was then unnecessary to remove the sutures later. In spite of this no wound infections occurred. There was no postoperative mortality, either. Six rabbits died during the operation from anesthetic complications, most from overdosage with anesthetics, one from hyperpyretic shock, because the warm plate of the operating table had become too hot, and one from bleeding shock. These cases and the preliminary experiments, in which the tension of the transplant was studied, were excluded from the series.

Operative technic for different cases:

For measuring the tensile strength of the normal skin, strips 1 cm wide were used, and also for transplantation on the Achilles tendon. A whole-thickness skin graft was used for all the following operations.

Replacement of tendon tissue by skin graft.

The Achilles tendon.

For the operation, the rabbit lay on its side, with the flank to be operated upon upwards. The leg to be operated on was bound to the edge of the table with a gauze loop and the opposite leg was drawn away from the operative field in the same manner. An incision was made in the lateral surface of the lower part of the hind leg and the Achilles tendon was dissected out, the paratenon was also split. As long a portion as possible was cut from the tendon, the length varying between 1.8 and 3 cm. This defect was replaced by a whole-thickness skin graft, the width of which was 1 cm and the length 25 per cent shorter than the portion removed from the tendon. The course of the strip was either strictly longitudinal or transverse to the long axis of the trunk. Preliminary experiments had shown that the abbreviation of 25 per cent was the maximal allowing suture of the transplant straight on to the tendon stumps with a suture imitating that of BUNNEL (KIVILAAKSO has used the same proportion in his own experiments). It is essential that the measurement of the transplant should be carried out before the skin strip is detached from the encircling skin, because a strip of skin loosened from the surrounding tissues either shrinks or stretches according to the direction of the long axis and reliable measurements are no longer obtainable. Preliminary experiments revealed that a strip of skin taken longitudinally along the trunk, measured after loosening and fixed in the usual manner might stretch in situ by even more than 100 per cent and the Achilles tendon lengthened so much that the function of the leg was greatly impaired. In these cases a wide decubitus developed in the heel of the rabbit and no active extension of the foot was noted. (KIVILAAKSO reported corresponding results in his experiments. He noted that the muscular part is able, by contracting, to compensate an absolute stretch of up to 1 cm). The paratenon was drawn over the transplant and closed with catgut sutures. The wound was then closed in two layers with interrupted sutures. Nobecutan was sprayed on the wound and a cardbord splint was applied, in which the foot was extended at an angle of 120 degrees at the ankle joint. The splint was kept in position for 3—28 days, according to the individual case.

Extensor hallucis longus tendon.

The rabbit was again laid in the lateral position, but with the leg to be operated on underneath, and the legs were fixed to the table in the same manner as above. The incision was made on the medial surface of the ankle. The extensor hallucis longus has a relatively long tendinous part, from which a piece as much as 4 cm long was successfully replaced by a skin graft in the same manner as above, except that the width of the transplant was now only 0.5 cm. (BENSLEY has given the following description of the anatomy of the extensor hallucis longus in the rabbit: it originates from the medial condyle of the tibia behind the medial collateral ligament and from the anterior medial edge of the tibia at the height of the distal end of the tibial tuberosity up to the central part of the bone. It also originates partly from the posterior medial surface of the tibia up to the middle third. This tendon extends around the medial malleolus, and the basal and medial surfaces of the 2nd metatarsal to the dorsal surface of the basal phalanx, where it is united to the first branch of the extensor digitorum longus.)

Long-distance skin tendons.

In these experiments only skin strips taken longitudinally along the trunk were used, the width of which was 0.75 cm and the length 8—9 cm. The end of the sartorious muscle was connected with a skin band brought subfascially to the region of the ankle and from there again under the cruciate ligament, to the lower portion of the extensor digitorum longus at the point immediately before this tendon branches out to the digits. The rabbit was placed supine with the legs fixed as in the gynecologic position. Incisions were made in the medial border of the knee joint, where the insertion of the sartorious muscle was loosened and in the anterior medial border of the ankle joint, where the tendon of the extensor hallucis longus was severed (Fig. 2 A). The leg was immobilized with both the knee and ankle joints flexed at an angle of 90 degrees (Fig. 2 B).

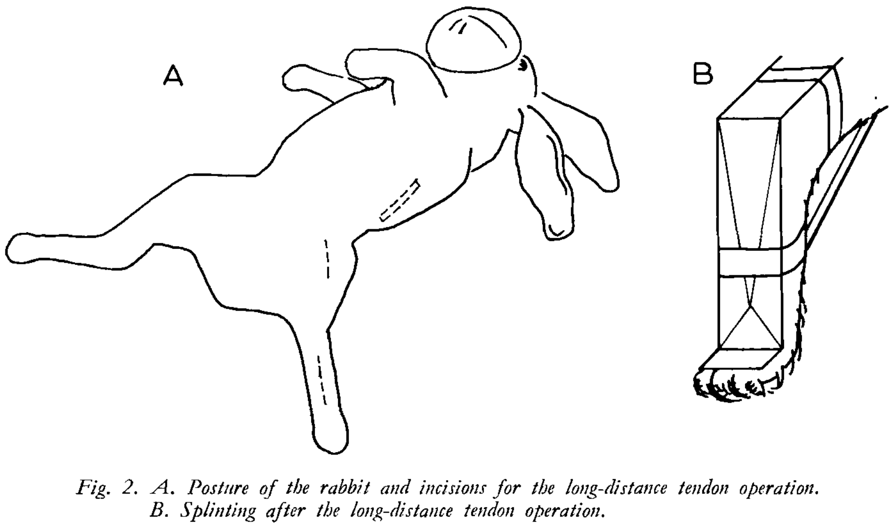


Fig. 2. A. Posture of the rabbit and incisions for the long-distance tendon operation. B. Splinting after the long-distance tendon operation.

These two tendons were chosen on technical grounds, because a sufficient distance between two points was needed. Functionally, this choice was perhaps not the best one, but the movements of the leg were not disturbed after the operation.

Interspinal ligaments replaced by skin graft.

The original method developed by Professor Kallio was not strictly adhered to. He makes a figure-of-eight skin loop through three successive spinous processes. Here only a simple loop through two successive spinous processes was used. The operation position was the natural sleeping posture of the rabbit. A skin incision was made in the thoracolumbar border of the back. Fascia and muscles were next loosened, as in laminectomy, and the region between the two uppermost lumbar vertebrae with the spinous processes was freed from muscles and ligaments. This was at first somewhat difficult to accomplish on account of the structure of the rabbit vertebra, (Fig.3) but gradually an adequate technic was developed. Holes were bored with a dental drill through the central part of two successive spinous processes and a skin band 0.5 cm wide was taken

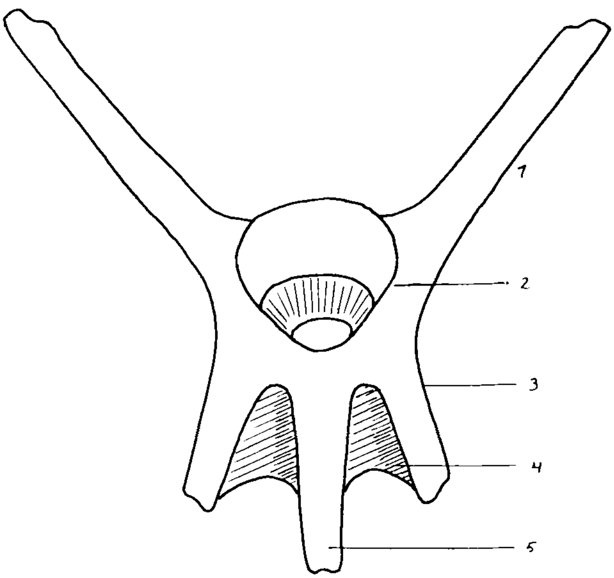


Fig. 3. The lumbar vertebra of the rabbit.
1 = transverse process
2 = vertebral corpus
3 = sup. artic. process
4 = inf. artic. process
5 = spinous process

longitudinally from the wound edge and sutured under maximal tension by tightening with two criles on itself (Fig. 4). The muscles were drawn together and sutured with catgut and in the same way the fascia and skin were closed, too. No immobilization was used after the operations.

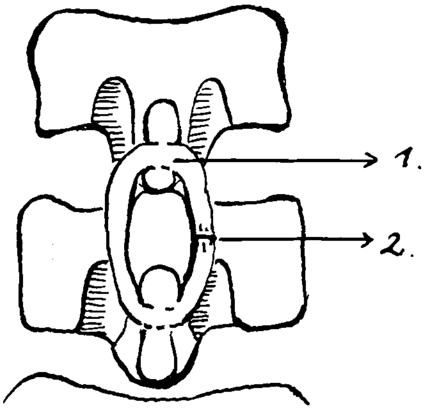


Fig. 4. The interspinal ligament replaced by whole-thickness skin graft.
1 = drill hole through the spinous process.
2 = suture in the graft.

Dermodesis.

The method is a modification of the tenodesis developed by HACKENBROCH and its aim is to prevent a particular movement at the ankle joint by fixing the peroneus longus tendon transosseously. The position was the same as in the Achilles tendon operations. A lateral incision was made in the lower part of the leg, the peroneus longus tendon was exposed and severed near the point of insertion and a portion 3 cm long was replaced by skin as described above. A hole was then drilled through the lower part of the tibia in the direction from outside inwards and upwards. The skin transplant was drawn through it and sutured to itself, thus forming a loop which fixed the peroneus tendon to the bone and held the foot in dorsiflexion. (A peroneal paresis was first brought about by cutting the peroneal nerve behind the m. peroneus above the lateral malleolus. The ankle joint was immobilized in dorsiflexion of 90 degrees).

The functionless skin graft buried in the muscle.

A lateral position was used. An incision was made along the lateral border of the upper fore-limb. The fascia of the biceps brachii muscle was opened and a furrow made in it with scissors in the direction of the muscle fibers. Into this furrow a piece of skin 0.5 cm wide and 1 cm long was implanted and the wound closed in three layers. No immobilization was used.

The control operations.

Tendons were severed and then sutured in situ with Bunnel sutures. Paratenon, fascia and skin were closed in the usual manner.

METHODS OF STUDY

Physical methods

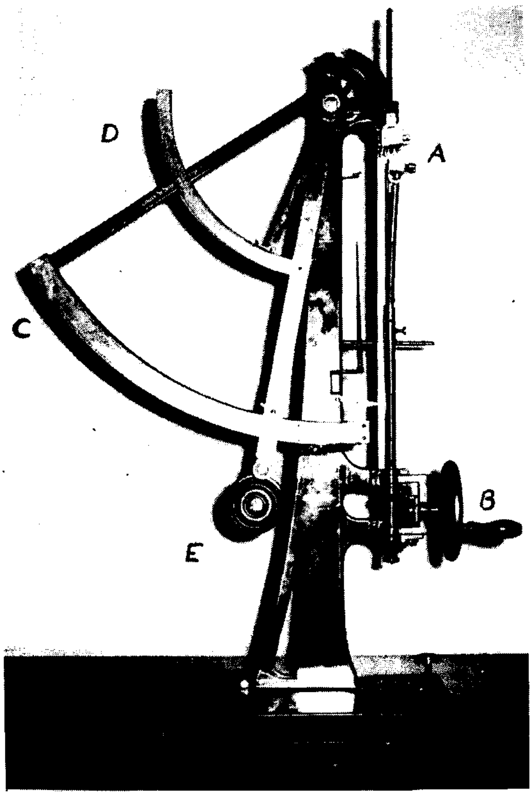
After a fixed time the rabbit was sacrificed by injecting 5—10 cc of 5 per cent Intraval sodium or 2.5 per cent Nembutal solution into the auricular vein. Immediately after death two specimens of skin were taken and the transplant with its immediate surroundings was loosened, wrapped in tupfers moistened with normal saline solution and brought to the Institute for Technical Research where the tensile strength was measured with the Schopper dynamometer (HOWES) (Fig. 5). For measuring the strength of tendons, these were loosened from their insertions and cut away from the border of the muscular portion. The skin replacements of tendons were fixed in the apparatus so that both the transplant and the normal tendon tissue united to it came under the influence of the tension (Fig. 6). It was found that the strong Achilles tendons were readily worked loose from the clamps by the pull and therefore ligatures of thick silk were tied on both ends of the tendon and the grip strengthened with those. The specimens for long-distance skin tendons and skin ligaments consisted of the transplant alone.

Histologic methods.

Histologic specimens were also taken from all cases. These specimens were first put into 10 per cent neutral formalin solution for 48—72 hours. After this they were embedded in paraffin for about one day and cut into sections of 3—5 μ thickness. They were stained with Weigert-van Gieson's hematoxylin, but some specimens were also stained with Weigert's resorcin fuchsin to reveal the elastic fibers.

Statistical methods.

The results were compared chiefly by means of the t-test. When it was possible to compare different experiments performed on the same individuals, use was made of the matching test.



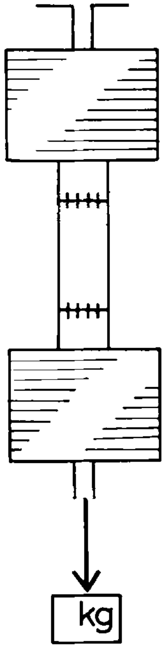


Fig. 5. Dynamometer of Schopper type from the Institute for Technical Research
A = clamps by which the preparation is fixed
B = wheel rotated by hand at a rate of 200 mm/min, when an even tension, read on the scale C, is exerted on the praparation.
Simultaneously the stretching can be read on the scale D.
E = weight

Fig. 6. Preparation under examination fixed by clamps.

The following quantities were determined from the different observation groups:

Statistical formulas.

Mean = x

Standard deviation $= s = \sqrt{\dfrac{\Sigma(x-\overline{x})^2}{n-1}} = \sqrt{\dfrac{\Sigma x^2-(\Sigma x)^2/n}{n-1}}$

Standard error of the mean $= \varepsilon = s/\sqrt{n}$

Two groups have been compared with each other by means of the t-test, $t = d/\varepsilon d$

where the difference of means $= d = x_2 - \overline{x}_1$

Standard error of the difference of means $= \varepsilon d = \sqrt{\varepsilon_1^2 + \varepsilon_2^2} =$

$$\sqrt{\frac{n_1 + n_2}{n_1 \; n_2} \cdot \frac{Q_1 + Q_2}{n_1 + n_2 - 2}}$$

Now

n = number of cases

Σx = sum

Σx^2 = sum of squares

Q = mean square $= \Sigma x^2 - (\Sigma x)^2/n$

where $(\Sigma x)^2/n$ = reduction term.

From the t-distribution table we can now find the risk P.
If $P \leqq 5\,\%$ or 0.05, the difference of the values is nearly significant.
If $P \leqq 1\,\%$ or 0.01, the difference of the values is significant.
If $P \leqq 0.1\,\%$ or 0.001, the difference of the values is highly significant.
The *primary* or *spontaneous stretch* determined in connection with the tendon experiments has been calculated as a percentage of the length of the transplant and it denotes the distance which the transplant has postoperatively lengthened in its new site.
The *maximal stretch* or the *break elongation* signifies the lengthening which can be verified in the transplant or tendon just before it breaks in the dynamometer. It is calculated as a percentage of the original length.
The *strength* signifies the power which makes the object under examination break in the stretching test.

VI. RESULTS

MACROSCOPIC CHANGES IN THE WHOLE-THICKNESS SKIN GRAFT USED AS REPLACEMENT OF TISSUE DEFECTS

Skin graft replacement of the Achilles tendon

The main purpose of the present study was to determine the tensile strength of the skin graft, but for the sake of completeness the macroscopic changes were also noted and are briefly reported here.

3—7 days.

No gross macroscopic changes are noted in the transplant. Thin edema fluid begins to collect around it and at the same time the surrounding tissues, tendon stumps and paratenon seem slightly swollen. At this stage the spontaneous stretch is relatively low, about 10 per cent. The transplant lies in exactly the same position as it was placed. The strength of the tendon is obviously entirely dependent on the sutures and in the stretching experiment the rupture takes place at the site of the juncture. It is noteworthy that no spontaneous rupture occurred after removal of the splint although the immobilization time was only 3 days. The rabbit makes no attempt to use the operated leg at this stage.

7—14 days.

The edema increases considerably in the whole leg. When the wound is opened, greenish exudate and new loose connective tissue are noted around the transplant. The graft is still flat. The spontaneous stretch begins gradually to rise above 20 per cent. The rabbit is already using the limb somewhat cautiously, but the active extension of the ankle joint is still limited. In the stretching test rupture takes place at the site of the juncture.

14—30 days.

The edema begins gradually to disappear and the transplant is attached to the tendon stumps by the granulation tissue, with which it forms a region thicker than the tendon. The paratenon is clearly thickened, too. The spontaneous stretch is relatively high during this stage, almost 40 per cent. Rupture in the stretching test takes place in the region of the tendon immediately above the suture point and this may be due to the softening and possible necrosis at the tendon stumps.

30—60 days.

The transplant is already quite round and at the same time beginning to grow thinner as the adhesions to the surroundings decrease considerably. Rupture takes place in the area of the tendon near the juncture. Movement is already fairly normal.

3rd month.

The situation has not greatly changed. The transplant is now completely fused to the tendon stumps. Only the black sutures indicate the juncture.

4th month.

The skin transplant is now slightly thinner than the normal tendon and also that part of the tendon which is nearest to the muscle is slightly thinner, perhaps owing to contraction of the muscle fibers in compensation for the stretch. The spontaneous stretch is almost unchanged. Rupture takes place in the area of the tendon above the juncture.

6th month.

The spontaneous stretch begins again to decrease. Obviously a contraction is also occurring in the transplant, the diameter of which entirely corresponds to that of the normal tendon. The attachment to the tendon stumps is revealed by the fact that rupture generally occurs in the area of the tendon near the juncture but sometimes also in the area of the transplant.

8th—12th month.

The spontaneous stretch again approaches a value of 20 per cent. The appearance is quite comparable with that of normal tendon tissue. Only the tendinous gloss is lacking in the area of transplant, which is grayish and dull.

Skin graft replacement of the extensor hallucis longus tendon.

The changes are quite comparable with those in the Achilles tendon. This tendon is very thin and relatively weak in the rabbit and therefore the skin graft always seems disproportionately thick, though a strip only 0.5 cm wide was used. The spontaneous stretch rarely exceeds 10 per cent, because the power of the tendon is not adequate to stretch the transplant more. In the stretching test, rupture always takes place in the area of the tendon or exceptionally at the point of the juncture, but never in the area of the transplant. Owing to the technical difficulty of the operation, only 10 extensor tendons were replaced by skin grafts.

Long-distance skin tendons.

1st month.

A beautiful even skin tendon is developed and its diameter is almost the same as that of the sartorious muscle. There are no strong adhesions to the surroundings. For fear of cutting through the sutures and because the tendon of the extensor digitorum longus was relatively thin and weak, immobilization was maintained for at least 14 days. Nothing exceptional was noted in the function of the leg when the splint was removed. The spontaneous stretch was about 15 per cent. Only the skin transplant was used in the stretching test.

End of the 2nd month.

The skin tendon begins to become thicker and rounded. There is further free mobility with respect to the surrounding tissues. The spontaneous stretch is almost unchanged.

4th — 6th months.

The skin tendon seems relatively thick. It is obvious that more epithelial debris accumulates in the longer transplant. The spontaneous stretch still increases slightly during this stage.

8th month.

The transplant remains to some extent thicker than the tendons to which it is united. The muscles are obviously not able to offer sufficient resistance for the transplant and use is not made of its full capacity. The length of the transplant has not changed much since the second month. The skin transplant forms a tissue resembling normal tendon tissue in quality to a surprising extent, having an even smooth surface and being rounded like a tendon, but dull. (Fig. 7).

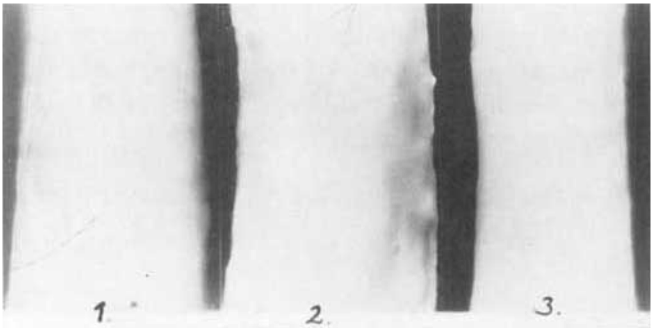


Fig. 7. Normal Achilles tendon (1), Achilles tendon replaced by whole-thickness skin graft (2) and long-distance skin tendon (3) side by side. All specimens taken from rabbits 12 months old, observations made 6 months after skin graft operation.

Skin graft replacements of interspinal ligaments.

End of the 1st month

already the skin graft is forming a nice, rounded ligament, which is slightly adherent to the muscles over it. The adjacent tissues have also recovered well. The sutures have held in spite of absence of immobilization. The spontaneous stretch is less than 10 per cent. The rabbit moved a little cautiously during the first few days after the operation and was anxious when handled. Such a contact tenderness was noted up to the end of the second week.

2nd month.

The skin ligament adheres to some extent more firmly to the adjacent muscles. No major reaction is noted in the spinous processes close to the drill holes. The stretch increases slightly.

4th month.

The new ligament is probably under suitable tension, because its development continues to progress without complications. No great accumulation of epithelial debris is noted, in spite of the incomplete removal of the epithelium. The skin transplant turns into a slightly solid fibrotic tissue closely resembling cicatriceal tissue. No excessive reaction on the part of the adjacent tissue is noted.

6th month.

The skin loop has stretched by about 15 per cent of its original length. It is naturally attached to the adjacent tissue. No cyst formations are found.

Dermodesis.

2nd month.

The skin loop resembles tendon tissue, being smooth and even. In the drill hole around the transplant callus has formed and the periosteum is also to some extent thickened. Nothing exceptional is noted in the function of the leg after removal of the immobilization.

4th month.

The appearance of the skin loop is as above, but in the bone around the drill hole there is an excessive reaction. The corticalis is thickened almost like a tumour and there is also reaction in the periosteum.

6th month.

The skin loop is to some extent thickened, but the reaction in the bone is decreased.

10th month.

The diameter of the skin loop is decreasing, the reaction in the bone is already almost unnoticeable and the drill hole is reduced in size.

The functionless skin graft in the muscle.

1st month.

During the second week the skin graft assumes the form of a bean, its diameter being about one-half of the length of the transplant. It seems as if the epithelial surfaces bend against each other during the first month, forming a round body around which a white capsule of connective tissue develops.

2nd month.

The diameter of the graft increases to some extent, but its shape and appearance remain almost unchanged.

4th month.

An oval structure resembling a pearl has developed in the muscle. Its diameter is almost the same as the length of the original transplant. It is slightly adherent to the surrounding muscles, causing no reaction around it.

6th month.

The size, consistency and appearance of the transplant have remained unchanged compared with the former specimens.

SYNOPSIS of the RESULTS

During the first few weeks the transplant is still readily distinguishable from the surrounding tissues and its length is almost unchanged. At the end of the second month, when the excessive edema around the transplant begins to decrease, the graft is seen to be attached to the tendon stumps. At the same time the length of the graft has clearly increased, possibly in response to the increasing tension at the site of the juncture. At the end of the second month the transplant is, practically speaking, already able functionally to replace the tissue for which it has been substituted. After this changes are still noted, which contribute to improving the outer form and the graft becomes united still more firmly with the tendon stumps. At the end of the third month metamorphosis is already complete and the replacement does not obviously differ from the original tissue.

MICROSCOPIC CHANGES IN THE WHOLE-THICKNESS SKIN GRAFT USED AS REPLACEMENT OF TISSUE DEFECTS

Tendon replaced by skin graft.

The experiments carried out by KIVILAAKSO were particularly concerned with this group, and hence only a brief survey is given here. These studies have been carried out only because it was interesting to study whether the changes observed in the present study were of the same kind. The histologic preparations were made from parts of the same specimens, on which the tensile strength was measured.

3—7 days.

There are numerous cells in the exudate around the transplant. The chief type of cell is the lymphocyte, but granulocytes are also present. These cells also penetrate between the epithelium and the fibril bundles of the transplant. Cell islands are formed between the thickened paratenon and the exudate.

7—14 days.

The exudate is replaced by granulation tissue richly supplied with capillaries. This also penetrates between the epithelium and dermis and in some places through the epithelium, too. At the tendon stumps necrosis is noted at the site of the sutures. The cell-rich granulation tissue also begins to penetrate between the tendon fibrils. (Fig.8).

14—30 days.

The epithelial cells have disappeared, but hair follicles are still to be seen. The granulation tissue begins to resemble a connective tissue richly supplied with fibrils, the latter orientated parallel with the long axis of the tendon.

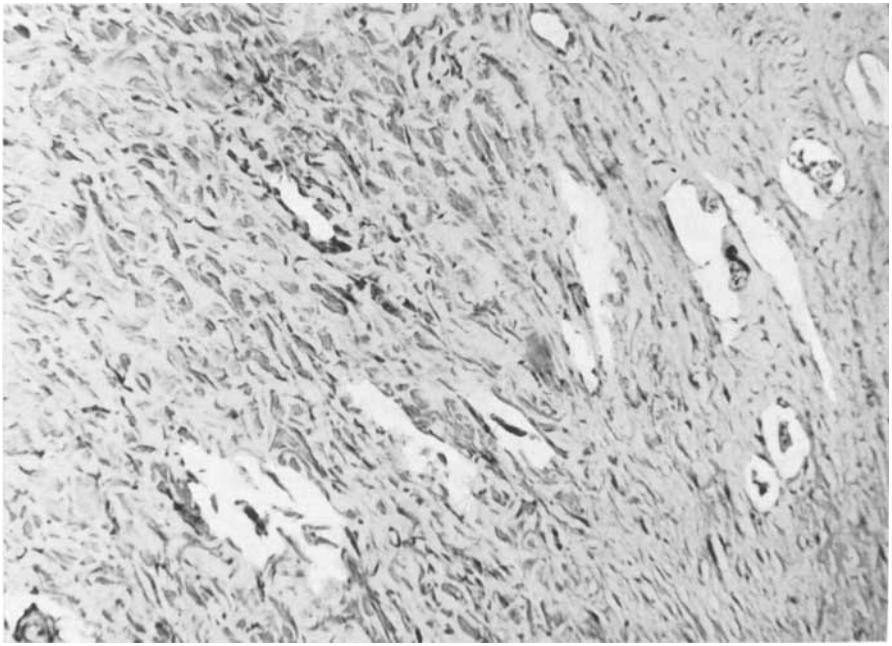


Fig. 8. Whole-thickness skin graft replacing the Achilles tendon 2 weeks after operation. On the left connective tissue of the skin, in which the direction of the fibrils is still unchanged. At the right edge granulation tissue very rich in capillaries, which unites the transplant to the surroundings. Weigert-van Gieson staining × 70.

2nd month.

The number of inflammatory cells decreases considerably, even in the vicinity of the hair follicles. The fibril bundles increase in strength and undulate to some extent in their course. (Fig. 9.)

After the 3rd month.

The histologic picture does not change much. The transplant resembles tendon tissue more and more (Fig. 10). It contains greater numbers of cells than tendon tissue.

No macroscopic epithelial cyst was encountered. In specimens taken after the 30th postoperative day some microscopic cysts were seen. These results are in conformity with those obtained by KIVILAAKSO.

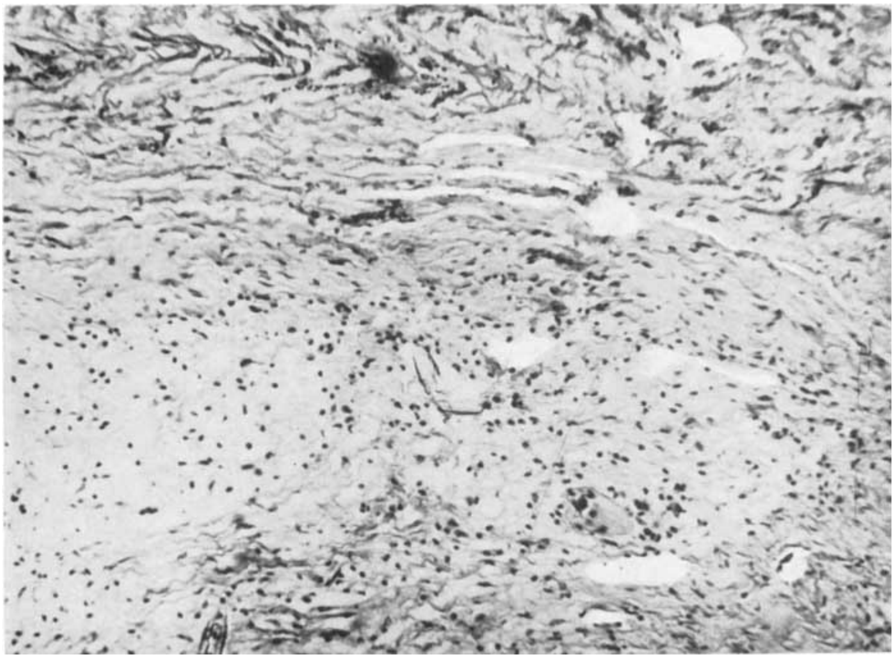


Fig. 9. Whole-thickness skin graft replacing the Achilles tendon 2 months after operation. The epithelium has quite disappeared and inside the tubular new tendon there is only loose connective tissue rich in cells. Weigert-van Gieson staining × 70.

Long-distance skin tendons.

1st month.

The margins of the transplant are curved towards each other so that a tube is formed with the epithelial surface inward. In cross section the fibrils are noted at first to run circularly round the lumen. Inside the new tubular tendon there is an exudate containing numerous inflammatory cells (Fig. 11).

2nd month.

The epithelial debris in the tube slightly increases and a horny substance and remnants of hair are also found in it. Some narrow columns of cells, in which the nuclei stain weakly, are all that remain of the epithelium.

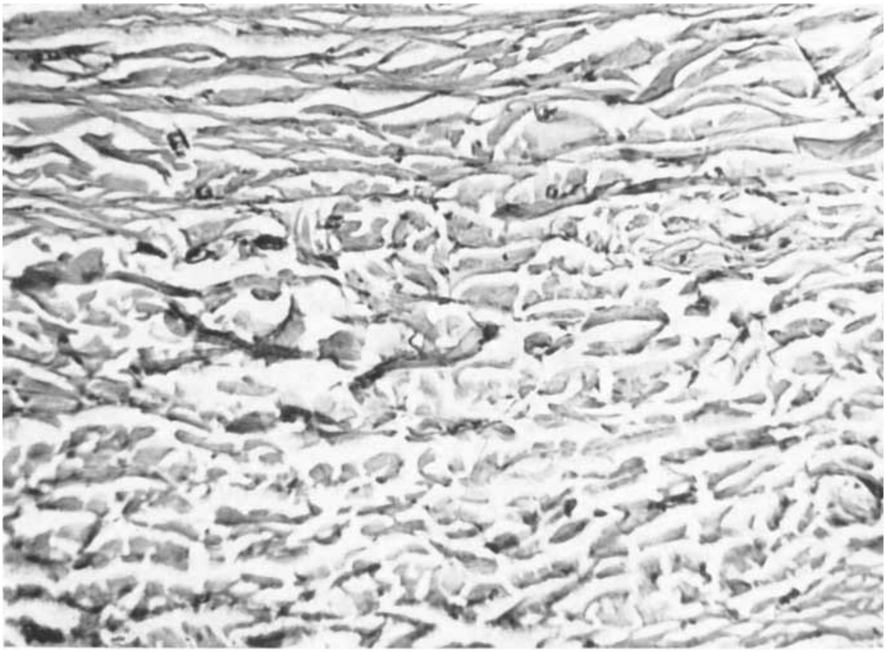


Fig. 10. Whole-thickness skin graft replacing the Achilles tendon 4 months after operation. The connective tissue of the corium forms fibril bundles, orientated longitudinally. Weigert-van Gieson staining × 150.

4th — 8th month.

The fibrils begin more and more exclusively to orientate longitudinally. In the tube there is an amorfous mass, the only cell type of which is the inflammatory cell.

Interspinal ligaments replaced by skin.

1st month.

Exudate accumulates around the transplant and begins later to organize to granulation tissue. Necrosis is noted at the site of the sutures in the surrounding muscles (Fig. 12).

2nd month.

The transplant is seen to attach to the surrounding muscles and bone by the granulation tissue.

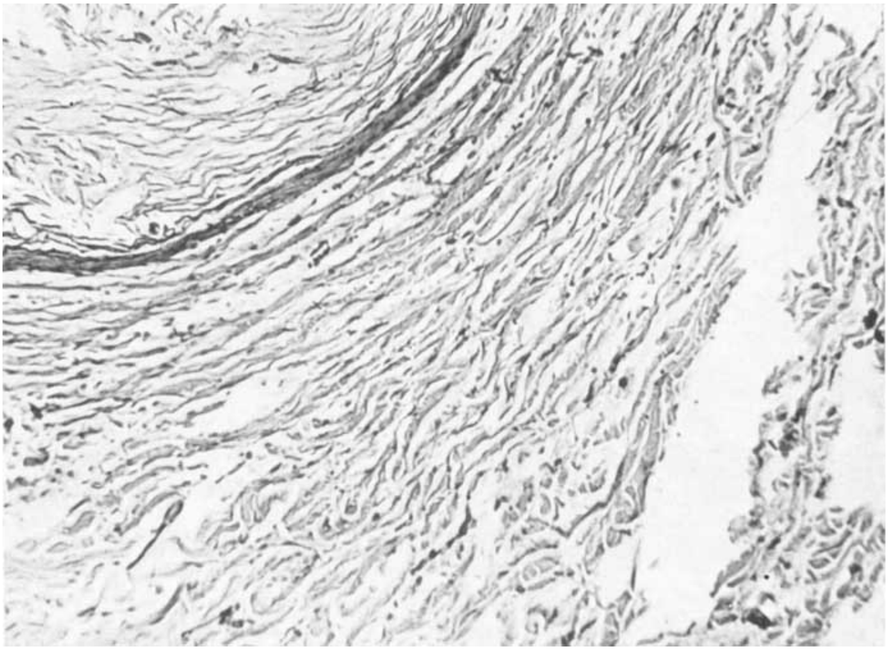


Fig. 11. Long-distance skin tendon 1 month after operation. Cross-section of the specimen. The system of the fibril bundles is in this phase principally circular. On the right below, however, there are longitudinally orientated fibrils, too. The epithelium is quite flattened and has almost disappeared already, it resembles a demarcation line (the dark line in the photo). Weigert-van Gieson staining × 70.

4th — 6th month.

Strong longitudinal fibril bundles are noted in the transplant (Fig. 13). No signs of epithelial cysts are seen. In a few specimens taken in the initial phase flattening islands of epithelial cells were noted, but these disappeared soon after the first month.

Dermodesis.

The histologic changes correspond to those noted in the skin ligament. More epithelial debris, however, is seen in the skin loop, but the development of the fibrous structure is comparable with that of the skin ligament. The tension of the transplant is obviously not satisfactory (Figs. 14 and 15).

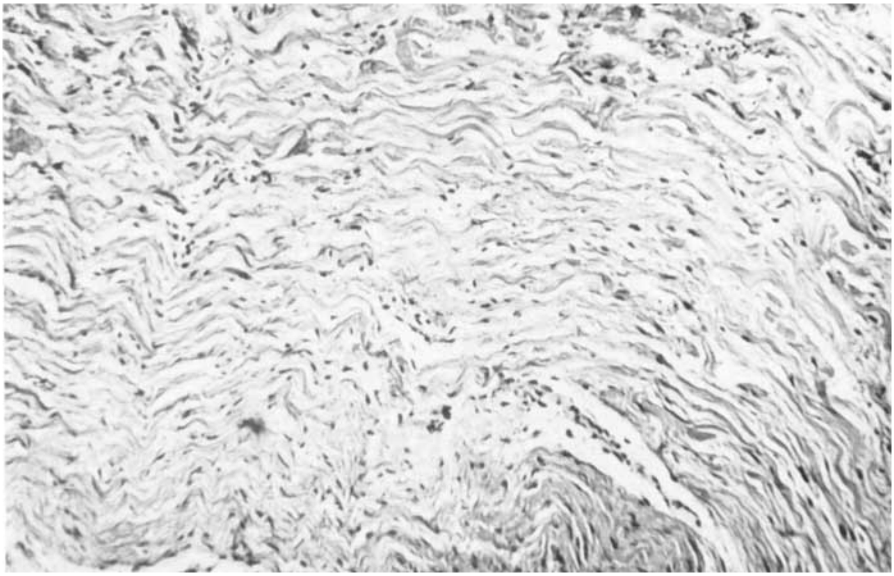


Fig. 12. »Skin ligament» 1 month after operation. The fibril bundles have already become orientated in the direction of the tension and in part still undulate in their course. Weigert-van Gieson staining × 70.

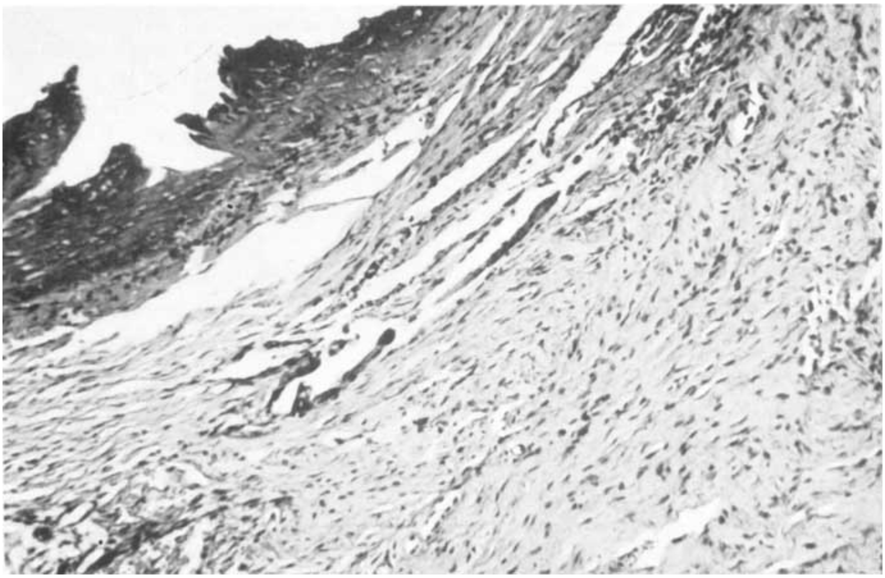


Fig. 13. »Skin ligament» 6 months after operation. The specimen was taken from the vicinity of the bone, which is seen on the left above. The fibrils of the new ligament have become orientated parallel with the bone surface (i.e. in the direction of the tension). On the right below young connective tissue. Weigert-van Gieson staining × 70.

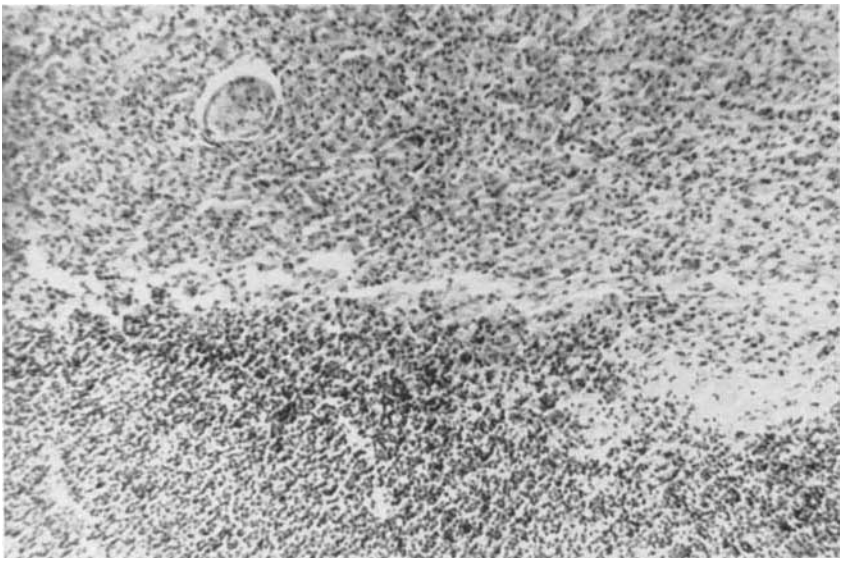


Fig. 14. Dermodesis 2 weeks after operation.
Mass rich in inflammatory cells from the inside of the skin loop.
Weigert-van Gieson staining × 70.

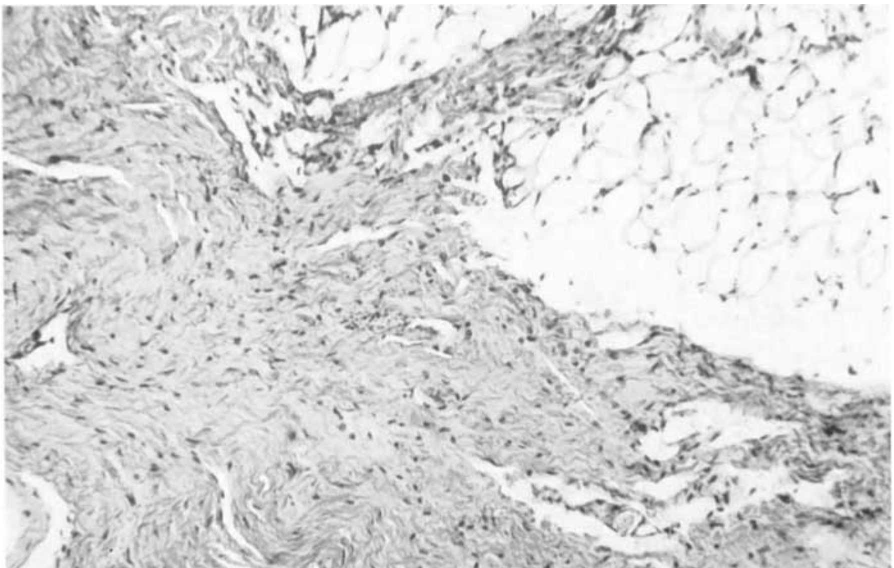


Fig. 15. Dermodesis 1 month after operation.
Fibril bundles have become orientated in the direction of the tension. On the right above loose subcutaneous fat tissue. Weigert-van Gieson staining × 70.

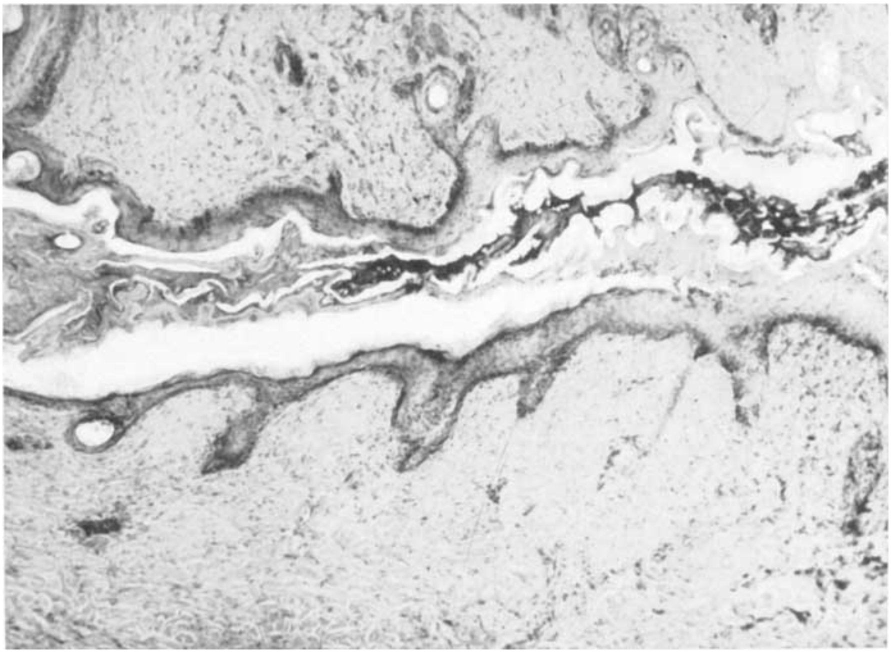


Fig. 16. The functionless skin graft buried in the muscle 2 weeks after operation. The epithelial surfaces have come to lie against each other and between them there remains some debris. The corium near the epithelium contains numerous inflammatory cells. Weigert-van Gieson staining × 70.

The functionless skin graft in the muscle.

1st month.

The transplant is noted to be folded upon itself, the epithelial surfaces against each other. The corium of the skin graft is united to the surrounding connective tissue by the exudate and later by the granulation tissue (Fig. 16).

Beginning of the 2nd month.

Contents are noted in the cyst and its diameter continues to increase. Cells from the inner layers begin to loosen and form epithelial debris in the cavity of the cyst. At the same time cells towards the surface flatten, the cyst walls growing thinner.

4th — 6th month.

The walls of the cavity consist partly of an epithelial layer, but in places only of connective tissue. In the specimens remnants of hair follicles are seen in the form of microscopic cysts.

SYNOPSIS of the RESULTS.

During the first few days exudate accumulates around the transplant and this fluid contains numerous inflammatory cells. About the beginning of the second week this is replaced by granulation tissue, which better unites the transplant to the surroundings. At the same time it is possible to detect the first fibrils; these continue to increase in number and to orientate in the direction of tension and later make up the greater part of the transplant.

STATISTICAL METHODS

Next follow the results for the separate observation groups in table form and after them the statistical analysis of each.

The development of the whole-thickness skin graft in the tendon tissue is also illustrated by graphs.

The grouping has been made on the basis of the age of rabbits and the length of the postoperative observation time.

CHANGES IN THE TENSILE STRENGTH

A. SKIN AS SUCH.

TABLE 2.

1) Fresh skin.

N:o	Age in months	Strength longitud. in kg	Maxim. stretch %	Strength transvers. in kg	Maxim. stretch %
1	18	8.3	102	10.0	89
2	18	6.5	106	7.4	90
3	18	8.5	110	11.0	80
4	18	8.9	106	10.0	84
5	16	8.5	112	9.8	93
6	16	5.4	121	7.2	102
7	16	4.5	126	5.4	96
8	16	5.9	112	7.6	106
9	14	6.8	96	8.9	82
10	14	6.5	102	7.5	91
11	14	8.5	121	9.4	111
12	14	7.4	118	9.0	100
13	14	9.6	94	11.0	80
14	14	7.4	110	8.5	90
15	14	5.3	110	4.9	92
16	12	8.1	110	11.5	80
17	12	6.8	96	8.9	81
18	12	3.2	143	4.1	115
19	12	8.3	95	10.3	86
20	12	3.2	140	6.1	110
21	12	8.0	95	7.5	80
22	12	5.9	120	7.5	100
23	12	4.5	150	6.5	118
24	12	3.2	98	5.3	93
25	12	7.2	98	5.3	83
26	12	4.6	130	8.4	92
27	11	7.5	96	4.5	94
28	11	8.5	89	9.9	83
29	11	3.8	116	4.4	106
30	11	8.2	98	12.0	80
31	11	8.5	87	9.9	81
32	11	8.3	95	10.4	88
33	10	7.4	98	9.2	86
34	10	8.5	115	11.0	80
35	10	9.5	90	10.3	82
36	10	7.3	92	8.0	87
37	10	7.1	90	9.4	73
38	10	4.3	98	6.9	86
39	10	3.2	120	4.3	106
40	10	3.2	143	4.6	121
41	10	6.5	90	10.0	82
42	10	3.6	108	6.4	93
43	10	3.2	112	5.4	96
44	10	3.2	121	5.6	102

N:o	Age in months	Strength longitud. in kg	Maxim. stretch %	Strength transvers. in kg	Maxim. stretch %
45	10	3.1	110	4.6	101
46	10	2.7	126	3.1	111
47	10	6.3	110	8.4	94
48	10	10.0	90	7.3	83
49	10	5.1	95	6.3	81
50	10	5.8	120	7.9	90
51	10	6.7	110	8.4	92
52	9	5.6	108	8.3	89
53	9	6.5	90	10.0	81
54	9	4.5	155	6.5	120
55	9	4.2	150	5.9	108
56	9	4.4	130	5.6	100
57	9	6.5	90	7.5	80
58	9	3.6	109	6.6	98
59	9	3.6	120	5.2	103
60	9	7.3	123	7.5	95
61	8	4.1	120	7.6	100
62	8	3.8	121	6.9	101
63	8	4.3	98	6.9	82
64	8	7.4	120	8.3	110
65	8	4.4	140	5.3	100
66	8	5.3	110	4.7	80
67	8	7.3	110	6.9	83
68	8	3.5	120	4.7	80
69	8	6.3	130	7.2	80
70	8	5.4	105	4.2	92
71	8	5.1	96	6.1	86
72	8	6.3	101	8.4	86
73	8	4.1	130	4.5	80
74	8	7.2	112	9.1	90
75	8	6.1	120	7.5	100
76	8	2.8	100	4.2	80

N:o	Age in months	Strength longitud. in kg	Maxim. stretch %	Strength transvers. in kg	Maxim. stretch %
77	8	3.6	108	6.4	96
78	8	3.2	96	6.3	80
79	8	2.2	140	4.3	102
80	8	3.8	128	4.9	105
81	8	2.8	110	4.3	92
82	8	1.8	132	3.1	108
83	8	7.3	102	8.3	85
84	8	3.1	120	4.5	100
85	8	5.4	116	4.9	94
86	8	3.4	132	7.0	98
87	7	1.5	102	1.8	90
88	7	3.2	96	5.3	80
89	7	3.1	93	4.6	82
90	7	3.6	104	6.5	98
91	7	4.6	158	6.7	106
92	7	3.6	150	4.9	110
93	7	4.7	110	6.4	100
94	7	6.5	90	7.5	80
95	7	3.1	123	4.6	100
96	7	4.5	126	5.4	93
97	7	2.4	140	4.2	100
98	7	1.9	150	2.3	110
99	7	1.7	120	2.1	102
100	7	1.0	125	2.9	99
101	7	1.7	115	3.2	100
102	7	2.0	120	3.1	105
103	7	4.6	140	6.7	96
104	7	2.4	110	4.4	91
105	7	4.4	126	5.6	98
106	7	3.9	133	6.1	103
107	7	2.8	127	5.6	99
108	7	1.9	130	3.7	101

TABLE 3.

2) Bank skin.

N:o	Quality of skin	Strength longitud. in kg	Maxim. stretch %	Strength transvers. in kg	Maxim. stretch %
38	Fresh skin	4.3	98	6.9	86
	Preserv. 7 d.	2.8	90	4.8	82
	» 14 d.	1.3	84	3.6	86
42	Fresh skin	3.6	108	6.4	92
	Preserv. 7 d.	3.1	92	5.1	81
	» 14 d.	2.4	81	3.9	72
45	Fresh skin	3.1	110	4.5	101
	Preserv. 7 d.	2.6	92	3.8	89
	» 14 d.	2.1	86	2.4	78
47	Fresh skin	6.3	110	8.4	94
	Preserv. 7 d.	5.1	92	6.9	87
	» 14 d.	4.8	89	5.8	79
49	Fresh skin	5.1	95	6.3	89
	Preserv. 7 d.	4.6	92	4.9	87
	» 14 d.	4.1	87	4.7	79
71	Fresh skin	5.1	95	6.2	89
	Preserv. 7 d.	4.7	92	5.3	87
	» 14 d.	3.5	86	4.6	73
73	Fresh skin	4.1	120	4.5	80
	Preserv. 7 d.	3.8	98	3.8	78
	» 14 d.	3.3	94	3.6	76
75	Fresh skin	5.9	120	7.5	100
	Preserv. 7 d.	4.7	109	6.2	95
	» 14 d.	4.3	91	5.8	86
78	Fresh skin	3.2	96	6.3	87
	Preserv. 7 d.	2.5	93	4.2	78
	» 14 d.	1.9	88	3.7	72
80	Fresh skin	3.8	112	6.7	105
	Preserv. 7 d.	4.1	99	6.3	96
	» 14 d.	3.6	89	4.9	84

Strength of the fresh skin.

Age in months	Number of cases	Range in kg	Mean in kg	Standard deviation	Standard error of the mean
Skin strip taken longitudinally along the trunk					
7— 8	48	1.0— 7.4	3.94	1.69	0.24
9—10	28	3.1—10.0	5.37	2.10	0.40
11—12	17	3.2— 8.5	6.34	2.11	0.51
14—18	15	4.5— 9.6	7.20	1.51	0.39
All	108	1.0—10.0	5.14	2.20	0.21
Skin strip taken transversely across the trunk.					
7— 8	48	1.8— 9.1	5.42	1.73	0.25
9—10	28	3.1—11.0	7.12	2.00	0.38
11—12	17	4.1—12.0	7.80	2.60	0.63
14—18	15	4.9—11.0	8.44	1.84	0.47
All	108	1.8—12.0	6.65	2.28	0.22

The maximal stretch of the fresh skin

Age in months	Number of cases	Range in kg	Mean in kg	Standard deviation	Standard error of the mean
Skin strip taken longitudinally along the trunk.					
7— 8	48	90—158	118.8	16.2	2.33
9—10	28	90—155	110.6	18.8	3.55
11—12	17	87—150	109.2	20.2	4.92
14—18	15	94—126	109.7	9.19	2.37
All	108	87—158	113.9	17.2	1.66
Skin strip taken transversely across the trunk.					
7— 8	48	80—110	94.5	9.52	1.37
9—10	28	73—121	93.4	12.4	2.35
11—12	17	80—118	92.4	12.9	3.14
14—18	15	80—111	92.4	9.28	2.40
All	108	80—121	93.6	10.8	1.03

t -tests showing the increase in strength of the skin with age.

Interval in months	Number of cases	Difference of the means	Standard error	t	p
Strength of longitudinally taken skin.					
7— 8/ 9—10	76	1.43	0.47	3.06	0.01
7— 8/11—12	65	2.40	0.57	4.23	0.001
7— 8/14—18	63	3.26	0.46	7.08	0.001
9—10/11—12	45	0.97	0.65	1.50	..
9—10/14—18	43	1.83	0.56	3.29	0.01
11—12/14—18	32	0.86	0.64	1.34	..
Strength of transversely taken skin.					
7— 8/ 9—10	76	1.70	0.45	3.74	0.001
7— 8/11—12	65	2.38	0.68	3.51	0.001
7— 8/14—18	63	3.02	0.54	5.62	0.001
9—10/11—12	45	0.68	0.73	0.92	..
9—10/14—18	43	1.32	0.51	2.18	0.05
11—12/14—18	32	0.64	0.79	0.81	..

Strength of the bank skin.

Quality of skin	Number of cases	Range in kg	Mean in kg	Standard deviation	Standard error of the mean
Skin strip taken longitudinally along the trunk.					
Fresh skin	10	3.1—6.3	4.45	1.11	0.35
Preserv. 7 d.	10	2.5—5.1	3.80	0.98	0.31
» 14 d.	10	1.3—4.8	3.13	1.15	0.36
Skin strip taken transversely across the trunk.					
Fresh skin	10	4.5—8.4	6.39	1.19	0.38
Preserv. 7 d.	10	3.8—6.9	5.13	1.07	0.34
» 14 d.	10	2.4—5.8	4.30	1.07	0.34

The maximal stretch of the bank skin.

Quality of skin	Number of cases	Range %	Mean %	Standard deviation	Standard error of the mean
Skin strip taken longitudinally along the trunk.					
Fresh skin	10	95—120	106.0	9.82	3.11
Preserv. 7 d.	10	90—109	94.9	5.72	1.81
» 14 d.	10	81— 94	87.5	3.63	1.15
Skin strip taken transversely across the trunk.					
Fresh skin	10	80—105	92.3	7.75	2.45
Preserv. 7 d.	10	78— 96	86.0	6.34	2.01
» 14 d.	10	72— 86	78.5	5.42	1.71

Changes in strength of the bank skin.

N:o	Change in longit. skin strip after 7 days, kg	Skin preserv. 7 d./skin preserv. 14 d.	Change in transv. skin strip after 7 days, kg	Skin preserv. 7 d./skin preserv. 14 d.
1	— 1.5	— 1.5	— 2.1	— 1.2
2	— 0.5	— 0.7	— 1.3	— 1.2
3	— 0.5	— 0.5	— 0.8	— 1.4
4	— 1.2	— 0.3	— 1.5	— 1.1
5	— 0.5	— 0.5	— 1.4	— 0.2
6	— 0.4	— 1.2	— 0.9	— 0.7
7	— 0.3	— 0.5	— 0.7	— 0.2
8	— 1.2	— 0.4	— 1.4	— 0.5
9	— 0.7	— 0.6	— 2.1	— 0.4
10	— 0.3	— 0.5	— 0.4	— 1.4
Number of cases	10	10	10	10
Mean	— 0.65	— 0.67	— 1.26	— 0.83
Standard error	0.17	0.12	0.18	0.15
t	3.82	5.58	7.00	5.53
P	0.01	0.001	0.001	0.001

Changes in the maximal stretch of the bank skin.

N:o	Change in longit. skin strip after 7 days, kg	Skin preserv. 7 d./skin preserv. 14 d.	Change in transv. skin strip after 7 days, kg	Skin preserv. 7 d./skin preserv. 14 d.
1	— 4	4	— 8	— 6
2	—11	— 9	—16	—11
3	—12	—11	—18	— 6
4	— 7	— 8	—18	— 3
5	— 2	— 8	— 3	— 5
6	— 2	—14	— 3	— 6
7	— 2	— 2	—22	— 4
8	— 5	— 9	—11	—18
9	— 9	— 6	— 3	— 5
10	— 9	—12	—13	—10
Number of cases	10	10	10	10
Mean	— 6.3	— 7.5	—11.5	— 7.4
Standard error	1.21	1.65	2.23	1.41
t	5.21	4.55	5.16	5.25
P	0.001	0.01	0.001	0.001

Synopsis of the Results

It is established that the tensile strength of the skin significantly differ in the longitudinal and transverse directions of the trunk. A strip of skin taken longitudinally (i.e. parallel with the long axis of the collagen fibril bundles of the corium) is stronger (ratio of the means: 6.65 kg: 5.14 kg t = 0.001). The maximal stretch in the long axis of the fibrils was less than transversely to them (93.6 %: 113.9 % t = 0.001). It has long been known that the elasticity of the skin is at a minimum in this direction.

As to the effect of age on the tensile strength of the skin, the maximal absolute strengths are found to be reached at about 10—12 months of age. After this there is no significant increase in the tensile strength. A rabbit becomes adult at the age of 8 months and thereafter aging probably begins to affect the results.

A comparison of bank skin with normal fresh skin reveals that there is a significant reduction in the tensile strength of the specimens whose long axis is parallel with that of the collagen fibrils during the period of preservation. It is possible that the fibril structure of the skin loses its characteristics under the influence of the preservative used becoming to some extent »denatured».

B. SKIN USED AS REPLACEMENT OF TISSUE DEFECTS.

TABLE 4.

1) Achilles tendon operations.

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %	Course	Immob. days	Nature of oper.
1	18	360 300	25.0 23.0	9	83 86	Longit.	21 21	A-t A-s
2	18	360	20.0 28.0	18	80 89	Longit.	28	A-t A-n
3	18	360 300	21.0 26.0	8	78 84	Transv.	21 28	A-t A-s
4	18	360	18.0 26.0	10	79 90	Transv.	28	A-t A-n
5	14	240 300	20.0 24.0	21	75 79	Longit.	21 21	A-t A-s
6	14	240	18.0 27.0	30	81 92	Longit.	21	A-t A-n
7	14	240 180	16.0 19.1	39	84 89	Longit.	21 21	A-t A-s
8	14	240	12.1 25.0	27	84 86	Transv.	21	A-t A-n
9	14	240 300	21.0 24.0	20	79 81	Transv.	21 21	A-t A-s
10	14	240	17.1 23.0	17	86 90	Transv.	21	A-t A-n
11	12	180	19.8 22.0	16	81 98	Longit.	21	A-t A-n
12	12	180 120	21.0 19.3	23	78 91	Longit.	18 21	A-t A-s
13	12	180	20.0 23.0	27	78 89	Longit.	18	A-t A-s
14	12	180 120	19.1 20.1	12.5	83 98	Transv.	18 21	A-t A-s
15	12	100	16.0 26.0	13	85 88	Transv.	21	A-t A-n
16	12	180 120	18.4 18.2	20	83 98	Transv.	21 21	A-t A-s
17	10	120 180	18.0 21.0	38	89 87	Longit.	18 21	A-t A-s
18	10	120	9.4 18.5	39	89 98	Longit.	18	A-t A-n
19	10	120	17.1 24.0	41	91 99	Longit.	18	A-t A-n

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %	Course	Immob. days	Nature of oper.
20	10	120 180	17.0 22.0	42	90 92	Longit.	18 21	A-t A-n
21	10	120 180	16.0 22.0	36	87 83	Transv.	16 21	A-t A-s
22	10	120 60	12.6 19.8	41	89 85	Transv.	16 21	A-t A-s
23	10	120	13.4 25.0	26	87 88	Transv.	16	A-t A-n
24	10	120	17.0 22.0	24	87 98	Transv.	16	A-t A-n
25	9	90 120	17.2 20.9	39	86 110	Longit.	14 14	A-t A-s
26	9	90	13.3 22.2	40	100 103	Longit.	14	A-t A-n
27	9	90 120	16.2 22.0	42	90 92	Longit.	14 14	A-t A-s
28	9	90	13.1 22.0	37	89 92	Longit.	14	A-t A-n
29	9	90 120	15.0 21.0	36	91 90	Longit.	14 14	A-t A-s
30	9	90	12.2 19.6	42	92 86	Transv.	12	A-t A-n
31	9	90 120	14.9 20.0	37	90 89	Transv.	12 14	A-t A-s
32	9	90	16.8 22.0	36	97 91	Transv.	12	A-t A-n
33	9	90 60	19.1 18.9	28	93 91	Transv.	12 14	A-t A-s
34	8	60	21.0 23.0	22	78 82	Longit.	14	A-t A-n
35	8	60 30	15.3 19.8	31	81 83	Longit.	14 14	A-t A-s
36	8	60	17.9 20.0	38	90 89	Longit.	14	A-t A-n
37	8	60 30	16.0 16.6	40	82 86	Longit.	14 14	A-t A-s
38	8	60	12.4 16.9	39	78 88	Longit.	14	A-t A-n
39	8	60 30	14.4 17.8	33	79 83	Transv.	12 14	A-t A-s
40	8	60 30	12.1 17.9	39	76 79	Transv.	12 14	A-t A-s

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %	Course	Immob. days	Nature of oper.
41	8	60	19.1	27	82	Transv.	16	A-t
			25.0		86			A-n
42	8	60	16.2	26	76	Transv.	16	A-t
			17.1		88			A-n
43	8	60	8.6	37	89	Transv.	16	A-t
		30	16.3		86		14	A-s
44	8	30	12.4	38	90	Longit.	12	A-t
			18.5		87			A-n
45	8	30	7.5	41	91	Longit.	12	A-t
		60	18.9		89		16	A-s
46	8	30	6.2	38	89	Longit.	12	A-t
			16.3		86		12	A-n
47	8	30	8.0	36	90	Longit.	12	A-t
		60	17.9		88		16	A-s
48	8	30	11.0	34	79	Longit.	10	A-t
		14	6.0		90		14	A-s
49	8	30	8.5	15	72	Transv.	12	A-t
			21.0		83			A-n
50	8	30	6.8	36	98	Transv.	12	A-t
		60	18.8		87		16	A-s
51	8	30	7.8	28	75	Transv.	12	A-t
			20.8		86			A-n
52	8	30	5.1	37	100	Transv.	10	A-t
		60	19.8		90		16	A-s
53	8	30	6.1	38	89	Transv.	10	A-t
			16.3		86			A-n
54	7	14	7.0	40	76	Longit.	10	A-t
			15.0		83			A-n
55	7	14	7.1	35	63	Longit.	10	A-t
		60	16.1		70		16	A-s
56	7	14	6.9	33	87	Longit.	7	A-t
		30	13.0		89		16	A-s
57	7	14	6.8	40	85	Longit.	7	A-t
		60	19.5		86		16	A-s
58	7	14	4.9	38	79	Longit.	7	A-t
			23.0		82			A-n
59	7	14	6.0	26	68	Transv.	10	A-t
			18.2		86			A-n
60	7	14	6.6	22	70	Transv.	10	A-t
		60	17.9		85		16	A-s
61	7	14	5.3	34	89	Transv.	10	A-t
			26.0		85			A-n

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %	Course	Immob. days	Nature of oper.
62	7	14	6.3	29	69	Transv.	7	A-t
			16.4		89			A-n
63	7	14	5.7	27	73	Transv.	7	A-t
		30	15.4		88		14	A-s
64	7	7	3.8	19	63	Transv.	3	A-t
			18.4		90			A-n
65	7	7	3.1	26	71	Longit.	3	A-t
		30	16.9		78		14	A-s
66	7	7	1.9	16	63	Longit.	3	A-t
			25.0		71			A-n
67	7	7	2.6	7	64	Transv.	7	A-t
		30	14.1		76		14	A-t
68	7	7	3.3	11	80	Transv.	3	A-t
			17.8		86			A-n
69	7	7	2.8	8	67	Transv.	3	A-t
		30	15.6		84		14	A-s
70	7	3	1.2	12	81	Longit.	3	A-t
			23.0		90			A-n
71	7	3	1.3	6	72	Longit.	3	A-t
		30	13.9		80		14	A-s
72	7	3	2.3	5	63	Longit.	3	A-t
			25.0		72			A-n
73	7	3	0.9	9	65	Transv.	3	A-t
		30	14.2		78		14	A-s
74	7	3	2.4	14	58	Transv.	3	A-t
			22.0		85			A-n
75	7	3	1.2	17	71	Transv.	3	A-t
		30	12.3		84		14	A-s
76	16	300	23.0		75		21	A-s
			28.0		81			A-n
77	16	300	23.0		87		21	A-s
			25.0		85			A-n
78	16	300	22.0		83		21	A-s
			26.0		92			A-n
79	12	180	20.0		90		21	A-s
			21.0		89			A-n
		120	14.3	49	78	Longit.	21	A-b
80	12	180	21.0		90		21	A-s
			23.0		86			A-n
		120	9.4	51	80	Transv.	21	A-b
81	12	180	22.0		86		21	A-s
			24.0		100			A-n
		120	12.9	48	81	Longit.	14	A-b

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %	Course	Immob. days	Nature of oper.
82	12	180	22.0		78		21	A-s
			24.0		81			A-n
83	11	180	21.0		90		21	A-s
			22.0		85			A-n
84	11	180	17.9		88		21	A-s
			18.5		89			A-n
85	10	120	17.1		102		21	A-s
			24.0		92			A-n
		180	14.2	52	90	Longit.	14	A-b
86	10	120	23.0		85		21	A-s
			25.0		84			A-n
		180	14.9	45	86	Transv.	14	A-b
87	10	120	19.1		103		21	A-s
			21.0		83			A-n
		180	13.8	48	87	Transv.	14	A-b
88	8	60	18.1		82		21	A-s
89	8	60	14.1	38	81	Longit.	14	A-b
90	8	60	11.8	36	79	Transv.	14	A-b
91	8	60	13.8	45	84	Longit.	14	A-b
92	8	60	16.7	34	82	Transv.	14	A-b

The spontaneous stretch of the Achilles tendon
replaced by skin graft.

Observ. time in days	Number of cases	Range %	Mean %	Standard deviation	Standard error of the mean
Achilles tendon replaced by skin.					
3	6	5—17	10.5	4.68	1.91
7	6	7—26	14.5	7.29	2.97
14	10	22—40	32.4	6.20	1.96
30	10	15—41	34.1	7.53	2.38
60	10	22—40	33.2	6.43	2.03
90	9	28—42	37.4	4.25	1.42
120	8	24—42	35.9	7.00	2.47
180—240	12	12.5—39	22.1	7.66	2.21
360	4	8—18	11.25	4.57	2.29
All	75	5—42	27.8	11.27	1.30
Achilles tendon replaced by bank skin.					
All	10	34—52	44.7	6.41	2.03

Strength of the achilles tendon.

Observ. time in days	Number of cases	Range in kg	Mean in kg	Standard deviation	Standard error of the mean
Achilles tendon replaced by skin.					
3	6	0.9— 2.4	1.55	0.63	0.26
7	6	1.9— 3.8	2.92	0.65	0.27
14	10	4.9— 7.1	6.18	0.77	0.24
30	10	5.1—12.4	7.9	2.25	0.71
60	10	8.6—21	15.3	3.64	1.15
90	9	12.2—19.1	15.4	2.13	0.71
120	8	9.4—18	15.1	2.98	1.05
180—240	12	12.1—21	18.2	2.59	0.75
360	4	18—25	21.0	2.94	1.47
All	75	0.9—25	11.8	6.47	0.75
Achilles tendon replaced by bank skin.					
30—60	4	11.8—18.1	14.1	2.01	1.01
90—120	3	9.4—14.3	12.2	2.52	1.46
180—	3	13.8—14.9	14.3	0.56	0.32
All	10	9.4—18.1	13.6	1.94	0.61
The sutured Achilles tendon.					
30	13	12.3—19.8	15.9	2.09	0.60
60	10	16.1—19.8	18.6	1.12	0.36
120	10	17.1—23	20.1	1.76	0.55
180—240	10	17.9—22	20.7	4.03	0.47
300—360	7	22—26	23.6	1.27	0.48
All	50	12.3—26	19.1	3.48	0.50
Normal Achilles tendon.					
210	10	15—25	19.4	5.24	1.51
240	10	16.3—25	19.5	3.01	0.96
270	4	18.9—22	21.5	1.24	0.62
300	10	18.5—28	22.7	2.25	0.80
330—420	11	18.5—27	23.2	2.27	0.66
480—540	5	25—28	26.6	1.34	0.60
All	50	15—28	21.7	3.89	0.55

The maximal stretch of the Achilles tendon.

Observ. time in days	Number of cases	Range %	Mean %	Standard deviation	Standard error of the mean
Achilles tendon replaced by skin.					
3	6	58—86	68.3	8.07	3.30
7	6	63—80	68.0	6.63	2.71
14	10	63—89	75.9	8.87	2.80
30	10	72—100	87.3	9.21	2.91
60	10	76—90	81.1	4.93	1.56
90	9	89—100	92.6	4.56	1.52
120	8	87—91	88.6	1.51	0.53
180—240	12	78—89	81.4	3.34	0.96
360	4	78—83	80.0	2.16	1.08
All	75	58—100	81.2	9.69	1.12
Achilles tendon replaced by bank skin.					
30—60	4	79—84	81.5	2.08	1.04
90—120	3	78—81	79.7	1.58	0.91
180—	3	86—90	87.7	2.12	1.22
All	10	78—90	82.8	1.22	0.39
The sutured Achilles tendon.					
30	13	76—89	82.1	3.80	1.10
60	10	70—91	85.3	6.00	1.90
120	10	85—110	95.8	7.71	2.44
180—240	10	78—92	86.8	4.02	1.34
300—360	7	75—87	82.1	4.18	1.58
All	50	76—110	86.6	7.23	1.03
Normal Achilles tendon.					
210	10	72—90	84.0	6.40	1.85
240	10	82—89	86.1	2.18	0.69
270	4	86—103	93.0	7.16	3.58
300	10	83—99	92.2	6.52	2.30
330—420	11	81—100	89.4	5.30	1.53
480—540	5	81—92	87.4	4.39	1.96
All	50	72—100	88.0	6.05	0.85

Some t-tests.

Observ. time in days	Number of cases	Differ. of means	Standard error	t	P
Strength					
Achilles tendon replaced by skin contra sutured Achilles tendon.					
30	22	7.96	0.93	8.56	0.001
60	20	3.27	1.20	2.73	0.02
120	18	5.01	1.19	4.21	0.001
180—240	21	2.46	0.88	2.80	0.02
300—360	11	2.57	1.55	1.66	..
Achilles tendon replaced by skin contra normal Achilles tendon.					
30	20	11.5	1.19	9.68	0.001
60	20	4.16	1.50	2.77	0.02
90	13	6.03	0.941	6.40	0.001
120	16	7.63	1.32	5.78	0.001
180—240	24	5.00	0.994	5.03	0.001
300—360	9	5.60	1.59	3.52	0.01
The maximal stretch					
Achilles tendon replaced by skin contra sutured Achilles tendon.					
30	22	— 5.2	3.11	1.67	..
60	20	4.2	2.46	1.71	..
120	18	7.2	2.50	2.88	0.02
180—240	21	5.4	1.65	3.27	0.01
300—360	11	2.1	1.91	1.10	..
Achilles tendon replaced by skin contra normal Achilles tendon.					
30	20	— 1.2	3.00	0.40	..
60	20	5.0	1.71	2.92	0.01
90	13	0.4	3.89	0.10	..
120	16	3.6	2.36	1.53	..
180—240	24	8.0	1.81	4.42	0.001
300—360	9	7.4	2.24	3.30	0.02

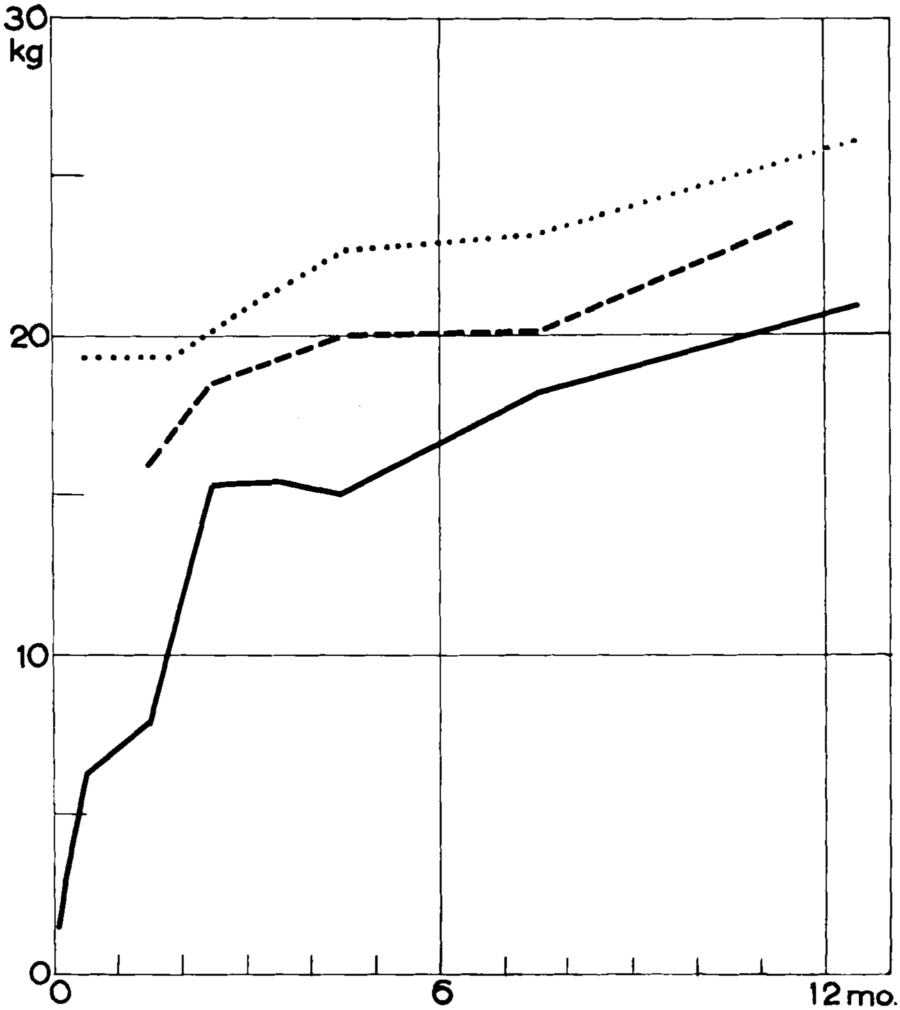


Fig. 17. Increase in the strength of the whole-thickness skin graft replacing the Achilles tendon compared with that of the sutured and normal tendons. Groups according to the observation time. The normal tendons taken from rabbits of the same age as the operated ones at the time of observation.

Normal achilles tendon	....
Sutured achilles tendon	- - - - - - - -
Achilles tendon replaced by skin	————

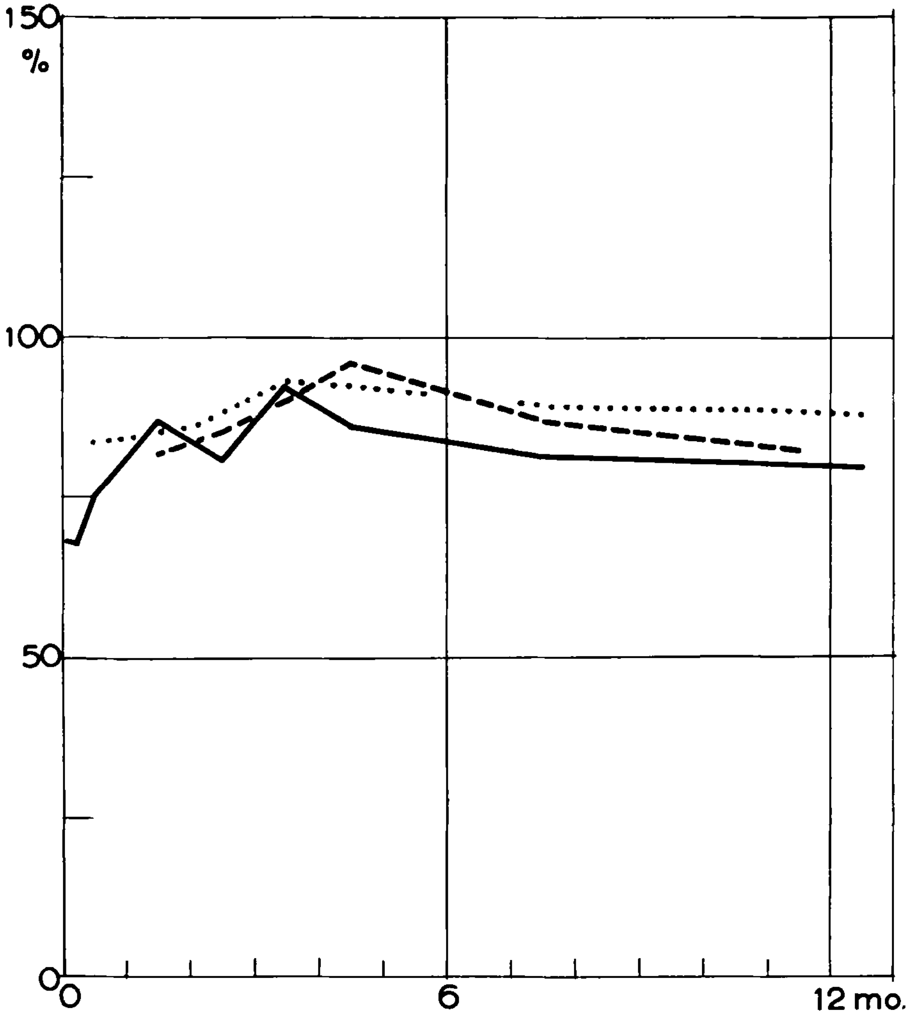


Fig. 18. Increase in the maximal stretch of the Achilles tendon replaced by whole-thickness skin graft compared with that of the sutured and normal tendons. Groups the same as in the previous figure.

Normal Achilles tendon . . . .
Sutured Achilles tendon - - - - - - - - - - - -
Achilles tendon replaced by skin ————————

Synopsis of the Results

Within two months a whole-thickness skin graft replacing the Achilles tendon develops a considerable strength comparable with the normal tendon, but after this point it seems as if development ceased. This latent phase continues beyond the fourth month. After this there is again a slower increase, which continues up to the 12th month, when the difference from the normal is at a minimum again.

The simply sutured tendon also reaches practically the strength of the normal tendon within two months. The development curve then continues in regular form.

The maximal stretch increases uninterruptedly up to the fourth month, after which a slight decrease is noted. The same phenomenon is seen in the normal and sutured tendons, too, so that it is probably a consequence of some general characteristic of tendon tissue.

The spontaneous stretch of the skin transplant increases up to the second month and then comes to a standstill at the same point as in the course of development of the tendon. After this there is only a slight increase up to the third month, when the maximum is reached and then a decrease again begins, until at the 12th month the same values are reached as in the first weeks.

The difference between the values obtained from the transplants taken longitudinally and transversely along the trunk is no longer significant ($t \gtreqless 0.02$), as it was in the case of the skin itself.

TABLE 5.

2) Extensor hallucis longus.

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %	Course	Immob. days	Nature of oper.
1	18	300	4.8 5.2	12	89 90	Longit.	21	E-t E-n
2	18	300	3.9 4.6	13	85 89	Transv.	21	E-t E-n
3	16	180	2.1 3.6	11	89 84	Longit.	21	E-t E-n
4	16	180	2.5 4.2	5	87 87	Transv.	18	E-t E-n
5	16	180	2.2 3.8	16	84 90	Longit.	18	E-t E-n
6	14	120	1.9 2.8	11	90 88	Transv.	18	E-t E-n
7	11	120	2.2 3.6	9	83 85	Longit.	18	E-t E-n
8	8	60	1.9 3.8	10	87 87	Transv.	14	E-t E-n
9	8	60	1.4 2.4	7	91 86	Longit.	14	E-t E-n
10	8	60	1.3 2.8	8	84 88	Transv.	14	E-t E-n
11	10	180	5.1		74		21	E-s
12	10	180	4.6		81		21	E-s
13	10	180	4.3		82		21	E-s
14	10	120	4.6		83		21	E-s
15	10	120	4.2		81		21	E-s
16	11	60	1.9		87		18	E-s
17	10	60	1.4		86		18	E-s
18	10	60	2.1		86		18	E-s
19	10	30	0.8		82		14	E-s
20	10	30	1.4		83		14	E-s

Strength of the extensor tendon.

	E-t.	E-s.	E-n.	All controls
Number of cases	10	10	10	20
Range	1.3—4.8 kg	0.8—5.1 kg	2.4—5.2 kg	
Mean	2.42 kg	3.04 kg	3.68 kg	3.36 kg
Standard deviation	1.10	1.65	0.86	1.32
Standard error of the mean ..	0.35	0.52	0.27	0.30

t-tests.

		E-t/E-s.	E-t/E-s.	E-t/all controls
Difference of the means		0.62	1.26	0.94
Standard error of the difference		0.63	0.44	0.45
t		0.98	2.86	2.09
P		..	0.02	0.05

The maximal stretch of the extensor tendon.

	E-t	E-s	E-n	All controls
Number of cases	10	10	10	20
Range	83—91 %	74—87 %	84—90 %	
Mean	86.9 %	82.5 %	87.4 %	84.5 %
Standard deviation	2.81	3.70	2.00	3.83
Standard error of the mean ..	0.89	1.17	0.63	0.86

t-tests.

		E-t/E-s.	E-t/E-n.	E-t/all controls
Difference of the means		4.40	0.50	2.40
Standard error of the difference		1.47	1.09	1.23
t		2.99	0.46	1.95
P		0.01	..	..

Synopsis of the Results

The results are comparable with those for the Achilles tendon. There is no significant difference from the normal tendon values. The extensor tendon is not able to provide a sufficient tension for the transplant.

TABLE 6.

3) Long distance tendons.

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %	Immob. days
1	14	240	5.5	16	79	21
2	14	240	6.3	19	80	21
3	14	240	4.8	17	92	21
4	14	240	7.9	20	84	21
5	12	180	8.3	18	81	21
6	12	180	7.6	21	86	21
7	12	180	10.3	17	86	21
8	12	180	6.7	16	89	21
9	10	120	8.0	15	83	18
10	10	120	6.8	17	90	18
11	10	120	6.9	18	88	18
12	10	120	7.1	16	91	18
13	8	60	11.2	16	81	18
14	8	60	9.3	13	80	14
15	8	60	8.7	15	78	14
16	8	60	10.8	18	83	14
17	7	30	3.1	17	86	14
18	7	30	2.2	14	92	14
19	7	30	3.5	16	87	14
20	7	30	6.1	12	89	14

Statistics.

Strength, spontaneous and maximal stretch of the long-distance tendon.

	Strength	Spontaneous stretch	Maximal stretch
Number of cases	20	20	20
Range	2.2—11.2 kg	12—21 %	78—92 %
Mean	7.06 kg	16.6 %	85.2 %
Standard deviation	2.45	2.19	4.48
Standard error of the mean	0.55	0.49	1.01

TABLE 7.

4) Interspinal ligaments

replaced by skin graft.

N:o	Age in months	Observ. time in days	Strength in kg	Spont. stretch %	Maxim. stretch %
1	12	180	6.7	19	83
2	11	180	4.8	12	78
3	11	180	5.1	18	83
4	11	180	3.9	11	89
5	12	180	5.3	12	78
6	10	120	4.3	11	84
7	10	120	3.9	16	89
8	10	120	2.9	12	91
9	10	120	3.6	11	83
10	10	120	4.8	13	81
11	8	60	1.8	13	79
12	8	60	3.4	10	76
13	8	60	4.6	11	81
14	8	60	6.6	8	80
15	8	60	2.5	9	86
16	7	30	4.3	9	63
17	7	30	2.2	5	68
18	7	30	2.9	8	76
19	7	30	1.6	7	83
20	7	30	0.9	7	79

Statistics.

Strength, spontaneous and maximal stretch of the skin ligaments.

	Strength	Spontaneous stretch	Maximal stretch
Number of cases	20	20	20
Range	0.9—6.7 kg	7—19 %	76—91 %
Mean	3.80 kg	11.0 %	80.5 %
Standard deviation	1.57	3.85	6.66
Standard error of the mean	0.35	0.80	1.49

Synopsis of the Results

The tensile strength of a long-distance tendon only exceptionally exceeds 10 kg. Probably the tendons to which the skin transplants are joined are not able to provide a stronger resistance and use is not made of all the possibilities of the skin. It is interesting, however, to establish that the »skin tendon» can exceed the strength of the tendons to which it is united. (In connection with the preliminary examinations it was found that the average strength of the m. sartorius was 5 kg and that of the tendon of the m. extensor hallucis longus only 3.9 kg.)

In the case of the interspinal ligaments replaced by the skin graft, the course of development is entirely comparable with that of the former group. There is no substantial increase in the tensile strength after the second month. The surrounding tissues seem to be to some extent more stabile than the tendon in question, where the muscle tension has an influence.

VII.

DISCUSSION

Material and technic.

In the animal experiments, a total of 108 young, white rabbits just becoming adult have been used. All the rabbits were operated on at the same age, 5—6 months. At least one month was allowed to elapse before the second operation, so as to enable the rabbit to recover from the previous operation.

In connection with the operation all the rabbits received 500,000 units of water-soluble penicillin applied partly to the wound area, partly intramuscularly. No wound infection occured in the experiments, despite the fact that complete sterility was not guaranteed in the operations. It is probable that the rabbit is very resistant to infection.

During the first month specimens were taken more frequently than later, because it was anticipated that changes would take place more rapidly during this stage.

As far as possible the whole transplant with the close surrounding tissue was always taken as a specimen, because this facilitated the examination of the attachment of the transplant to the adjacent tissues. For the same reason, the measurement of the tensile strength of the skin graft replacement were made on a specimen which included the whole tendinous part of the muscle. It was only of interest to ascertain the practical tensile strength of the newly formed tendon in its entirety. This could, of course, have been expressed as kg/cm^2, as has been done by some earlier authors, but this has not been considered to have any practical value. All the measurements and other examinations were made immediately after the death of the rabbit, in order that secondary factors should not influence the results. It is known, for instance, that desiccation essentially alters the strength and elasticity of the tissue.

Macroscopic and microscopic changes in whole-thickness skin graft used as replacement of tendon and ligament defects.

As long ago as 1865, HISS advanced the theory that connective tissue, when exposed to tension anywhere in the organism is transformed into tendon tissue. In this connection BENNINGHOFF (1931) drew attention to the skin of the abdominal wall, where under the influence of tension there develop obviously tendonlike formations, the striae distensae. EITEL (1933) focused his attention upon the remarkable power of regeneration and great vitality of the connective tissue of the skin.

SCHNEIDER (1936) made a biochemical study of the skin and established that it contained little reduced glutathione, an observation which signifies the occurrence of oxidation and reduction processes in the tissue. Those tissues which contain large amounts of glutathione do not readily regenerate.

STRAHAN (1951) explained that the epithelial elements of the skin graft disappear because under tension the nutrition of the tissue suffers from disturbances in the electrolyte balance. He emphasized that if the epithelium does not disappear during the reparative phase, i.e., the first 14 days, it continues to live. The developing granulation tissue prevents the growth of the epithelium, too. No epithelial cysts are found during the exudative and fibroblastic phases.

KIVILAAKSO (1955) established that within 90 days the connective tissue of the skin graft is transformed into tissue resembling tendon and that the new tissue differs from normal tendon tissue only in its dullness and histologic richness in cells. He confirmed that the epithelium disappears during the first two weeks. He says: »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.»

In connection with the present work it was noted that specimens taken 3—7 days after the operation are in the exudative phase. Inflammatory cells proliferate in its vicinity, probably owing to the irritation caused by the transplant. In this phase it is quite apparent that the organism reacts as if getting rid of a foreign body.

In the specimens taken about 2 weeks after the operation changes typical of the reparative or fibroblastic phase are noted. The organism now begins to adjust itself to the transplant, which it is beginning to incorporate as an organic part of itself. The exudate is replaced by granulation tissue, in which there appear numerous fibroblasts and capillaries. Simultaneously the epithelium begins to disappear.

At the end of the first month the maturation phase sets in and the granulation tissue is replaced by connective tissue. In this phase two subphases are distinguishable: the first lasts up to the end of the second month, when development seems to come to a standstill at the level attained. It is invariably resumed, however, the second phase beginning during the fourth month. This biphasic development is not so obvious in the histologic preparations as in the measurements of tensile strength. But changes in the diameter of the transplant are still visible to the naked eye in this later phase. The epithelium has disappeared before this phase and only exceptionally can remnants of it be seen, e.g. near the former hair follicles there are some microscopic cysts.

In the dermodesis and the functionless graft in the muscle corresponding phenomena have been noted. The course of development is admittedly to some extent more linear and the separate phases differ less from each other, but here, too, the accumulation of debris in the epithelium lined cavity ceases between the first and second months. In the dermodesis the debris begins to be resorbed after this, but in the cyst the pressure of the contents rises uninterruptedly. Later on, the cavity becomes filled with a fluid which exerts an even pressure upon the structure of the wall.

Changes in the tensile strength of the skin itself and the skin graft.

In the experiments reported above it was noted that the skin of a young rabbit which has just become adult is at its strongest. The tensile strength of the skin seems to follow the general growth and weight curves of the rabbit.

Levy (1906) alleged that inactivity essentially delays the healing of a tendon. Roux (1913) laid emphasis on the phenomena of activity hypertrophy and inactivity atrophy. According to him, function promotes the transformation of the regenerating transplant into its final structure, — in other words, the structure adapts itself to its function.

In the present work immobilisation was discontinued before the end of the observation time (except in the cases examined 3 days after operation) and the rabbits had the opportunity to use their extremities. In connection with the interspinal ligament operation no immobilisation was applied and function was allowed to affect the transplant from the start.

In the exudative phase the strength of the skin replacement of tendon or ligament depends solely upon the sutures, because no union with the surrounding tissues has yet taken place.

In the fibroblastic phase the tensile strength is likewise low, because in the stumps of the tendon changes occur which further weaken the area of juncture.

Only after the beginning of the maturation phase is the real strength of the skin tendon and ligament established. Then a rapid improvement is noted up to the beginning of the third month, when the tensile strength approaches that of the normal and sutured tendons. After this, the development of the simply sutured tendon continues at the same rate, but that of the skin tendon seems to come to a standstill for a long period and only after the fourth month does the process continue again, until about one year after the operation the difference from the normal is at a minimum again.

On the basis of a few measurements performed by himself KIVILAAKSO (1955) supposed that the skin tendon can never acquire the same strength as the normal tendon. In his experiments the tendon always broke at the point of juncture or at the site of implantation. The present experiments point to the same conclusion, but it seems that the tensile strength of the skin replacement of tendon or ligament is fully adequate to meet the stresses to which it will in practice be exposed.

As regards the controls used in this work, it might be argued that the tensile strength of the skin graft should have been compared with that of a free tendon transplant rather than with a simple suturing of the tendon. But because the actual method is especially designed for cases in which for some reason or other not enough tendon tissue is available for transplantation, i.e., where the tendon defect is too wide or otherwise difficult to replace by a tendon transplant, the aim has been only to find out whether skin in general is able to replace tendon tissue.

The skin may even be best suited for replacement of relatively wide defects in strong tendons, because here it can be placed under sufficient tension, which is the essential condition for good results.

It may be advisable at least to reduce the epithelium in reconstructive operations for long-distance skin tendons and skin ligaments, because the abundant epithelial debris may delay the healing process — and the epithelium will disappear at all events.

VIII. CONCLUSIONS

1) The strength of the normal rabbit skin is greater in the transverse than in the longitudinal direction along the trunk. The maximal stretch, on the other hand, is lower in this direction, i.e., parallel with the long axis of the fibrils, than longitudinally along the trunk.
2) The tensile strength of the whole-thickness skin graft replacement of tendon increases relatively rapidly up to the end of the second month, when it is already comparable with the normal. It then comes to a standstill for two months and only after the fourth month does a further rise begin, the tensile strength approaching the normal again about the 12th month.
3) An 8 cm long whole-thickness skin graft used as long-distance tendon is transformed into a tissue resembling tendon and is able to fulfil the function of power transference between two distant points which it unites.
4) In the original skin there is a highly significant difference in the tensile strength in the longitudinal and transverse directions, but in the skin graft this difference is levelled and is not significant.
5) It is concluded from macroscopic and microscopic studies and measurements of tensile strength that an immobilization time of 7—10 days is satisfactory for the skin tendon.

IX. SUMMARY

The purpose of the animal experiments here described was to obtain further information concerning the tensile strength of whole-thickness skin grafts used to replace tendon and ligament defects.

For the experiments, a total of 108 young purebred white rabbits were used. Altogether 85 Achilles tendons were replaced by whole-thickness skin grafts, homogenous bank skin being used in 10 of these cases. In 10 animals a portion of the tendon of the m. extensor hallucis longus was replaced by a skin graft. In addition to this, 20 long-distance tendons were constructed from whole-thickness skin grafts in the region of the hind leg of the rabbit. In 20 cases interspinal ligaments were replaced by skin grafts in the lumbar region. A dermodesis was performed on the hind leg in 10 animals in which peroneous paresis had previously been brought about. Finally in 10 rabbits a functionless whole-thickness skin graft was buried in the m. biceps brachii, the transplant not being fixed to the adjacent tissues. The purpose of this last operation was to induce the formation of true epithelial cysts within the same series of experiments and so to allow comparisons with any similar structures that might possibly arise in the other cases. In all, 155 operations involving whole-thickness skin graft were performed. The control series consisted of 50 simple suturings of the Achilles tendon and 10 similar operations on the extensor hallucis longus tendon. In addition to this, the tensile strength of 50 normal Achilles tendons and 10 normal extensor hallucis longus tendons was measured. Two specimens were taken from each rabbit for measurement of the tensile strength of fresh skin. Besides, skin from 10 rabbits was removed at autopsy and preserved in merthiolate solution. Specimens from these skin strips were also taken for determination of the tensile strength one to two weeks after autopsy. Altogether 511 measurements of tensile strength were performed. The periods of observation ranged from 3 days to 12 months.

The skin transplant with its adjacent tissues was also studied macroscopically and histologically, although strictly the purpose of the study was to examine the tensile strength of the new tissue entity thus formed.

The following results were obtained from the experiments:

Macroscopically the appearance of the transplant does not alter much during the first few weeks. The exudate which at first appears around the transplant begins, after the second week, to be replaced by granulation tissue, which gradually unites the graft to the tendon stumps. At the same time the margins of the skin strip begin to curl, forming a closed, cylindrical tube, with the epithelial surface to the inside. By the third month the fusion of the tendon stumps is almost complete and it is very difficult to identify the juncture with the naked eye, except by the black silk sutures.

Microscopically exudate containing numerous inflammatory cells is at first seen around the transplant. At the end of the second week this is replaced by granulation tissue containing numerous capillaries and fibroblasts, which penetrates between the epithelium and corium of the skin graft and forms cell columns towards the connective tissue around the transplant. The natural union of the graft with the tendon stumps is brought about by this granulation tissue. In it increasing numbers of fibrils, orientated in the direction of tension, appear in all specimens during the second month. Thus the dermis of the skin graft gradually comes to resemble fibrillar connective tissue, i.e., tendon or ligament tissue. In the whole-thickness skin graft joined to the Achilles tendon under great tension the epithelium disappears, as a rule, during the first two weeks, only a few remnants of epithelial cells persisting close to the remains of hair follicles. In the same way, the epithelium disappears from the skin ligament during the first month. In the dermodesis, epithelial remnants are noted a little longer than in the ligament, but generally these, too, disappear during the first month. In the long-distance tendons the tension is obviously not strong enough, for degenerating epithelial cells, in the form of flattened islands, are still seen at the end of the first month. These, however, relatively soon disappear from the inside of the new tubular tendon and all the debris begins to be resorbed. Nothing resembling an actual epithelial cyst has been observed.

Determinations of tensile strength revealed a rapid increase after the second week, at the onset of the maturation phase. This increase continues steadily up to the end of the second month, when it comes to a standstill for two months. A new increase in tensile strength begins at about the fourth month and this seems to continue up to the end of the first year. The increase in the tensile strength of the sutured tendons is steadier and virtually normal values are reached within two months. In the other experimental transplantations, the m. extensor hallucis longus, long-distance tendons and dermodesis, the tension exerted by the muscles involved is insufficient to enable the skin graft to develop as regularly as in the case of the Achilles tendon.

From the experiments reported above it is evident that the whole-thickness skin graft used to replace tendon and ligament tissue is able in practice to provide the tensile strength required of the tissue for which it is substituted, although its strength does not actually equal that of the normal tissue. A continuous improvement in the tensile strength of the transplant was noted during the first year of observation. No epithelial cysts were formed.

Although the lumbar region was not immobilized after replacement of the interspinal ligament, rupture did not occur in a single case. After replacement of tendons, an immobilization period less than a week was used, yet no suture gave way.

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