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SEVERE INJURIES TO THE LIGAMENTS

OF THE KNEE JOINT

AN EXPERIMENTAL AND CLINICAL STUDY

by

EWEN A. JACK, O.B.E., M.B., F.R.C.S.E.

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INTRODUCTION

Severe injuries to the ligaments of the knee joint have only recently begun to attract attention as a profitable field for early reparative surgery. Prior to 1938, attention had first centred on injury to the anterior cruciate ligament, because rupture frequently occurs at the tibial attachment and includes a fragment of bone which can be demonstrated by radiological examination. There were many reports of operative replacement of the fragment with successful results. An occasional paper had appeared from the Continent describing immediate repair of more extensive injuries involving the collateral ligaments (Bircher, 1933; Folliason, 1934; Merle d'Aubigné, 1935), but these early efforts were criticised (Böhler, 1935; Felsenreich, 1935) on the grounds that surgery was impracticable and in any case, unnecessary. It was generally affirmed that prolonged immobilisation of the knee would permit nature to effect a cure.

There was abundant evidence, however, that nature frequently fails in her purpose. Over a period of many years a mass of literature had accumulated around the problem of the lax unstable knee joint resulting from old ligamentous injury. The large number of the papers, and the variety of the methods recommended for restoration /

restoration of stability, suggested two things - first that conservative treatment of the recent injury was too often unsuccessful, and secondly that late repair of a damaged and incompetent ligament is difficult and unsatisfactory in result.

In 1938 Palmer published the first reasoned report on the mechanism of the ligaments of the knee, and at the same time presented a detailed description of the first significant group of cases subjected to critical clinical scrutiny, verified by exploration, and treated by immediate repair. With minor differences, his work has been confirmed by Brantigan and Voshell (1941, 1943). The main reason for the earlier policy of conservatism was uncertainty in diagnosis and lack of knowledge concerning the clinical effect of injury to the structures of the knee. Once the diagnosis was placed on a sounder footing, operation began to become more popular, and subsequently Valls (1939), Abbot et al. (1944) and Leger and Olivier (1945) have added contributions supporting immediate surgical repair.

These reports come almost exclusively from the Continent and the United States, and the subject seems to have received very little attention in this country. An indication of the persistent attitude of conservatism may be obtained from papers by Platt (1940) and Hight and Holmes (1943). These authors described between /

between them seventeen cases of severe ligamentous and capsular damage to the lateral side of the joint, associated with lateral popliteal nerve injury. Only two cases were subjected to exploration within three weeks of the injury. Highet and Holmes reported that in seven cases in which conservative treatment of the capsular damage was instituted, six retained serious lateral and antero-posterior instability of the joint.

There is no doubt that improvement on the end results of conservative therapy is very necessary. The knee joint, more than any other joint, requires stability as its primary attribute, and for its stability depends on the integrity of its capsular and ligamentous apparatus. Insufficiency of one or more of the ligaments usually results in serious disability which precludes a patient from indulgence in many of the normal activities of life, both in work and in play. Sooner or later the faulty joint undergoes degenerative changes which cause further permanent disablement.

Acceptance of early operation as a rational measure, and one likely to reduce subsequent disability, depends on the answers to four questions:-

1. Is surgical repair necessary from an anatomical standpoint?
2. Is repair technically possible?
3. Is the regenerative power of the damaged tissue such /

such as to render repair worth while?

4. Is operative repair justified by improved end-results?

Regarding the first of these, several cases have been described in which wide displacement of ruptured structures has been discovered. If such a state of affairs is the rule, it is a very strong indication for surgical restoration of anatomical position, and it is a very obvious reason for the failure of conservative treatment.

The feasibility of operative repair is governed by the nature of the tissue itself, and the damage that is inflicted on it. Can a ruptured ligament be replaced and held satisfactorily in position? There is evidence to show that in the case of the collateral ligaments, at least, the tissue lends itself readily to accurate repair. The cruciate ligaments are a more complex problem, and in severe combined injuries in which there is already extensive damage to collateral ligaments and capsule, it is questionable whether the wide additional exposure that is necessary in order to achieve repair, is justifiable. In such cases, however, it may be well worth while repairing the collateral damage.

The third question involves the problem of healing. It may be that injury so affects the blood supply /

supply or the structure of the tissue, that cellular reaction is impaired and all therapeutic measures are doomed to failure. All investigations up to the present, have been confined to the clinical and mechanical aspects of ligament damage, and to the macroscopic effects of the injury. There is no information regarding the process of repair, which appears to be taken for granted whatever form of treatment is recommended. It has not been established that a ligament can, in fact, heal sufficiently firmly to resume its normal function.

However strong the theoretical indications may be, the ultimate justification of any operative procedure must be proved by results. As yet, there is too little information on the follow-up of cases for any assessment to be made. Palmer, for instance, includes among thirty-one cases of assorted ligament injuries treated by early repair, eight which come under the category of severe combined injuries. Only three of these were observed after operation, and they only for a short time. Other authors submit small groups or isolated cases with very scanty information regarding the subsequent effect of operation.

Interest in these problems was aroused by experience of a large number of knee joint injuries of varying nature and severity, provided by the unusual conditions /

conditions of active service. As a result, a series of experimental investigations was planned in which the detailed nature of injury to ligament tissue, and the subsequent process of healing could be studied. Part I of this communication is devoted to an account of these investigations and a discussion of the findings in application to the clinical problem. Part II contains a report of nine clinical cases which have been selected as a corollary to the experimental work, and as a further contribution to the knowledge of severe ligament injuries and the result of operative repair.

PART I

INVESTIGATION INTO THE EFFECT OF

EXPERIMENTAL RUPTURE OF THE MEDIAL

COLLATERAL LIGAMENT, AND THE

SUBSEQUENT PROCESS OF HEALING

PROLOGUE

"A ligament never heals."

This chance remark, passed by a prominent orthopaedic surgeon during a visit to his clinic, lingered irritatingly in the memory. It was said casually, in justification of an operation to fuse the acromioclavicular joint in a case of severe dislocation, and in its context, may have contained a germ of truth. The injury is a notoriously difficult one to treat successfully. But as a generalisation, it seemed to nullify all aspirations in the treatment of ligament injuries in other parts. Whatever its value, it drew attention to a problem, and it was largely responsible for promoting the following investigation.

OBSERVATIONS ON ANATOMY AND PHYSIOLOGY

Structure

Ligament tissue consists of a compact formation of collagen fibres firmly bound together in parallel bundles. Individual fibres branch and unite with one another, and so, to some extent, do the bundles, so that an interlacing effect is produced. In normal undamaged ligament tissue the fibres are practically straight, and rarely show any of the waviness which is the feature of collagen fibres in loose connective tissue.

Cells are present in very small numbers and are sparsely scattered between the fibres. They present a spindle-shaped or oval appearance and have the characteristics of fibroblasts.

Between the fibre bundles there is a very thin layer of connective tissue, sufficient to carry small capillary vessels and to allow a little gliding movement between the bundles and so permit flexibility. The quantity of connective tissue varies in different situations, according to the requirements of mobility in various ligaments. In the conoid and trapezoid ligaments for instance, where universal movement is necessary, there is a higher proportion than in the medial collateral ligament of the knee, where little movement of the ligament is required. In the latter the /

the fibres are very densely packed.

The presence of elastic tissue in the ligament itself is an arguable point. Maximov and Bloom (1938) claim that there is a fine elastic network between the bundles, while their presence is denied by other workers. Palmer states that he found elastic tissue only in the superficial fibres of ligaments. In the present study a special search was made, but in none of the preparations of human or animal material was any evidence of elastic tissue found in the actual ligament, though it is present in the investing layers of connective tissue.

The intrinsic structure and grouping of the bundles of fibres, and their arrangement at the attachments of ligaments to bone are variable according to the method in which a particular ligament performs its function. In the human knee joint, the main part of the medial collateral ligament forms a long band which moves very little in relation to the tibia when flexion and extension of the joint occurs. In the lower half, the main fibres are parallel, and remain so down to their attachment to the tibia which occupies a relatively large area. At the upper end, the femur rotates freely about an axis which approximates to the point of insertion of the ligament. Here the ligament fibres fan out slightly to be inserted into a crescentic- /

crescentic-shaped area on the femoral condyle, while just below the insertion there is a criss-cross arrangement of the ligament bundles. This cunning arrangement of the fibres has the effect of maintaining relative tautness in the ligament throughout the whole range of movement (Fig. 1). When the knee is flexed only the anterior fibres of the upper attachment are stretched. When it is extended, the posterior fibres become taut. Owing to the criss-cross pattern, in either position tension is transmitted to the major part of the ligament below.

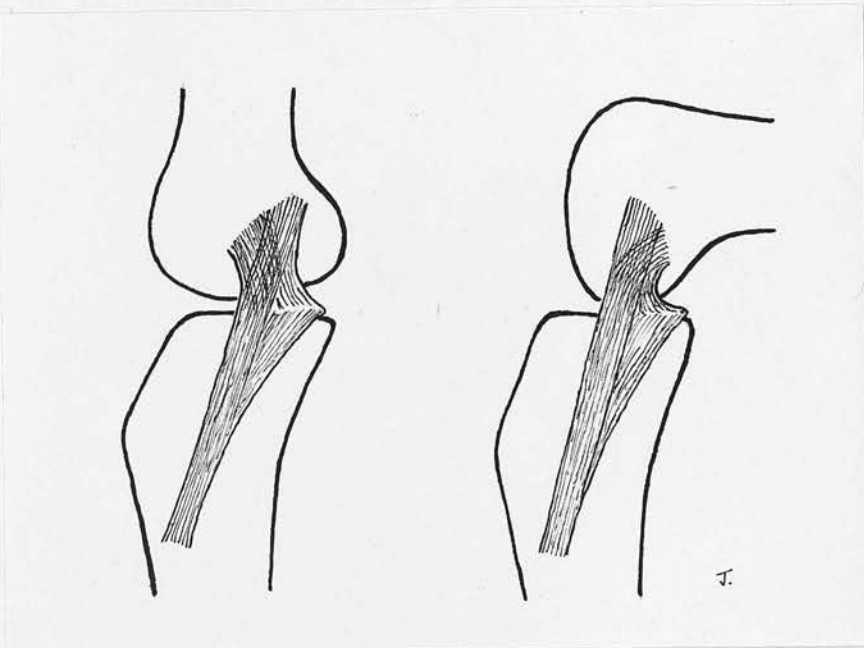


Fig. 1. Diagram to show the method of attachment of the femoral end of the medial collateral ligament, and the action of the fibres in flexion and extension.

The cruciate ligaments are short, but have a somewhat similar anatomical arrangement of fibres. The fibres run upward from the tibial attachment in a slight spiral, rather like the stalks in a sheaf, and fan out to be attached to the femoral intercondylar notch in a crescentic outline, roughly corresponding to the axis of rotation of the femoral condyles. The effect of this arrangement is that part of the ligament is taut throughout the range of movement. The fibular collateral ligament pattern is almost the same as that of the medial collateral at the upper end, although tension is somewhat relaxed in this ligament on flexion of the knee.

In all four ligaments it is the femoral attachment which is responsible for adapting the ligament to alterations in position of the joint. The tibial attachment has very little action in movement. This point may be important in determining function after injury.

Blood Supply

Normal adult ligament tissue seems to require a negligible quantity of blood for its maintenance. Examination of a section of ligament microscopically gives the impression that the tissue is practically avascular. It is rare to see a vessel of any sort. After /

After injection of Indian ink into a main vessel, careful dissection will show a few small capillaries running longitudinally throughout the length of the ligament in the scanty loose connective tissue which separates the collagen bundles. There is practically no branching, or intercommunication between the capillaries. They are most evident near the superficial surface of the ligament, and trail off towards the extremities where the ligament is attached to bone. There is very little evidence that any blood reaches the ligament through vessels which communicate direct from the bone. In a number of specimens examined, no sign of ink could be found at the insertions, either on naked-eye or microscopic examination. The blood supply at this point seems to be minimal.

The most impressive feature in dissecting the collateral ligaments of the knee, after Indian ink has been perfused, is the demonstration of the loose connective tissue which invests the ligaments and covers the whole fibrous capsule of the joint. This tissue, although evident on microscopic examination, is not very noticeable in a straight dissection either on the cadaver, or at operation. But after ink has been injected, layer after layer of fine tissue, outlined clearly by its generous network of capillaries, must be stripped away before the firm collagen tissue is exposed /

exposed. This loose connective tissue forms a sheath about the collateral ligaments and joint capsule which permits free gliding movement beneath the overlying structures. The sheath is highly vascular, deriving its supply from branches of the circulus vasculosus and geniculate vessels which run over the surface of the capsule, and it is from this sheath that the capillaries in the ligament are fed. Several small twigs from the deeper layers of the sheath enter the substance of the ligament at various points along its length, mainly on the superficial surface and towards the extremities (Figs. 2, 3 and 4).



Fig. 2. Drawing of a dissection of human medial collateral ligament after perfusion of Indian ink. Anastomosis of branches from circulus vasculosus and geniculate vessels is shown supplying longitudinal capillaries in the superficial layers of the ligament. The areolar layers have been almost completely removed.

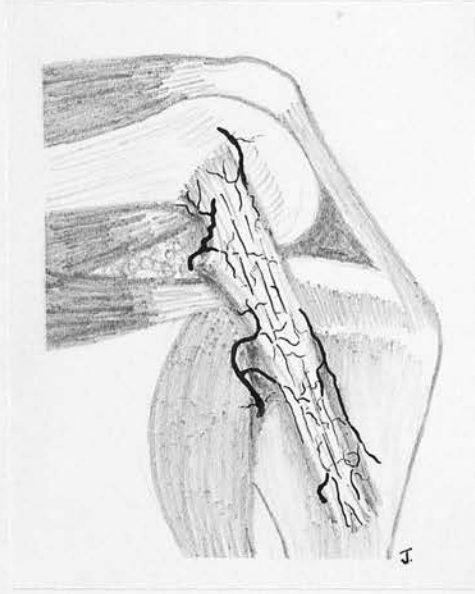


Fig. 3. Medial collateral ligament of a cat for comparison. The deeper areolar layers remain, showing free anastomosis of fine vessels. The pattern of supply is very similar to that in Fig. 2.

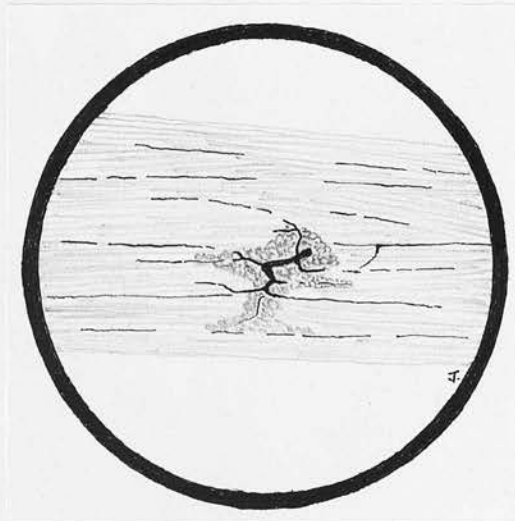


Fig. 4. Low power magnification of human medial collateral ligament to show parallel capillaries between fibre bundles, and a small vessel entering the surface through a fragment of sheath which remains adherent.

Palmer has stressed the importance of the blood supply to the collateral ligaments from the synovial reflections above and below the meniscus. The collateral ligaments are related to synovial membrane for a very small part of their length, but there is certainly a small contribution to the deeper layers of the medial collateral ligament which may be of some significance. The vascular reaction after injury was particularly studied in the experimental specimens to be described later. Rupture of the upper end of the medial collateral ligament was usually accompanied by damage to the synovial reflection above the meniscus and by a tear along either side of the ligament to the level of the joint. Several of these examples showed avascular necrosis of the torn end of the ligament, which affected the deeper layers constantly. Revascularisation started in the superficial layers, due no doubt to the free blood supply in the areolar sheath. These specimens confirmed the absence of blood supply through the bony attachments.

The blood supply to the cruciate ligaments is also a surface supply derived from the synovial membrane which covers the posterior cruciate and most of the anterior cruciate ligament. Towards the lower attachment of the anterior cruciate ligament the membrane thins out and disappears, so that the supply to the lower /

lower end of the ligament must reach it through longitudinal capillaries in the substance, which come from the upper half. Injection of Indian ink was noted to be most intense on the surface of the upper femoral part of the anterior cruciate ligament, and tailed off toward the tibial attachment. Palmer quotes Pfab in stating that ruptures at the upper end of the anterior cruciate ligament frequently result in early atrophy and disappearance of the ligament, due to interruption of the blood supply from the femoral end.

Nerve Supply

From a histological point of view, dense collagenous tissue is difficult material to work with, and very unsuitable for the demonstration of nerve fibrils and nerve endings. Penetration of stains is poor and the firm, hard, but friable fibril bundles make poor specimens. For this reason detailed information on the innervation of ligaments is scanty, and is likely to remain so until more reliable staining methods have been evolved. The standard histological authorities (Carleton, 1934; Maximov and Bloom, 1938) tend to group tendons and ligaments together and suggest that various types of nerve endings occur, including Pacinian corpuscles, Ruffini bodies and Golgi bodies. A few workers have studied the innervation of joints in /

in detail. Amongst them Sfamini (1902) traced nerve fibres along blood vessels into ligaments and synovial membrane, and found nerve endings which he classified as Ruffini plaques. He found no Pacinian corpuscles. Oda (1935) studied foetal joints in man, rabbit and mouse and described myelinated and non-myelinated axons accompanying vessels, and ending in capsular ligaments and synovial membrane. More recently Gardner (1942) using a complicated staining technique in the joints of mice, confirmed the presence of nerve fibres along with the blood vessels, and described special nerve endings in the connective tissue of the capsule, and Pacinian corpuscles especially at the ligamentous attachments and periosteal reflection.

Several specimens of human and animal ligaments have been examined after staining by Kultschitsky's method, and the intravital methylene blue technique of Woollard. Nerve fibrils have been seen running in the substance of a ligament and crossing the collagen bundles, but only a very occasional nerve ending has been demonstrated, and it is not possible to add anything further concerning the distribution or type of endings in ligaments. The presence of nerve elements however, is confirmed.

Function of Ligaments

In /

In general, the function of a ligament is to guide a joint through its normal range and to check abnormal movement. Where a wide range of universal movement is present, as for instance in the hip joint, a particular ligament may be relaxed throughout much of the range, and become taut only when the movement which it controls reaches its extreme. The ilio-femoral ligament is quite slack in flexion of the thigh but tightens in full extension and abduction.

In the case of the knee joint, movement occurs, except for a minor rotatory range, in one plane only, and the ligaments are designed to stabilise the joint in that plane. Any tendency to abduction or adduction brings them into activity, and they similarly prevent forward or backward displacement of the condyles in relation to one another. It is not proposed at this stage to enter into a discussion of the detailed function of each individual ligament. The matter is outwith the present argument. It suffices to state here that throughout flexion and extension of the joint, part of the ligamentous system is constantly in action, guiding movement in its permitted direction and preventing any departure from the normal range.

The medial collateral ligament is perhaps paramount in this protective action, due to its anatomical position across the medial side of the joint. Normal slight /

slight valgus angulation at the knee tends to throw most strain on the inner side, and during the course of a day this ligament must be placed under great tension on innumerable occasions. In the resting position the ligament is not under tension. If it is divided at operation, the cut ends do not spring apart, and they can be approximated without difficulty. But if any attempt is made to produce abduction of the tibia on the femur, the fibres become tense immediately owing to the inelastic nature of the ligament tissue, without allowing any significant separation of the joint surfaces. The abnormal movement is checked before momentum is allowed to develop. When one considers the weight of an adult acting at the end of a long lever such as the femur, it is inconceivable that this strip of tissue can withstand unaided the strain placed upon it. Four inches long, half an inch wide, and less than a quarter of an inch thick, the tissue though admittedly very strong, is quite obviously out of proportion to the task, were it to act simply as an inert stay-wire across the side of the joint.

Ever since Payr (1927) produced his theory of the "Kinetic Chain" in which ligaments act as receptors in a reflex arc which ends in the muscles controlling the particular joint, his paper has been quoted in most /

most articles dealing with the function of ligaments and the maintenance of posture. In the standard textbooks and the special literature, there are many allusions to the interaction of ligaments and muscles. It has been commonly accepted that tension in a ligament sets up a train of nervous impulses, which result in a contraction, or increase of tone, in the group of muscles which will relieve the strain on the ligament (Johnston, 1935; Mitchell, 1947).

As far as can be ascertained, there is no record of physiological experimental work to bring actual proof to this theory which is demanded by the physical properties of ligaments, and by everyday clinical observation of joint function.

In the absence of scientific proof, there is nevertheless, abundant circumstantial evidence. Comparatively minor trauma to the medial collateral ligament results in increased muscle tone, or spasm, in the flexor groups, which limits full extension of the joint, - the position in which tension is greatest. In examining a case with a minor sprain, one has only to apply sudden abduction movement to the leg and feel the abrupt, involuntary snap back into position, to realise that this is due to an active reflex muscle contraction. Localised infiltration of novocaine into the ligament abolishes the muscle spasm by interrupting /

interrupting the reflex. On the other hand, if damage to the ligament has resulted in complete rupture, abduction can usually be applied without any muscular resistance, due no doubt to the fact that tension is no longer produced to initiate the stimulus. In the old-standing case, in which a complete rupture has healed by lengthened scar tissue, abduction to the limit of laxity in the ligament can also be easily demonstrated without any protesting response from the muscles. At the other end of the reflex arc, absence of muscle action allows unrelieved strain to fall upon the ligament alone, with the result that a previously healthy ligament yields and stretches. In a case of traumatic division of the tendon of tibialis posterior, a normal foot becomes completely flat in the space of a few months, due to stretching of the unassisted ligaments. The abnormal mobility in limbs affected by anterior poliomyelitis offers unlimited evidence of this phenomenon. Examples can be duplicated and reduplicated. From purely clinical observation, it may be confidently assumed that a ligament, per se, is incapable of performing its task without the coordinated function of particular muscle groups; that it acts, as it were, in the capacity of a sentry at a vulnerable point, and when tension rises, calls out the reinforcing action of its associated muscles to deal with /

with the situation.

This vital physiological function of a ligament must form an important consideration in the treatment of ligament injuries, and though it is so often quoted, is only too apt to be forgotten. It probably explains the disappointing results which attend operative replacement of unstable ligaments by grafted tissue. A transplanted strip of tendon or fascia lata can have no reflex nervous communication with the muscular system, and must act purely as a mechanical stay. There is little wonder that gradual stretch, with recurrence of instability, inevitably occurs.

Fig. 5. A and B. Normal knee joint. A, anterior view; B, posterior view.



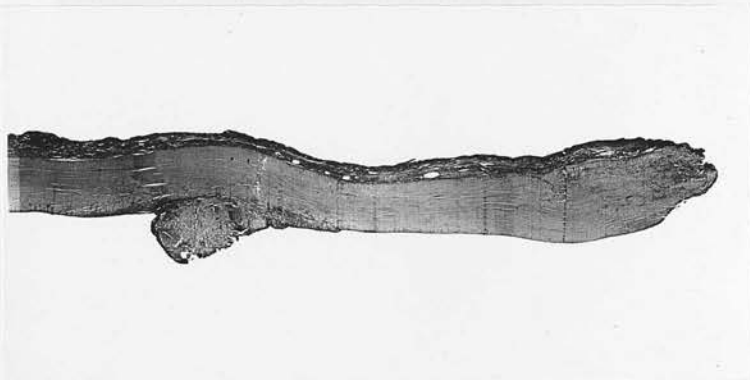
Fig. 6. A and B. Knee joint after ligament replacement. A, anterior view; B, posterior view.

THE PROBLEM OF REPAIR AFTER RUPTURE

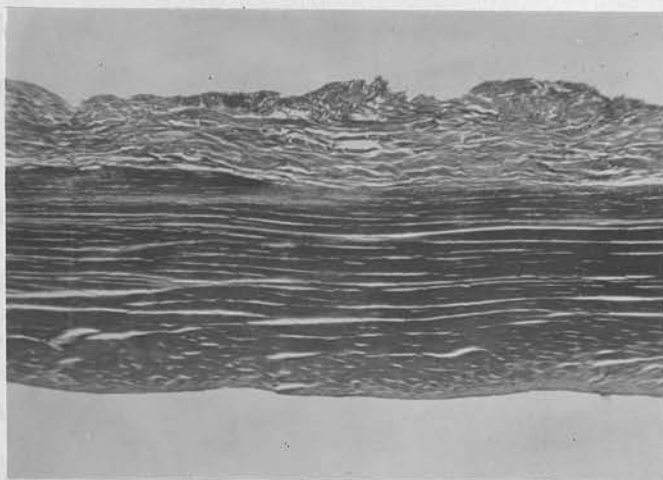
The salient features of anatomy and physiology which directly concern the process of repair and restoration of function after injury may be summarised from the preceding chapter.

The ligaments of the knee are composed of dense, inelastic, relatively acellular collagen tissue, with very modest metabolic requirements. The femoral attachment of each is of prime importance in normal function. The collateral ligaments are invested superficially by a vascular, loose areolar layer from which the main blood supply is derived. A small additional supply to the deep layers of the medial collateral ligament enters from the synovial reflections. The cruciate ligaments are supplied from the synovial covering. The nerve supply is an essential link in the reflex arc by which the ligaments are intimately associated with the muscles controlling the joint in the maintenance of stability.

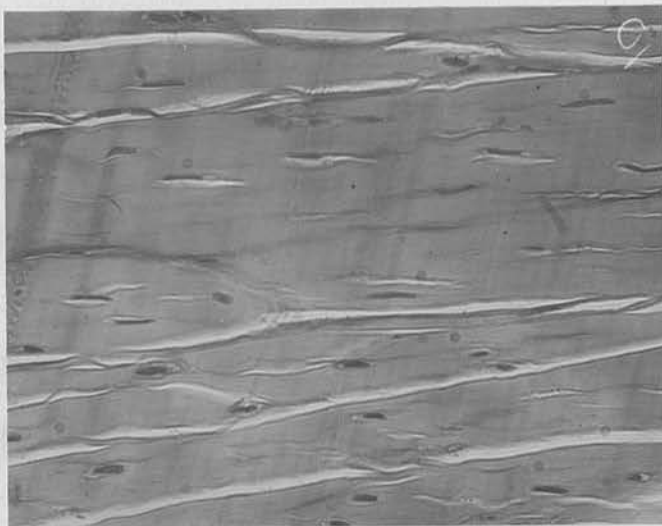
Fig. 5, A, B and C. Normal adult medial collateral ligament of cat.



A. x 5. Mallory. Upper half of ligament showing upper insertion and relation to meniscus.



- B. x 50. Mallory. Same ligament showing loose areolar sheath and fibre bundles. The animal was an old one, and the deeper layers of the ligament show hyalinisation - further evidence that the main blood supply is a surface one.



- C. x 400. Van Gieson. High power magnification to show paucity of cells and capillaries and high proportion of collagen.

Ligament tissue is very similar to that of tendons and, as has been stated, in most histological text-books the two structures are grouped together and described jointly as practically identical examples of regular connective tissue.

Healing in tendons has been very extensively studied by many investigators, and in this connection the work of Mason and Shearon (1932) is outstanding. It forms the basis upon which present day operative procedure for the repair of tendon injuries is founded. The conclusions at which these workers arrived are briefly as follows:-

When a tendon has been divided and then sutured, some retraction of the proximal end always occurs despite the suture. The gap between the ends fills with granulation tissue, which arises mainly from the investing layers of the loose connective tissue sheath. From the fourth day on, the cells of the tendon stumps begin to proliferate, and to form new collagen fibrils which migrate from the stumps into the granulation tissue. After two weeks, this proliferation of cells and fibrils has progressed to such an extent that the granulation tissue is largely replaced, and the gap is bridged by new tissue from the tendon ends. It is hardly possible to distinguish /

distinguish the original cut ends at this stage.

After three weeks, the gap is completely bridged by a fibrous-like strand of tissue composed of long parallel fibres continuous with those of the tendon, and oriented in orderly fashion in line with the pull of the tendon. The tendon is still vascular and very cellular, but has developed strength which will withstand a pull of many pounds. In time, cellularity and vascularity decrease, until the new tissue closely resembles normal tendon.

The value of longitudinal tension on the healing area, and relatively early function in the tendon, are stressed, both as a means of preventing adhesions, and as a stimulus to the longitudinal arrangement of the new fibrils. In reference to this, the work of Schwarz is quoted. He found that if a cut tendon is deprived of the stimulus of function by division of the nerve supplying the muscle, the wound heals by loose fibrous scar, which does not at all resemble normal replacement tissue.

These workers also note the disrupting effect of sutures in the healing stumps. The presence of the suture material has an adverse effect on the orderly proliferation of tendon tissue /

tissue.

In so far as ligaments and tendons are composed of virtually identical tissue, are relatively avascular, and are invested by a vascular loose connective tissue sheath, the process of healing in the two structures should run closely parallel. There are, however, certain definite physical differences which may modify the picture. A tendon is usually divided cleanly by a sharp instrument, whereas a ligament is torn by longitudinal tension which may cause gross disturbance of fibres over a wide area, or may interfere with blood supply. A ligament is not subject to the constant pull of a muscle, and therefore retraction of the ends should not occur. Neither is it subject to the beneficial effect of tension in stimulating regeneration and healing. Slight elongation of a tendon is of little consequence, as the muscle can take up slack. Elongation of a ligament will cause incompetence, and in the knee joint, instability will result.

DESCRIPTION OF EXPERIMENTAL PROCEDURE

Experimental rupture of a ligament and subsequent study have been carried out in nineteen limbs. In the first two experiments, dogs were the animals selected. Partly due to short supply at the time this work was started, but mainly because dogs as a general rule are far too active after operation and immobilisation is difficult, further work was performed on cats. In every case the medial collateral ligament of the knee was used. This ligament is accessible, easily traumatised, and anatomically comparable to its human counterpart. The mechanics of the knee joint in dogs and cats are admittedly rather different from those of the human joint, and no inferences will be drawn regarding the mechanical action of these ligaments, or the effects of injury on the ligament system as a whole. Observations on the reaction of the medial collateral to injury, and the process of healing that follows, should be applicable to the human ligaments.

In each case, the animal was anaesthetised with ether, and the medial collateral ligament was ruptured manually by sudden abduction of the tibia over the edge of the operating table, with the leg held in full extension. This was the only position in which sufficient stability of the femur could be obtained to /

to permit rupture. If the knee was held in the flexed position violence simply rotated the femur. The medial collateral ligament ruptured every time without fracture at the bony insertions.

Operation was then performed under aseptic conditions. The broad insertion of the pes anserina group, which covers the inner side of the knee joint of a cat, was divided at its musculo-tendinous junction to expose the ligament, and the nature of the damage was noted. The loose connective tissue sheath was respected as far as was compatible with ascertaining the extent of the injury. In some cases the ligament was smoothed straight, in others it was left just as it was found. Sutures were used in one instance only, as it was found that the disrupting effect in the small amount of tissue was very marked, and was apt to interfere with healing. The muscles and skin were then repaired and sealed, and the animal returned to its cage.

In the case of the two dogs, immobilisation by plaster of Paris was instituted, but this was not very satisfactory and caused a good deal of discomfort and irritation. Immobilisation was not used for the cats. They were kept in small cages where there was little room for activity. They proved to be very quiet animals in contrast to the dogs, and were apparently content /

content to lie still all day. A certain amount of movement must, however, have occurred in the joint from the beginning, and this fact should be taken into account.

Subsequently at intervals ranging from four hours to twenty-one weeks, the animals were killed and the ligaments once more exposed. After inspection they were carefully dissected out, detached from insertions to bone, and removed complete for microscopic study. The ligaments were mounted and cut longitudinally and sections were prepared with Mallory, Trichrome and van Gieson stains. The Mallory stained sections provided an unusual feature. Collagen fibres are normally stained blue by Mallory's method, but in adult undamaged ligament the tissue stains red. A short time after rupture the tissue alters in some way, possibly owing to the vascular changes, and the fibres stain a deep blue. As healing progresses and the tissue begins to approach normal, the red reaction returns. The colour of the fibres was some indication of the progress of healing.

EXPERIMENTAL DETAIL

In this detailed account of the naked-eye and microscopic features, the experiments will be described in order, according to the interval between injury to the ligament and recovery of the tissue.

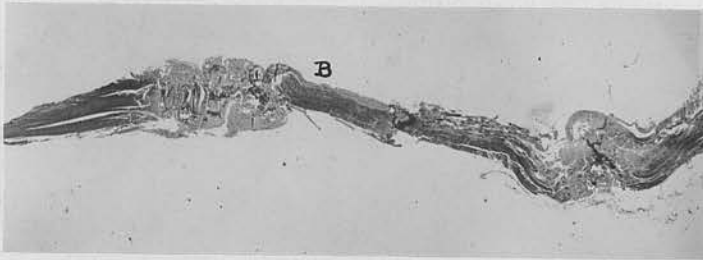
Cat 9 (L) - Immediate. The right ligament of this cat had been ruptured some weeks previously. The animal was killed by chloroform and just before death the left ligament was ruptured by forcible abduction. The knee joint was recovered and all tissues dissected off the ligament. The specimen was fixed in formalin and photographed and the ligament was then removed for section.

Rupture occurred at the femoral insertion and the ligament recoiled downwards so that a gap of more than five millimetres was left between the upper end and the point of insertion. The synovial membrane was open above the meniscus. One small bundle of fibres remained attached above and had ruptured at a lower level. The whole ligament was curled like a snake almost down to the lower insertion. Separation of the bundles into strands was noted throughout the whole length.

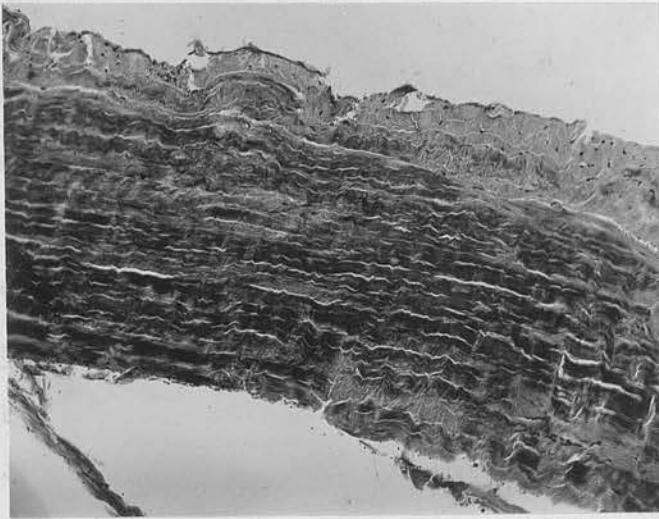
Microscopic Examination - Section showed the
gross /

gross curling at two main points. The upper end had ruptured fairly cleanly and the fibres terminated at much the same level. The effects of the injury were evident throughout the whole length of the ligament, excepting only the lower insertion where the structure was normal. Elsewhere the fibre bundles were separated to leave spaces between them, and the individual collagen fibres assumed a fine wavy appearance. The collagen stained red. The connective tissue sheath had been removed for photography and was not seen.

Fig. 6, A and B. Cat 9 (L). Immediate.
B. Upper end tear.



A. x 3. Trichrome. Gross curling of the ligament and disruption of the fibre bundles throughout most of the length.



B. x 50. Trichrome. Medium power through the point marked B shows separation of fibres and fine waviness.

Cat 8 (L) - Four hours. In the course of another experiment the left ligament was ruptured. Four hours later the animal was killed and the ligament inspected and recovered.

The rupture was a long oblique one in which the main tear crossed the ligament from the upper anterior to /

to the lower posterior corners, dividing it into two long triangular strips. The two insertions remained intact. The loose connective tissue sheath was intact, and at first sight the ligament appeared to be simply stretched and curled, without any actual rupture of continuity. On removal of the sheath the nature of the tear became evident.

Microscopic Examination - The specimen was exceedingly friable and difficult to mount and cut satisfactorily. A section was obtained which passed into the longitudinal tear above the joint line and demonstrated the lower half of the ligament. Red staining was seen only in small areas of minor damage. There was gross disruption of the fibre bundles with fine waviness throughout. The spaces between the bundles contained collections of red blood cells and there was dilation of capillaries in the substance of the ligament. The loose connective tissue was mainly stripped off, but a few small fragments showed oedema and round cell infiltration.

Cat 3 - Seven days. Routine rupture of left ligament. Rupture occurred at the upper insertion and the upper end was retracted almost to the joint line. The connective tissue was torn over the rupture. The ligament was curled up and very lax and separation of the fibres was noted along the whole length. The knee joint was open /

open deep to the ligament and a horizontal tear in the capsule three or four millimetres long extended anteriorly along the upper margin of the meniscus. The ligament was smoothed into position and the wound closed.

Exposure after seven days showed marked swelling and oedema of the connective tissue over the whole ligament. The ligament itself was red and swollen and the surface dull. Gross curling had not recurred following the smoothing out. The rupture area was filled with a blob of gelatinous haematoma with no strength, and the end of the ligament pulled away cleanly on very slight traction.

The specimen was lost and no microscopic examination was made.

Cat 4 (L) - Seven days. Routine rupture of left ligament and operative exploration. The connective tissue was intact in its outer layers and required division before the nature of the damage could be ascertained. Rupture occurred rather obliquely close to the lower end, where the fibres had torn at varying levels and were much frayed. The ligament was retracted upwards a little and was moderately curled. A stump of ligament tissue remained at the lower insertion. Some damage to fibres and separation of bundles was noted close to the upper end. The ligament was smoothed /

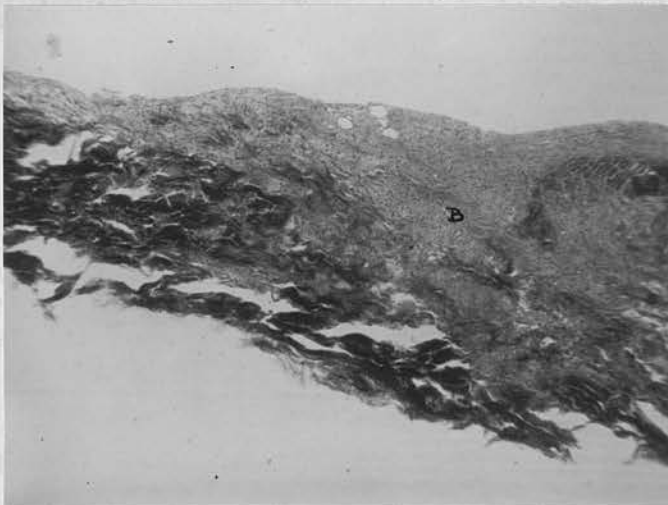
smoothed straight and the wound closed.

Recovery after seven days. There was much oedema of the connective tissue sheath over the whole ligament, and hyperaemia of the ligament which had remained straight. An area of granulation tissue covered the lower end. This had a certain strength and by careful dissection it was possible to remove the ligament intact, including the granulating zone.

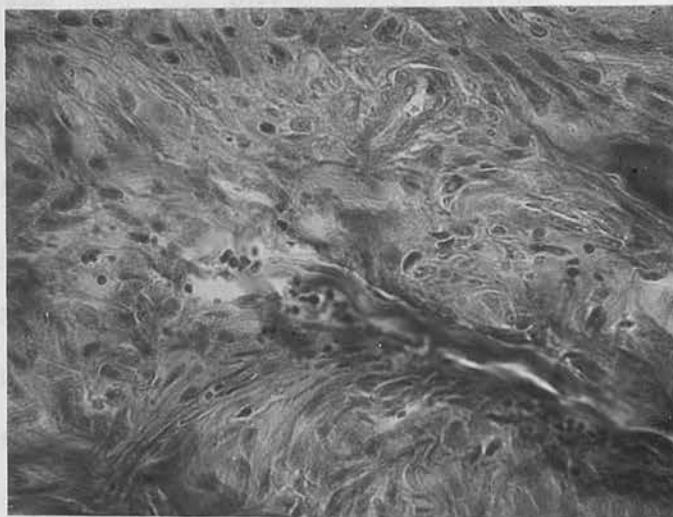
Microscopic Examination - The section showed the whole length of the ligament including the rupture zone and the lower stump. The fragile tissue had broken up slightly under the microtome. Damage was fairly widespread, and apart from a small intact area in the centre, red staining had disappeared and the whole ligament was coloured blue. At the upper end, and in the part adjacent to the rupture, the bundles were separated and broken up and the fibres were finely wavy. The spaces were filled by masses of cells, mostly fibroblasts with a roughly parallel arrangement. Extravasated red cells were still evident and several small haematomata still present. Blood vessels were numerous and the ligament cells increased. The areolar coverings were thickened and highly cellular. The gap between the ruptured ends was filled with a mass of highly cellular granulation tissue which dipped into it from the areolar sheath. This tissue surrounded and suspended the ragged collagen strands. Ligament cells /

cells between the torn fibrils were active and showed many mitotic figures, and from some of the strands there was evidence of proliferation of new fibrils which branched out into the supporting callus.

Fig. 7. A and B. Cat 4. Seven days.
Lower end tear.



A. x 50. Mallory. The tissue has broken up in cutting the section, but the main rupture is shown. The gap is filled with granulation tissue callus from the areolar layers.



B. x 400. Mallory. A strand of ligament suspended in the callus is beginning to show proliferation of ligament cells and production of fibrils which reach out into the granulation tissue. Many mitotic figures are seen.

Cat 15 - Seven days. Routine rupture of left ligament and exploration. The connective tissue was damaged over the upper end of the ligament. Rupture had occurred at the upper end, with a longitudinal split down the posterior border of the main band, extending half way down the ligament to well below the joint line. The ligament was displaced downwards and forwards leaving a wide gap, and the upper end was curled down to the level of the joint. Disruption of bundles was marked in the upper half of the ligament. It was smoothed straight and the wound closed.

Recovery /

There was no attempt at healing.

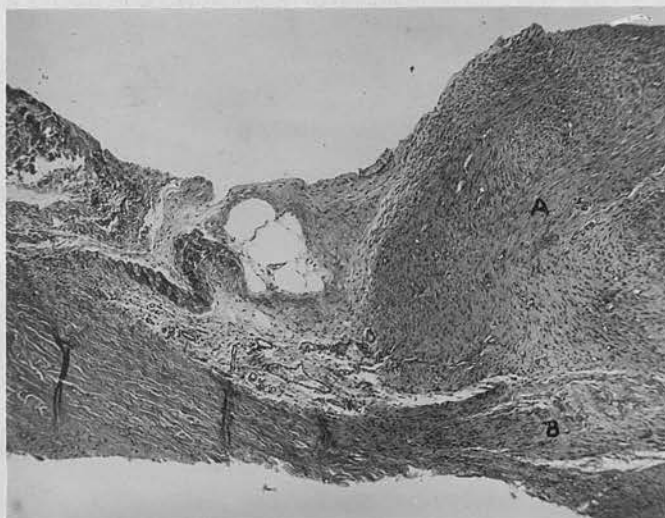
Cat 14 (R) - Ten days. Rupture of right ligament.

No exploration carried out.

Recovery after ten days. The ligament had ruptured at the lower insertion. The upper half looked quite normal and there was no reaction in the overlying tissues. At the lower end, localised to the rupture zone, there was a thick blob of granulation tissue.

Microscopic Examination - The upper half of the ligament was undamaged and showed no reaction. At the lower end the areolar tissue was thickened and vascular, and enclosed a large organised haematoma which filled the wide gap and overlay the torn end of the ligament. There was no semblance of orderly arrangement in the granulation tissue. There was an increase in the cells of the ligament stump, and evidence of proliferation of new fibrils which penetrated the granulation tissue for a short distance, and then trailed away and became lost.

Fig. 8. Cat 14 (R). Ten days. Lower end tear.



x 50. Mallory. The torn end of the ligament is displaced by a larger organising haematoma (A). Some proliferation is seen at (B), but the fibrils become lost in the haematoma.

Recovery after seven days. A fluid haematoma occupied the gap and covered the upper half of the ligament. The torn end was widely separated from its insertion and there was no evidence of healing. The ligament was removed for section.

Microscopic Examination - At the lower end some minor disruption of fibres was present. Increased cellular reaction and dilatation of vessels were noted. The connective tissue sheath was thickened and very vascular. At the upper ruptured end it covered a large, partly organized, haematoma which separated it from the ligament. About the centre of the ligament the superficial half contained many new blood vessels. The deeper fibres were avascular and showed no reaction. The vascular reaction in the superficial zone tailed away towards the upper end until in the upper few millimetres, where the haematoma overlay the ligament, there was not the slightest sign of vascular or cellular activity in the whole thickness. The collagen fibres ended abruptly with a few scattered red blood cells between them. Most of the deeper layers were quite inactive excepting for one small area opposite the synovial reflection above the meniscus. In the lower half the collagen stained blue, but at the upper end the red reaction was still present.

The appearances suggested that the blood supply to the upper half of the ligament was interrupted.
There /

Cat 8 (R) - Fourteen days. Rupture of right ligament and exploration. There was a long oblique rupture from the upper anterior to the lower posterior borders. Fraying of fibres was marked and the ligament was elongated and curled inside the areolar layer, which was intact. The wound was closed without disturbing the ligament.

Recovery after fourteen days. The whole ligament area was very vascular and much thickened. The areolar tissue was firmly adherent to the ligament and was divided along each side. The insertions were detached and the ligament and coverings removed. Union was firm and there was no tendency to tear away at the rupture.

Microscopic Examination - The section ran through the upper end of the ligament, entered the rupture which it traversed for half the length of the specimen, and then passed into more normal tissue at the lower end. There was not much disruption at the upper end where red staining persisted, but vessels were numerous and ligament cells increased progressively towards the rupture. The lower end was very vascular and more frayed. The covering tissues were greatly thickened and cellular. The gap was filled with highly cellular, very vascular callus, which showed a more or less longitudinal arrangement of its cells. The torn ligament strands were supported by this tissue, and from their /

their ends long leashes of proliferating fibroblasts and young collagen fibrils were seen penetrating into the granulation tissue with a horse's tail effect. Similar fibrils spread from the opposite side of the rupture until the gaps were practically bridged. Cellular activity was intense and many mitotic figures were seen. New strands could be followed through the whole length of the rupture.

Fig. 9. Cat 8 (R). Fourteen days. Oblique tear.



x 50. Trichrome. Leashes of new fibrils reach out across the rupture with a horse's tail effect, to meet similar fibrils from the opposite side. Note the intense cellular activity and general longitudinal arrangement of fibres.

Cat 14 (L) - Seventeen days. Rupture of right ligament and exploration. Rupture occurred at the lower insertion /

insertion and left no distal stump. Retraction was moderate and the ligament was slightly curled. A small area of bone was bared at the insertion. The wound was closed without disturbing the ligament.

Recovery after seventeen days. Curling had disappeared and the ligament was quite straight. The majority of it had a normal appearance, and there was little thickening of the areolar sheath except towards the lower end. Granulation tissue with moderate tensile strength filled the gap.

Microscopic Examination - Owing to twisting of the specimen in mounting, the section included the upper half and missed the ruptured zone. The upper half showed no significant change.

Cat 16 - Seventeen days. Rupture of left ligament and exploration. A long oblique rupture from the upper anterior corner to the lower posterior corner of the main band was found. Fraying along the rupture was marked but the fragments had not become much displaced apart from a little retraction. The connective tissue sheath was not torn. The ligament was smoothed straight and the wound closed.

Recovery after seventeen days. The whole ligament area was much thickened and oedematous and the areolar layers firmly adherent to it, and to the superficial muscular aponeurosis. The area was dissected /

dissected out in a block. Tensile strength was high.

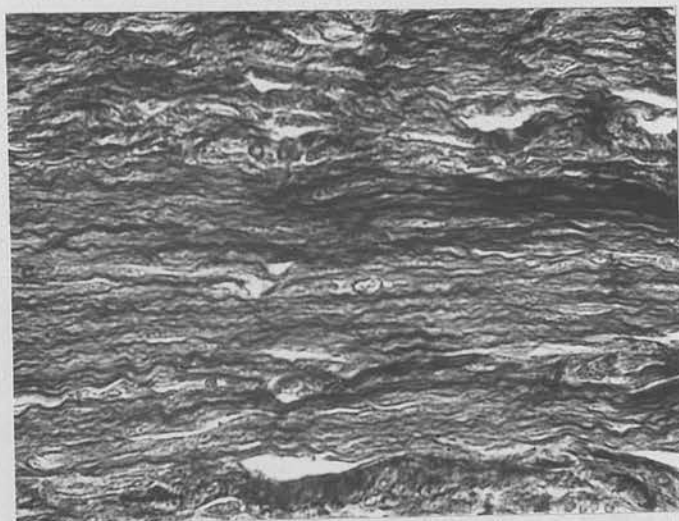
Microscopic Examination - The section passed longitudinally through the rupture which occupied the central half of the specimen. The two ends were not grossly distorted and showed an increase in vascular channels with many cells in the spaces. Ligament cells were increased excepting at the insertions. The areolar tissues were greatly thickened, very vascular, and presented a solid homogeneous appearance without evidence of layering. The rupture was filled with well-organised, very vascular callus, in which several strands of the ligament were suspended. From these, numerous leashes of new, slender, finely wavy collagen fibrils bridged the gap and linked one strand with another. Longitudinal arrangement was highly developed and could be followed through the whole length. Cellular activity and mitosis was very marked in the strands, and the new fibres seemed to emanate from the cells of the strands and to entwine the old collagen fibres. In most places it was difficult to distinguish the termination of the torn strands.

Fig. 10 /

Fig. 10, A and B. Cat 16. Seventeen days.
Oblique tear.



A. x 50. Mallory. Part of the rupture zone is shown under medium power. New fibres from both ends bridge the gap with regular longitudinal orientation.



B. x 400. Mallory. High power shows finely wavy new collagen fibrils surrounding and incorporating an original strand. Note many capillaries.

Dog 1 - Twenty-one days. Rupture of right ligament and exploration. The rupture occurred mainly behind the ligament in the inferior oblique fibres, probably because the leg was held in hyperextension when abducted. The main ligament was partly torn below the joint line, and on abduction in extension it slipped forward. The short fibres were torn from the tibial margin and the meniscus was detached from the tibia. The tear was repaired with fine silk sutures and the wound closed. Plaster of Paris was applied, but was not satisfactory. The animal was very active and tore away its plaster and the immobilisation was doubtful.

Recovery after twenty-one days. Inspection showed the silk to be buried in oedematous areolar tissue which was very thick. The ligament was removed but as the tear was mainly behind the longitudinal band the section was unsatisfactory. Inflammatory changes were very marked, possibly due to mild infection. The silk sutures were surrounded by large inflammatory areas and caused gross disturbance of the collagen strands.

Dog 2 - Twenty-one days. Rupture of right ligament and exploration. Rupture occurred obliquely near the lower insertion and left a good stump of ligament attached to bone. The upper part had retracted producing /

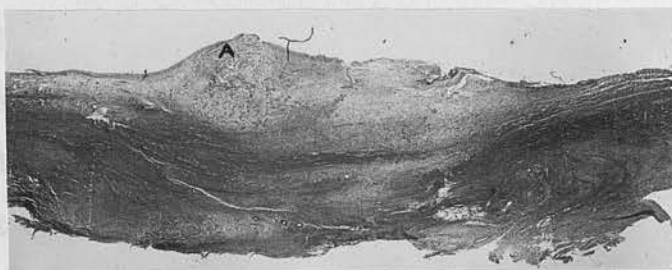
producing a gap of half a centimetre and the ligament was somewhat curled. The areolar layers were torn over the rupture. A small vertical tear at the joint line behind the longitudinal band, opened the joint below the meniscus. The ligament was smoothed into position and the wound closed. Plaster fixation of the limb was more satisfactory than in the preceding case.

Recovery after twenty-one days. The tissues were swollen and oedematous. The rupture zone was identified as a soft, rather translucent area compared with the firm ligament tissue. The ligament was straight and tensile strength seemed quite good. Lateral mobility was very slight.

Microscopic Examination - The section traversed the whole length of the ligament including the rupture zone and the lower stump. The upper half was little disturbed and stained red. Blood vessels were prominent, and towards the rupture cellular proliferation became evident. The ruptured zone was marked by a fusiform swelling consisting partly of thickened blue staining ligament tissue, but mainly due to a partially organised haematoma in the areolar layers. The gap was bridged by very vascular tissue consisting of very active fibroblasts and closely packed young collagen fibres with a finely wavy outline. The arrangement was strictly longitudinal and well-developed /

well-developed, and it was impossible to distinguish the original points of rupture of the ligament fibres.

Fig. 11. Dog 2. Twenty-one days. Transverse tear near lower end.



x 5. Mallory. There has been some retraction of the ends and the gap is now fairly completely bridged by new collagen fibres. A partly organised haematoma is seen in the areolar tissue at (A).

Cat 7 - Thirty-five days. Rupture of right ligament and exploration. A long oblique rupture involved the whole length of the ligament. The edges were frayed and there was moderate retraction with curling. No damage to outer layers of areolar sheath. Ligament left undisturbed and wound closed.

Recovery after thirty-five days. A few degrees of lateral rock were still present, but much less than immediately after rupture. The muscle was not adherent to the underlying connective tissue. This was moderately thick and fleshy. On removal, the ligament /

ligament was found to be in continuity, much thickened and dull on the surface, but apparently homogeneous. It resisted a strong pull.

Microscopic Examination - The section passed longitudinally through the rupture for most of its length. The ends were not shown. The tissue was dense and contained large numbers of capillary vessels. Old collagen strands were seen merging imperceptibly into newly formed strands which ran solidly throughout the length. The new fibrils were thicker than those noted in earlier specimens, much less wavy, and becoming arranged into bundles. Cells were numerous but much less so than in previous sections, and they were losing the rounded or oval shape and assuming the elongated spindle shape of ligament cells.

Cat 11 - Forty-nine days. Rupture of the left ligament and exploration. The ligament tore at the lower end, leaving a short stump with a few longer strands in the anterior margin which had ruptured at a higher level. There was a little retraction and the body of the ligament was tortuous at the level of the joint line. The upper end was undamaged and there was no fraying. The areolar sheath was not much disturbed. The ligament was smoothed straight and the wound closed. After operation the cat was very active and paced its cage most of the day.

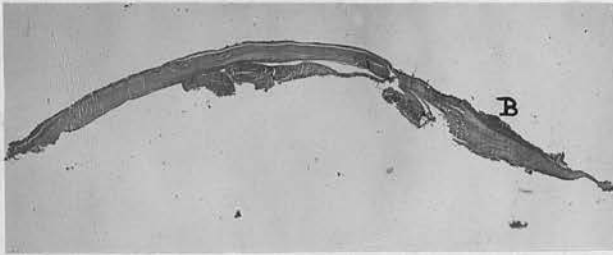
Recovery /

Recovery after forty-nine days. The knee was quite stable and no lateral mobility could be produced. The connective tissue over the ligament was slightly thickened and adherent at the lower end. Elsewhere it appeared normal and the layers moved freely on one another. The ligament was in continuity and presented a normal straight, smooth, shiny appearance. It moved freely on flexion and extension of the knee. There was a little thickening at the site of the rupture. Tensile strength was very good.

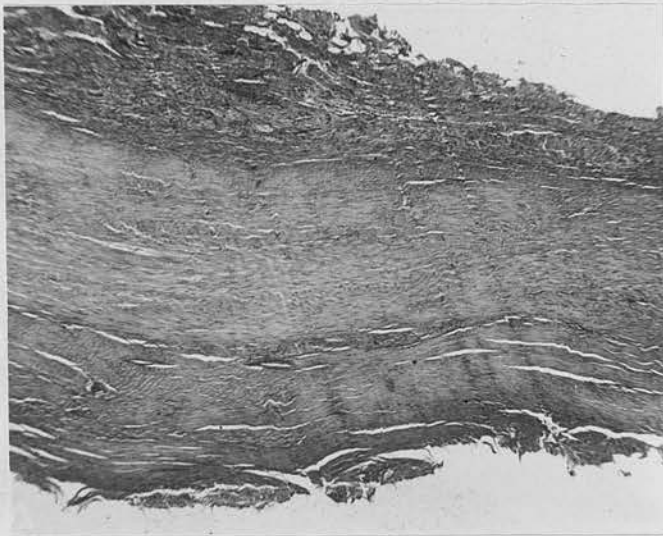
Microscopic Examination - The section showed the whole ligament, including the ruptured area and lower stump. Except for a little thickening of the areolar layers, and of the ligament at the lower end, it was difficult to distinguish under low power that there had been damage. Under high power the upper half was quite normal. About the level of the meniscus the ligament cells became rather more prominent, and increased towards the rupture. At the rupture the areolar sheath was a little thickened and more vascular than normal, but was beginning to separate into layers again. The ligament was composed of regularly arranged maturing bundles of collagen fibres in which the red staining reaction had almost completely returned. Cells were still numerous, spindle-shaped and elongated, and blood vessels were a little more prominent than normal. The new tissue was not far removed /

removed from normal ligament tissue.

Fig. 12. A and B. Cat 11. Forty-nine days.
Lower end tear.



A. x 3. Trichrome. The tissue has broken under the microtome, but the rupture is seen at (B), denoted by thickening of the ligament and the areolar sheath



B. x 50. Trichrome. The areolar tissue is still rather thick but is separating into layers again. The rupture has healed by regeneration of regular collagen tissue which now approximates normality. Cells and capillaries are still numerous.

Cat 13 (L) - Fifty-six days. Rupture of left ligament and exploration. Rupture occurred at the upper insertion leaving a few short ragged strands attached to bone. A vertical tear along the posterior border detached the upper end from its capsular attachments and extended down to just below the joint line. The joint was open above the meniscus. The upper end was retracted to the level of the meniscus and curled forwards. The whole ligament was tortuous and the bundles were disrupted. Wound closed after smoothing the ligament.

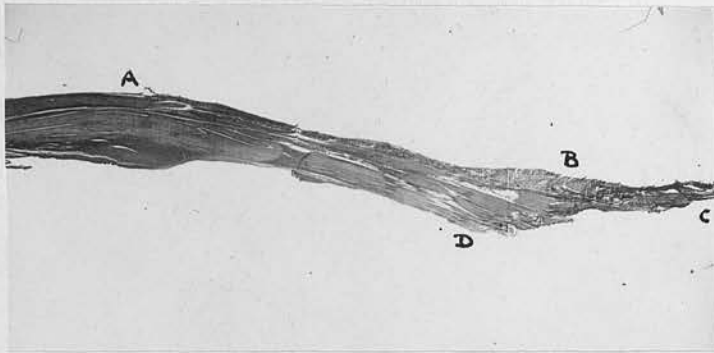
Recovery after fifty-six days. Definite lateral rock was present and the ligament was not tense. The lower two-thirds of the ligament were thickened. The upper third disappeared into a mass of scar tissue extending from the joint line to the upper insertion and involving the overlying connective tissue. This was adherent to the aponeurosis superficially and to the femoral condyle deeply, where it had become attached in the position of flexion. It pivoted with the condyle on movement of the knee, so that the ligament became bent when the knee was extended.

Microscopic Examination - The section traversed the whole ligament and ruptured zone, and showed no evidence of curling or waviness. The upper attachment consisted of a long area, three times the length of the normal /

normal attachment, consisting of the torn end of the ligament, a few strands at the normal insertion, and an area of intervening scar tissue mainly arising from the areolar sheath. A few very slender fibrils from the superficial strands had formed a tenuous bridge of regular collagen. In the upper third of the original ligament approximately two-thirds of the tissue on the deep aspect showed absolutely no cellular reaction. The strands stained palely red and were separated by empty spaces, and the fibrils had teased out in preparing the section. No vessels were present. The superficial one-third was rather more active with many small capillaries and round cells infiltrating the spaces between bundles from the surface. In contrast to this inactive zone the lower half of the ligament was very vascular and showed a great increase in cells. Between the ligament and the tibia, just below the joint, there was an area of scar tissue.

The appearances were those of ischaemia of the upper third with partial revascularisation superficially. Healing had failed.

Fig. 13. Cat 13 (L) Fifty-six days.
Upper end tear.



x 4. Mallory. The middle and lower parts of the ligament are thickened, cellular and vascular, and retain blue staining (A). The gap is bridged mainly by irregular scar from the areolar tissue (B). A few strands remaining at the original insertion (C) have formed a tenuous attachment to the superficial fibres of the ligament. The deep layers (D) stain palely red, and are completely inactive. Note the elongated upper attachment.

Cat 17 - Fifty-six days. Rupture of left ligament and exploration. There was an upper end rupture in which the findings were exactly the same as in the preceding animal - Cat 13 (L). In this case the ligament was left undisturbed.

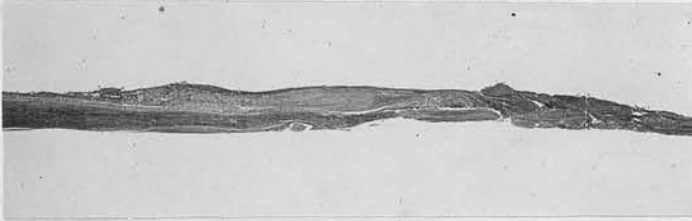
Recovery after fifty-six days. Lateral mobility was present. The upper two-thirds of the ligament area consisted of a mass of firm scar tissue adherent to the muscle, surrounding capsule and bone. No independent /

independent gliding movement was permitted and the scar pivoted with the femur. The lower part of the ligament was slack.

Microscopic Examination - The section showed the whole length from upper to lower insertion. The original ligament was a little thickened at the lower end and showed several small areas of damage, well healed by new regular collagen fibres. It was vascular and cellular. It narrowed and paled progressively towards the centre until just above the joint it petered out and disappeared. The dwindling fibres were not avascular and showed a moderate cellular reaction. The upper third of the section was composed entirely of irregular loose scar tissue continuous with the areolar layers, and there was no sign of regular collagen. The scar extended over the surface of the remains of the ligament for some distance.

Complete failure of regeneration. Healing by loose scar.

Fig. 14, A and B. Cat 17. Fifty-six days.
Upper end tear.



A x 4. Trichrome. Ligament tissue, seen on the left, gradually peters out, and is replaced in the upper third of the section by scar tissue. The areolar sheath is much thickened.



B x 50. Trichrome. The character of the loose irregular scar tissue at the upper third is shown.

Cat 10 - Sixty-three days. Rupture of right ligament
and /

and exploration. Long oblique rupture. The areolar tissues were not torn and before they were opened the ligament appeared to be simply stretched. It lay in an S-shape across the joint. Exposure revealed an oblique longitudinal tear from upper anterior corner to lower posterior corner of the long band. The two halves had slid apart and there was much fraying. The fragments were smoothed into position and the wound closed.

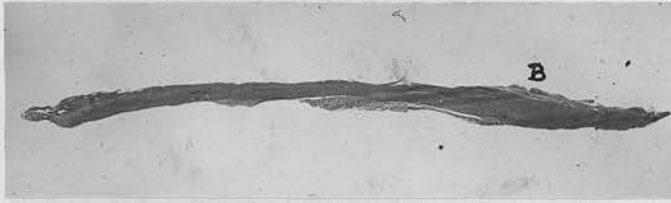
Recovery after sixty-three days. No lateral mobility could be demonstrated. The ligament was smooth and straight and not much thickened, and presented a shiny appearance. Thin filmy adhesions were present in the loose connective tissue but did not limit gliding movement which was normal.

Microscopic Examination - The section showed the whole length and crossed the rupture towards the lower end. There was a little thickening at the rupture, both of the ligament and the areolar sheath, but under low power the appearance was remarkably normal. High power showed that the rupture was healed by well-arranged, regular collagen fibres, maturing and becoming grouped into bundles. The staining reaction was red. Cells were numerous and were elongated and spindle-shaped. Vascularity was increased. In the upper part of the ligament capillaries were prominent, but otherwise the tissue looked normal.

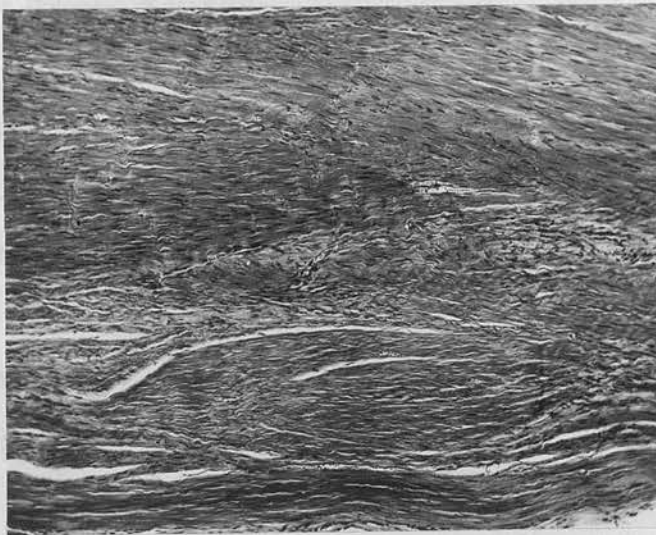
Firm /

Firm healing by regenerated regular connective tissue.

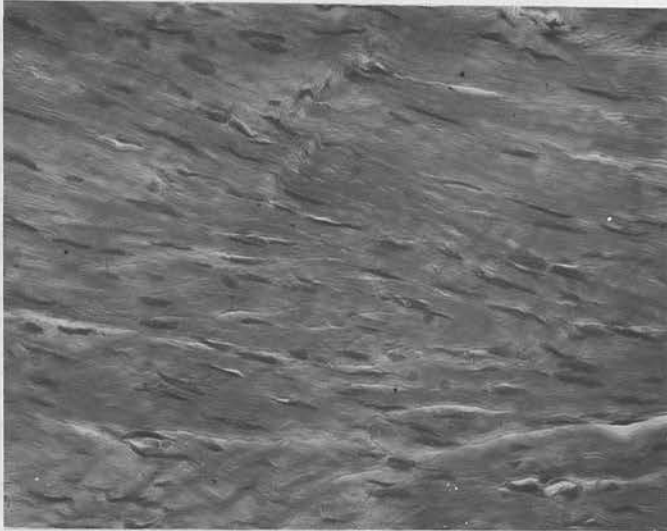
Fig. 15, A, B and C. Cat 10. Sixty-three days. Oblique tear.



A. x 3. Trichrome. Section has traversed the oblique rupture at (B) where ligament and areolar sheath are thickened.



B. x 100. Trichrome. Well orientated collagen tissue has repaired the gap and bundle formation is starting. Cells and vessels are diminishing.



C. x 400. Trichrome. Cells are assuming normal elongated spindle shape. Collagen fibres are losing the wavy outline and are consolidating into adult tissue.

Cat 18 - Seventy days. Rupture of left ligament and exploration. Rupture occurred at the upper insertion and, on opening the muscular aponeurosis, the torn end was found projecting through a hole in the areolar sheath just above the joint line. It was pushed back into its bed and smoothed straight through the loose tissue. Wound closed.

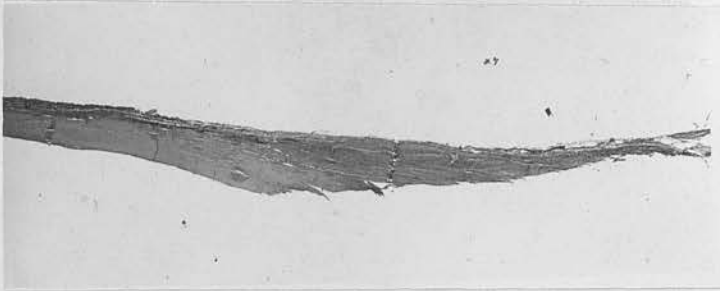
Recovery after seventy days. Slight lateral mobility was present. Thickening was found at the upper end of the ligament with moderate adhesions of /

of the loose connective tissue. The ligament appeared to be in continuity and presented a firm, slightly translucent appearance, at the rupture zone. It was not tense and the upper end pivoted to some extent with the femoral condyle on flexion and extension.

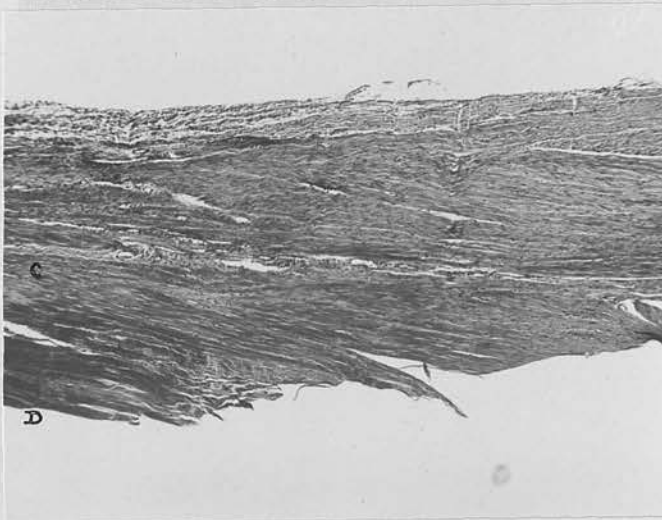
Microscopic Examination - The section showed the whole ligament and rupture site. The upper attachment was greatly elongated and consisted of a long triangular zone of new, longitudinally oriented, collagen fibres becoming grouped into bundles. Cells were numerous and were oval in shape. Capillaries were plentiful. At the extreme tip the arrangement became rather disorganised just before the new fibres merged with a tiny tag of the original ligament at the upper insertion. The new tissue originated from the superficial bundles of the torn end. The deeper fibres showed no reaction and were relatively acellular and avascular. Apart from slight increase in vascularity, the distal part of the ligament was normal.

Healing with some lengthening of the ligament by regenerated regular connective tissue. Ischaemia of a small part of the torn end, on the deep aspect.

Fig. 16, A, B, C and D. Cat 18. Seventy days.
Upper end tear.



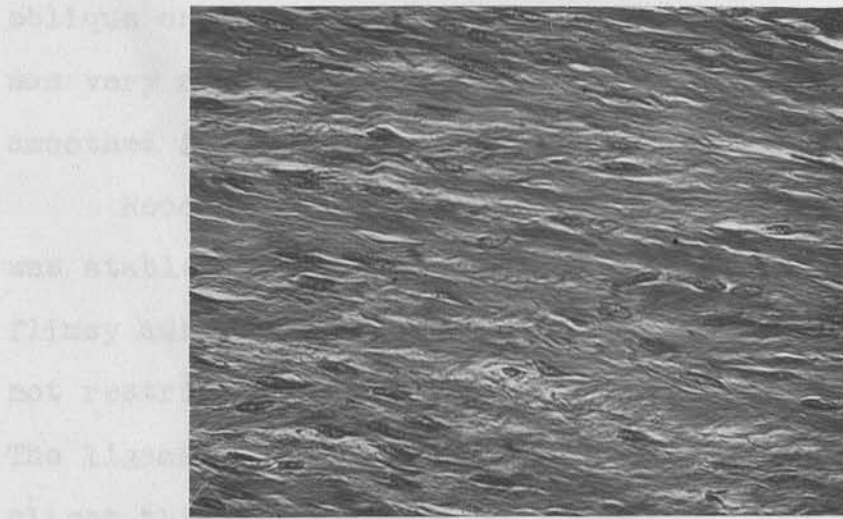
- A. x 4. Trichrome. The greatly elongated upper attachment is shown (compare with normal femoral insertion - Figs. 5A and 15A). Regenerated collagen fibres coming from the superficial layers of the original ligament have bridged the long gap. The deep fibres are inactive.



- B. x 50. Trichrome. The original end of the ligament is only distinguishable in the deep layers. Superficially the old and new tissue is continuous. The new fibres are well orientated and well differentiated from the areolar sheath which has separated into layers. Cells and blood vessels are numerous.

Oct 9 (18) - Seventy-seven days. Rupture of right

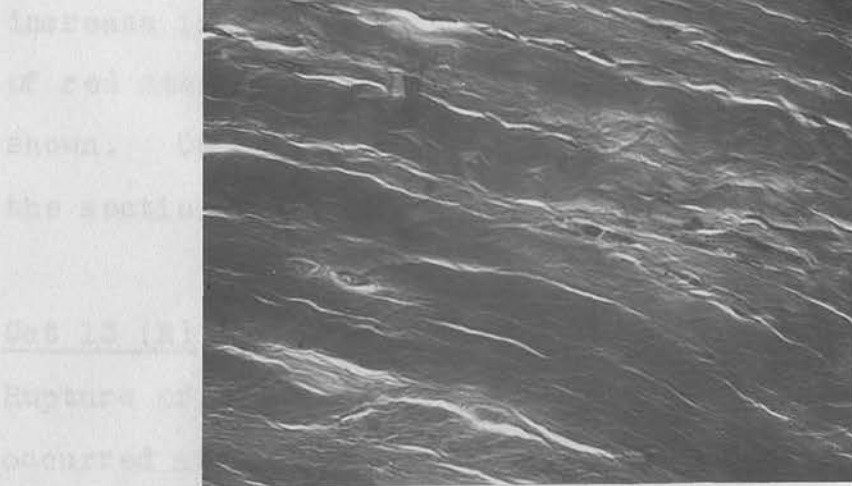
ligament and exploration. The rupture was a long



Microscopic Examination - The capsule was slightly

oblique and ran off the lower end of the specimen.

The upper part of the capsule was thin and contained a little



Oct 13 (18)

Rupture of

occurred

identical with that noted in the left specimen of this

animal. The ligament was completely ruptured.

C and D. x 400. Trichrome. High power magnification of the two areas marked on 16B. The contrast between the reactive vascular tissue and the closely adjacent ischaemic zone is marked.

Cat 9 (R) - Seventy-seven days. Rupture of right ligament and exploration. The rupture was a long oblique one in the usual situation and the ligament was very slack and tortuous. The two ends were smoothed into position and the wound closed.

Recovery after seventy-seven days. The knee was stable without lateral mobility. There were some flimsy adhesions under the aponeurosis, but these did not restrict normal gliding over the femoral condyle. The ligament was smooth and shiny and, apart from slight thickening, appeared normal.

Microscopic Examination - The section was slightly oblique and ran off the lower end of the specimen. The upper two-thirds were shown. There was a little increase in the cells and capillaries. Firm bundles of red staining collagen ran the length of the part shown. Owing to the oblique cut it was uncertain that the section included the actual rupture zone.

Cat 13 (R) - One hundred and forty-seven days. Rupture of right ligament and exploration. Rupture occurred at the upper insertion and the damage was identical with that noted in the left ligament of this animal. The ligament was smoothed straight.

Recovery after one hundred and forty-seven days. The ligament was straight but was not tense and lateral mobility was fairly marked. Adhesions fixed the /

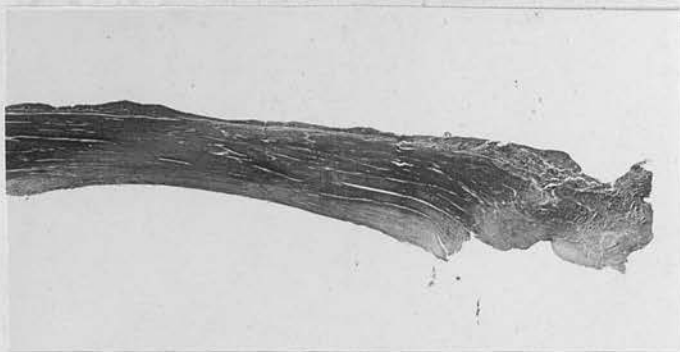
the upper third in relation to the femur and the capsule, and when the knee was extended the ligament became curved. In flexion the lower half of the ligament was slack and it tightened up in extension as the scar moved round with the femur. Scar tissue was evident at the upper end.

Microscopic Examination - The section traversed the whole ligament and rupture area. Even at this interval the ligament was highly cellular throughout its length and the vessels were greatly increased. The upper insertion was elongated and consisted of irregular scar tissue in which the torn end terminated rather abruptly at some distance from the tip. The deep fibres, composing one-third of the thickness, were completely inactive, contained no capillaries and few cells, and were not included in the scar. Superficially many capillaries invaded the ligament from the areolar sheath, and small round cells were numerous.

Healing by irregular scar with no regeneration of ligament tissue. Evidence of ischaemia of torn end with superficial revascularisation.

Fig. 17 /

Fig. 17, A, B and C. Cat 13 (R). One hundred and forty-seven days. Upper end tear.

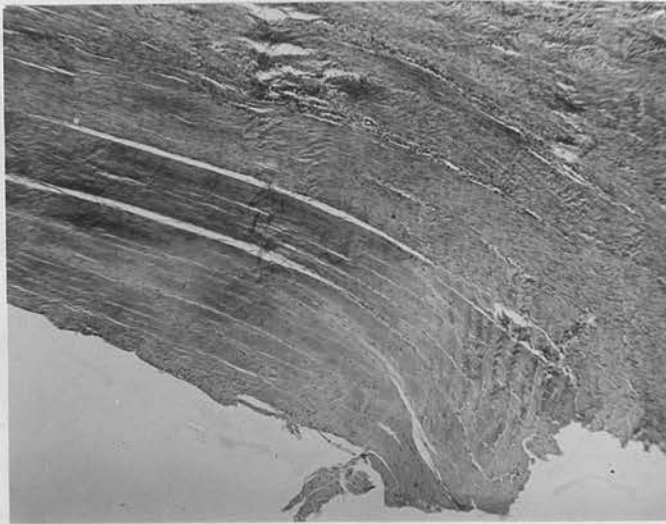


- A. x 4. Mallory. The upper attachment is elongated but has become curled in preparation. The gap has filled with irregular scar from the areolar layers. The original end of the ligament is still easily distinguished, terminating abruptly in the scar tissue. There has been no regeneration of regular collagen. The deep fibres are still avascular.



- B. x 100. Trichrome. This shows the termination of the original ligament and the character of the loose irregular scar tissue which has formed in the gap.

For case of rupture of ligament the skin
 features in above...
 redness...
 in the...



Cat 4 7 Days Gradual...
 first sign of...
 of ligament cells.

C. x 100. Van Gieson. The cellular elements
 close to the rupture are seen. The superficial
 half of the original ligament contains many
 blood vessels and cells, and is presumably becom-
 ing revascularised. The deep half remains quite
 avascular, with few cells, and appears inert.
 There has been not the slightest reaction in this
 part of the ruptured end which is still clearly
 demarcated.

Dog 2 14 Days The union...
 features regular collagen
 fibres. Slight lateral
 laxability in knee.

Cat 11 28 Days Healing by regular collagen
 almost complete.
 cellular reaction...
 instability.

For ease of reference in the analysis the main features in these experiments are summarised and reclassified, according to the location of the rupture, in the following tables:-

Table I

Rupture at the Lower Insertion

Animal	Interval	Summary of findings
Cat 4	7 days	Granulation tissue callus and first sign of proliferation of ligament cells.
Cat 14 (R)	10 days	Haematoma widely displacing ends.
Cat 14 (L)	14 days	No specimen.
Dog 2	21 days	Firm union across gap by new immature regular collagen fibres. Slight lateral instability in knee.
Cat 11	49 days	Healing by regular collagen tissue almost complete. Cellular reaction subsiding. No instability.

Table II

Oblique Ruptures

Animal	Interval	Summary of findings
Cat 8 (L)	4 hours	Haemorrhage and capillary dilatation.
Cat 8 (R)	14 days	Proliferation of regular collagen into provisional callus almost bridging the gap.
Cat 16	17 days	New longitudinally-arranged collagen strands extending whole length of rupture.
Cat 7	35 days	Old and new collagen fibres indistinguishable. New fibres consolidating. Cellular reaction subsiding. Very slight lateral instability.
Cat 10	63 days	Firm healing by regular collagen tissue. Appearances approximating normal but still an increase in cells. No lateral instability.
Cat 9 (R)	77 days	Macroscopically firm healing. Ligament appeared almost normal. No lateral instability.

Table III
Rupture at the Upper Insertion

Animal	Interval	Summary of findings
Cat 9 (L)	Immediate	-
Cat 3	7 days	No specimen
Cat 15	7 days	Large haematoma. Torn end of ligament avascular. No cellular reaction.
Cat 13 (L)	56 days	Healing by irregular scar tissue with elongation of attachment. Ischaemic ligament. Marked lateral instability.
Cat 17	56 days	Complete failure of regeneration. Atrophy of ligament, and union by loose irregular scar tissue. Marked lateral instability.
Cat 18	70 days	Partial healing by regular collagen tissue with elongated attachment. Partial ischaemia affecting deep fibres. Slight lateral instability.
Cat 13 (R)	147 days	Failure of regeneration. Partial ischaemia with superficial revascularisation. Healing by loose irregular scar tissue with elongation. Moderate lateral instability.

ANALYSIS OF EXPERIMENTAL FINDINGS

Situation and Nature of Injury.

Rupture occurred seven times at the upper insertion, five times at or near the lower end, and in six instances was a long oblique tear. One case (Dog 1) had a partial central tear of the main band. As a comparison, Palmer reported fifteen clinical cases in which the upper end was torn in seven and the lower end in six, with one oblique rupture and one "overstretching". The comparative frequency of oblique tears in the experimental cases is probably due to the position of full extension in which violent abduction was applied. In this position of the knee abduction over a fulcrum not only applies traction to the main band of the collateral ligament, but also tends to cause the medial femoral condyle to burst its way through the tightened postero-medial capsule. In addition to longitudinal stress on the ligament, there is also a horizontal strain on the capsule in a backward direction, which conduces to a vertical split. This vertical tearing was found not only in the long oblique ruptures, but nearly always occurred along the posterior margin of the ligament when the upper end gave way. Abduction violence in full extension is not common in human beings excepting perhaps in car bumper injuries, and the precise nature of the tears is not therefore /

therefore strictly applicable.

The knee joint of a cat is a great deal more resilient and mobile than the human knee, and the cruciate ligaments were never damaged, although twenty to thirty degrees of abduction rocking could always be demonstrated after the injury. A further explanation of the absence of gross combined injuries, which are common in clinical cases, is found in the fact that the violence was controlled. Once the medial collateral ligament was felt to snap, the force was released. This, of course, does not occur in the accidents of football or ski-ing, when a continuation of the violence often opens up the joint still further, so that capsule and cruciate ligaments are torn, and gross displacement of tissue results.

Associated injury to the capsule regularly accompanied the upper end tears. The short fibres which anchor the meniscus to the femur were torn, and the synovial membrane opened, so that when the leg was abducted the meniscus drew away from the femoral condyle. The possibility of interference with the deep blood supply at this point has been noted. The lower attachment of the meniscus was torn, and the joint opened between the meniscus and tibia in one case of lower end rupture. Exploration was not pursued in the oblique tears which were disturbed as little as possible.

Even with the controlled violence applied in the experiments, displacement of the torn ligament ends was a prominent feature. It was most prominent when the upper end gave way, in which case the areolar tissue was frequently /

frequently torn as well, the whole ligament was released down to the joint level, and the loose end was widely separated from its insertion (Fig. 18). It was least noticeable in the long oblique tears where the areolar tissues were often little disturbed and continued to contain the ruptured ligament. In several such cases the false impression of simple stretching was given at first and the true nature of the damage disclosed only after dissecting away the sheath.

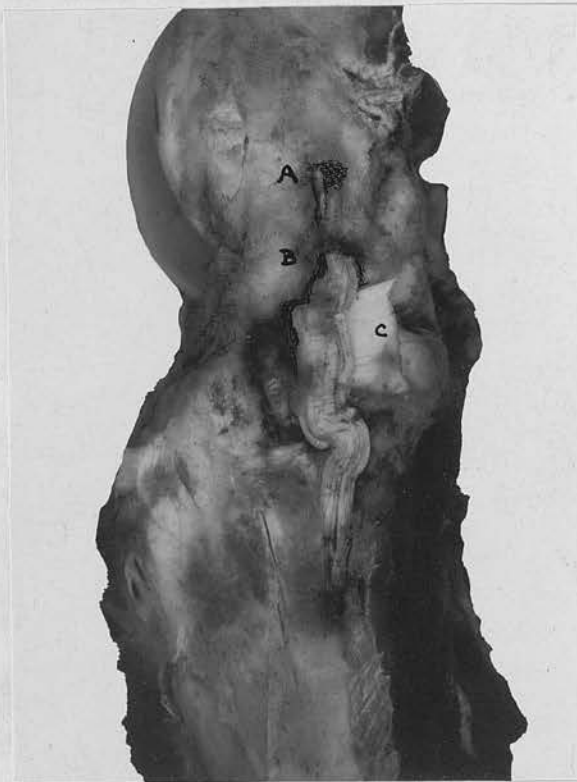


Fig. 18. Rupture of the medial collateral ligament at the upper insertion. Dissection was performed after fixation in formalin. The original insertion is seen at A, with a tiny strand of ligament still attached. B shows the upper torn end of the ligament which has recoiled almost to the level of the meniscus. The curling of the whole ligament, with disruption of the bundles is well shown. C marks semimembranosus tendon.

There was little evidence, in these experiments, of lengthening due to tearing of individual strands at many different levels. Rupture of continuity occurred along a definite line and though the edges were often ragged, and longitudinal disruption of bundles at a distance from the break was often found, diffuse tearing was not seen. In all cases displacement occurred in a longitudinal direction, the ends were separated, and the ligament was found to be tortuous throughout most of its length.

This recoil after injury is important and interesting. When the inelastic ligament snaps, the violence which causes the break continues, momentarily at least, and opens up the joint further, so that the elastic connective tissue sheath is stretched out over the torn ligament which slides down inside it. When the joint closes again it seems probable that the sheath grips the released ligament and prevents it from returning towards its intact insertion. As the elastic sheath retracts, the band becomes curled up inside it. Recoil is purely a matter of displacement and there is no question of retraction of the ends in the sense that elastic retracts, or the cut end of a tendon, due to muscle tone. It was always found that the tissue could be replaced accurately in position without abnormal tension and that little fixation was necessary to hold it in place.

In five of the cases in which the ligament was explored /

explored, the torn ends were left as found in the displaced position. In the remainder the ligament was smoothed straight and the aponeurosis was then closed over it. This probably helped to keep the fragments in place. Except in one case sutures were not used, and the ligament was therefore not held firmly in the taut position. A slight gap was almost certainly left, and quite probably a little redisplacement took place as the animal moved about its cage.

Observations on the Process of Healing.

Where conditions are favourable for healing, the process, as is to be expected, runs parallel to that described by Mason and Shearon in the healing of tendons. The immediate effect of injury on the ligament itself is a disruption and separation of the fibre bundles as well as a rupture. Due no doubt to release of tension, the fibres assume a fine wavy appearance. An immediate vascular response occurs in the ligament itself and in the overlying sheath, and many new capillaries open up. The spaces become filled with blood cells and the rupture zone is occupied by haematoma. In a short time this is converted into granulation tissue by an ingrowth of cells from the scanty loose connective tissue of the ligament itself, and from that of the areolar sheath. By the end of a week the gap is filled by a cellular granulation tissue callus which fixes the tissues but has /

has no tensile strength. Meantime, throughout the whole length of the ligament, an intense vascular reaction is seen with the formation of many new capillaries, and a great increase occurs in the ligament cells themselves. Tissue which before injury appeared practically avascular and inert shows the most extraordinary capacity for activity. By the seventh day there is evidence of proliferation of these cells, and the formation by them of young collagen fibrils which reach out into the callus. At fourteen days there is well-organised longitudinal arrangement of cells and fibres which have proliferated from the ligament ends and largely replaced the provisional callus. Thereafter longitudinal collagen fibres gradually increase as the cells decrease, and they become arranged into bundles as in normal tissue. Filmy adhesions remain between the sheath and the rupture zone, but in the main the sheath recovers its gliding function. The process takes time, and in one case examined on the seventy-seventh day after injury there was still a noticeable increase in cells and in blood vessels. There may be considerable variation in the time taken to achieve healing in individual cases.

Healing by regeneration of regular connective tissue from the ruptured ends of the ligament was found to be taking place in nearly all specimens when the tear /

tear had been oblique, or at the lower end. In only one of these cases did there seem to be a failure (Cat 14 (R)). This ligament was not explored and straightened out after rupture, and on recovery the lower end was found to be widely displaced, with a large organised haematoma filling the gap. The ligament fibres became lost in the haematoma and showed little tendency to regenerate.

Curling disappeared and slack was taken up quite early, even in the three cases in which the ligament was not smoothed (Cats 8 (R), 14 (L), 7). After fourteen days the tortuous appearance, which was invariably found immediately after rupture, was no longer evident. Fine waviness of the fibres remained rather longer, but also disappeared in due course. Two of these cases had some residual lateral mobility on testing before recovery of tissue - Dog 2, in which the ligament was straightened out, and Cat 7, in which it was left undisturbed in the displaced position. The remainder had stable joints. Abduction stress was not applied before an interval of twenty-one days had elapsed, but thereafter abnormal mobility was tested with moderate force. Regenerating ligaments appeared to have developed satisfactory strength after that period, but no attempt was made to assess it accurately. Mason and Shearon found that great tensile strength was recovered early in regenerating tendons. They reported a /

a muscle-tendon specimen in which, thirty-four days after division of the tendon, the musculo-tendinous junction ruptured before the healing zone, when force was applied.

Most remarkable of the findings was the almost complete failure of the upper end tears to achieve good healing. Cat 15, examined at seven days, had no vascular or cellular reaction in the upper third of the ligament which was found floating in haematoma. Even the cells of the areolar tissue sheath had failed to proliferate and organise the haematoma, and perhaps a constitutional factor was responsible for the delay. Four more examples were examined and only one showed regeneration of regular collagen tissue. One ligament (Cat 17) had been left undisturbed with wide displacement which persisted. The long gap was filled with irregular scar tissue. Two others (13 (L) and 13 (R)) showed no reaction in the ruptured end of the ligament which was tacked down to the femoral condyle over a much elongated area by irregular scar tissue. The appearance of these ligaments close to the rupture was in marked contrast to that of their more distant parts. In the latter there was the normal vascular and cellular proliferation in response to the injury, but towards the upper end the tissue became utterly inactive and was completely avascular. Ischaemia appears to have been the main cause of the failure. There /

There were signs of early revascularisation of the surface strands of the old ligament by capillaries growing in from the surrounding tissues. The fourth (Cat 18) had produced from its superficial two-thirds plenty of new regularly arranged fibres which had succeeded in bridging a long gap to the upper insertion. The deep part, however, was again ischaemic and inactive, and showed no regeneration.

All of these four cases were found to have a demonstrable amount of abnormal lateral rock on testing the ligament before recovery, and this was most marked when microscopic examination revealed least satisfactory healing. Even after replacement of the ligament at the original exploration, some retraction of the upper end always occurred, with the result that the ligament became reattached to a much elongated area on the femoral condyle. This was probably due to the absence of sutures to hold the ligament in place, and to lack of immobilisation. It has been noted that though the cats remained very still, there was certainly some movement of the knee every day after operation. The femoral attachment has been shown to be the mobile part of the ligament. It is therefore not surprising that there is a particular tendency to redisplacement by movement of the knee, when the rupture is at this point.

An interesting feature was the interference with the /

the delicate mechanism of tensioning at the upper attachment. Adhesion to an abnormally long area on the lateral condyle of the femur and to the surrounding capsule formed in the position of flexion, the habitual resting position of the animal. As a result, the ligament was no longer free to glide over the femoral condyle on extension of the knee. The upper third followed the condyle and the whole ligament assumed a curved shape (Fig. 19). The efficiency was obviously adversely affected.

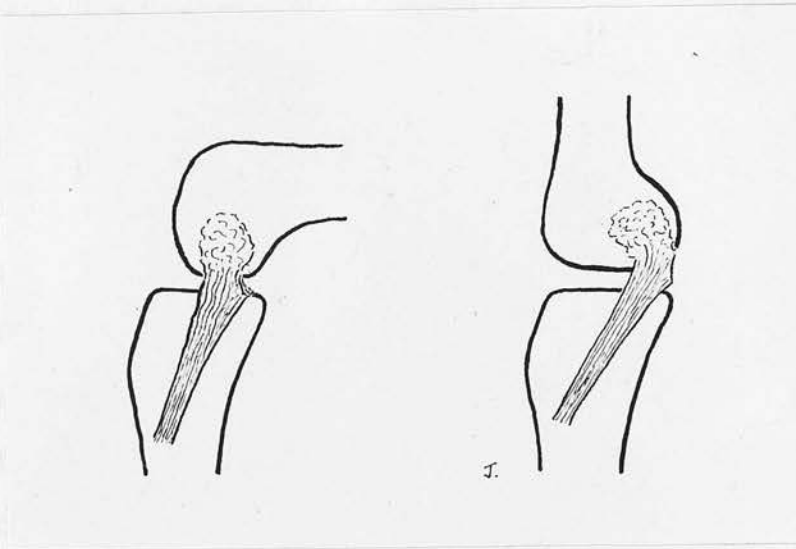


Fig. 19. Diagram to show the effect on the ligament in flexion and extension of an elongated and adherent femoral attachment.

CONCLUSIONS FROM THE EXPERIMENTAL STUDY

The experimental observations show that under favourable circumstances true healing by regeneration does, in fact, occur. A ruptured ligament will produce from its torn ends regularly arranged collagen tissue which eventually resembles the original tissue of the ligament. During the process of healing there is some shrinkage of the damaged fibres, which takes up slack produced by minor separation of the ends. Provided the gap is firmly bridged, the result is a strong, stably functioning structure. The prerequisites for such healing are, first, reasonable approximation of the ruptured ends of the ligament and, secondly, an adequate blood supply to the stumps.

When complete solution of continuity occurs in a ligament a greater or lesser degree of recoil always occurs, and there is often wide dislocation of the ruptured ends which may render spontaneous regeneration impossible. If displacement is allowed to persist the gap then fills with irregular scar tissue which can have little tensile strength and which results in adhesions to surrounding structures. The normal function of the ligament is thus seriously impaired. Damage to the tissue surrounding the ligament may be sufficient to interfere with the blood supply and to delay or prevent regeneration of collagen fibrils.

Revascularisation /

Revascularisation occurs slowly but organisation of the haematoma by irregular scar has already proceeded, and blocks any attempt at late regeneration.

The upper attachment of the ligaments of the knee are of paramount importance, because normal function during movement of the joint depends on the pattern of insertion of the fibres into the femoral condyle. The abnormal mechanical effect of reattachment of the upper end of the medial collateral ligament to an elongated area was well demonstrated, and it is suggested that this may be responsible for the state of chronic irritation of the ligament which sometimes follows these injuries.

There is also some evidence that interference with the blood supply may occur most frequently when the rupture occurs at the upper attachment of the medial collateral ligament, and in some cases healing may fail for this reason, whatever form of treatment is instituted.

The cruciate ligaments, due to their intra-articular position, may fall into a separate category as the torn ends are subject to the action of the synovial fluid. This action has not been studied, and requires further investigation. It is, however, reasonable to assume that if accurate apposition is obtained and blood supply preserved, regeneration will occur.

APPLICATION OF EXPERIMENTAL FINDINGS
TO THE PROBLEM OF TREATMENT OF
LIGAMENT INJURIES

Whenever marked lateral mobility of the knee, following a recent injury, provides clinical evidence of complete rupture of a ligament, wide dislocation of tissue should be suspected. If such a state exists the prospects of sound healing and a subsequent stable joint after simple immobilisation in plaster are poor. Manipulation of the joint, or particular positioning of the limb in the plaster, is very unlikely to have any effect on apposition. The only satisfactory way of obtaining reduction of the displaced structures, and so affording the best chance of sound regeneration, is by surgical exploration and repair.

Based on the experimental findings, certain conditions which should govern procedure may be laid down.

(1) Operation should be carried out early - preferably within a week of the injury, before organisation of the haematoma has sealed the gap and before shrinkage has occurred in the ligament tissue. If operation is delayed longer apposition may be difficult.

(2) The operation should be carried out with delicacy so as to interfere as little as possible with the blood and nerve supply of the ligament.

The /

The areolar sheath should be respected as far as possible, and the least dissection of the ligament compatible with repair performed.

(3) Accurate replacement of tissue is required, especially at the femoral attachments, and anatomical exactitude should be the aim so as to restore the detailed function of the ligament.

(4) If operation is performed early the tissue is easily replaced in position without tension. No strong tension sutures are required as in the case of tendon repair, and the minimum amount of fine suture material should be employed to anchor the tissue in position. Theoretically the practice of reinforcing the ligament by darning in strong silk strands (Valls, 1939) is likely to interfere with blood and nerve supply and to do more harm than good. Similarly, reinforcement by over-suture of a strip of fascia or tendon, may jeopardise regeneration.

(5) Immobilisation after operation should be maintained until reasonable tensile strength has developed in the regenerating tissue. Thereafter guarded function should be expected to stimulate orientation of the new fibre bundles and to prevent adhesion formation. Immobilisation should not be kept up for longer than necessary. In these experimental animals the regenerating ligaments were found to be quite strong after twenty-one days. After tendon /

tendon suture, Mason and Shearon recommend activity after three weeks. Complete fixation of the limb in plaster should be instituted for a period of three to four weeks after operation. The healing ligament should then be protected, during a further period of four to six weeks, by a removable splint, which would permit non-weight bearing exercises to be performed.

CLINICAL REPORT ON A SERIES OF CASES

OF SEVERE LIGAMENOUS INJURY

TO THE KNEE JOINT

ORIGINAL MATERIAL

PART II

CLINICAL REPORT ON A SERIES OF CASES
OF SEVERE LIGAMENTOUS INJURY
TO THE KNEE JOINT

CLINICAL MATERIAL

The following report concerns nine cases of extensive damage to the capsular and ligamentous apparatus of the knee joint. These cases were encountered during a comparatively short period, seven of them under active service conditions. Each one was subjected to operative exploration a short time after injury, accurate observation of the damage was made, and repair, in so far as it seemed reasonable, was carried out. The service cases were moved shortly after operation, owing to evacuation requirements, so that post-operative treatment was in other hands. All but one (Case 4) have been followed up for a period of at least two years, some by letter, some by personal examination, and a reasonable assessment of the result of operative treatment has been obtained.

Much discussion has been offered by previous authors concerning the mechanisms of injury, and the order in which damage occurs to the various capsular structures following particular types of trauma. Most of the work has come from countries in which ski-ing is a prominent feature of daily life. Accidents, therefore, tend to follow a recurrent pattern of violence. But service casualties, occurring in a wide variety of circumstances, follow no set pattern. Violence may come from any direction and at any level in a haphazard way /

way, and varying combinations of ligamentous injury may result, depending on the precise nature of the force.

It is not therefore intended to dwell on the action of individual ligaments, or the mechanics of injury to them. Nor is it proposed to discuss the diagnosis of injuries to specific structures. These matters have already received extensive study, and from experience in other cases, there is little to add to present knowledge. The cases to be described were selected for the purpose of investigating the pathological anatomy of the lesions, the possibility of operative repair, and the post-operative result as regards function.

According to the side of the joint mainly affected by the injury, they are divided into two groups: abduction capsular ruptures and adduction capsular ruptures. This classification is considered better than one which attempts to ascribe the main injury to one particular ligament. As will be seen in the adduction ruptures, the fibular collateral ligament tear was often a minor part of the gross damage.

FOUR CASES OF ABDUCTION RUPTURE

Case 1.

March 1945 - thrown out of a vehicle. The mechanism of injury was uncertain.

Examination - two days later. The knee was much swollen by capsular thickening and oedema. There was a moderate effusion in the joint. Swelling was noted, especially over the medial side of the joint where subcutaneous haemorrhage was beginning to appear. Tenderness was maximum along the medial joint line. Abnormal abduction rock could be demonstrated easily.

Under pentothal anaesthesia, thirty degrees of abduction rock and one inch anterior glide were discovered. X-ray examination showed no bony injury.

Operation - three days after injury. A vertical incision through the skin revealed a hole in the deep fascia at the level of the meniscus, through which the lower end of the long band of the medial collateral ligament projected. The ligament lay curled up, deep to the fascia, and could be pulled out through the hole. Further exploration exposed a complete rupture of the collateral ligament close to the lower attachment, a two inch long rupture of the capsule along the upper margin of the meniscus, and a complete tear of the anterior cruciate ligament from its tibial insertion. The meniscus was intact.

The /

The anterior cruciate ligament was trimmed short, and the medial collateral ligament and capsule were repaired with interrupted fine silk sutures.

Post-operative treatment. Immobilisation in plaster was maintained for six weeks. Physiotherapy was continued for ten weeks thereafter.

Follow-up. Examined personally, November, 1947. Patient completed his army service in category A1. He is now employed as a boot repairer. He does not play games, but walks long distances over rough ground without complaint, and says that he has no disability. Range of movement is full. There is a trace of abduction rock, and anterior glide of about one centimetre.

Summary. Ruptured medial collateral ligament and medial capsule repaired. Ruptured anterior cruciate ligament excised. Full function. Very slight instability. No disability.

Case 2.

June 1945 - football injury. Patient mis-kicked the ball and over-extended the knee which gave a crack.

Examination - the following day. The knee was held at 160° and marked muscle spasm rendered the assessment of normal or abnormal mobility impossible. Bruising was beginning to show over the medial side of the joint. Tenderness /

Tenderness was maximum over the medial side of the femoral condyle and along the joint line. There was a large effusion.

Under pentothal anaesthesia, aspiration yielded 60 c.c. of blood. 30° abduction rock and 1½ cm. anterior glide were found. X-ray examination demonstrated wide opening of the medial side of the joint and excluded fractures.

Operation - five days after injury. A vertical medial incision exposed the deep fascia which was torn over the femoral condyle. The medial collateral ligament was ruptured at the upper insertion, and the ruptured end lay at the level of the meniscus, leaving a gap of one inch. The capsule was split along the upper border of the meniscus which was partly detached, but undamaged in its substance. The anterior cruciate ligament was ruptured close to the tibia.

The anterior cruciate ligament was cut short, and the capsule and medial collateral ligament were repaired with silk sutures. It was possible to anchor the upper end of the ligament quite firmly to periosteal tissue surrounding the point of insertion.

Post-operative treatment. Immobilisation in plaster for seven weeks was followed by physiotherapy and rehabilitation for ten weeks.

Follow-up by letter, September, 1947. Patient is employed as a general labourer and claims that the knee gives /

gives no trouble. It feels perfectly stable, has never given way nor become swollen, and does not cause pain. He can straighten the knee fully, but cannot quite sit on his heels. He was discharged from the army in category A1.

Summary. Ruptured medial collateral ligament and medial capsule repaired. Ruptured anterior cruciate ligament excised. Stable knee. Slight limitation of flexion. No disability.

Case 3.

July 1945 - thrown from an overturning vehicle. Patient sustained severe damage to both knees - the left by abduction violence, the right by adduction violence (reported as Case 8).

Examination - a few hours after injury. The left knee was grossly swollen and contained a moderate effusion. Abduction rock to 30° and marked hyperextension and anteroposterior glide could be demonstrated without anaesthesia and without much pain. X-ray examination was negative.

Operation - four days after injury. A vertical medial incision was made. The deep fascia was widely ruptured at the level of the joint line, and after incision of the skin the interior of the joint could be inspected. The medial collateral ligament was found curled /

curled up about its upper end, having ruptured at the lower attachment. The capsule was split along the joint line from the fatty pad in front to the intercondylar notch behind, and the peripheral attachments of the posterior two-thirds of the meniscus were separated, allowing it to slip forward between the condyles. The posterior cruciate ligament was ruptured at the femoral attachment, the anterior at the tibial attachment, and both ligaments lay free across the joint.

Both cruciate ligaments were removed. The meniscus was anchored back to the capsule, and the capsular rent repaired as far back as possible. The medial collateral ligament was sutured to the short inferior stump and the aponeurotic tear closed.

Post-operative treatment. Immobilisation in plaster was maintained for eight weeks. Hot air and hand massage were given daily for three weeks, and the patient was then sent home to carry out exercises with very little supervision.

Follow-up by letter. Progress in this case was retarded by the injury to the other leg. Six months after operation there was a range of movement of only 45° from full extension and the knee periodically became swollen and painful. In November 1947 the range was 60° (180° - 120°), when he had a severe fall which flexed the knee forcibly and caused a loud crack. Pain and /

and swelling followed and lasted two weeks. In January 1948 he reported a range of 90° . The knee occasionally catches and swells, and there is creaking on movement. He is employed as an Insurance Agent and walks most of the day, but cannot run with ease.

Summary. Ruptured medial collateral ligament, medial capsule and meniscus attachments repaired. Ruptured anterior and posterior cruciate ligaments excised. Limited flexion. Persistent instability. Capsular adhesions. Disability considerable.

Case 4.

September, 1947 - knocked down by a motor car. The car bumper struck the inner side of the tibial tubercle, driving the tibia backwards and laterally.

Examination - four days after injury. There was gross thickening of the whole knee joint with a moderate effusion. Bruising had appeared over the medial side of the joint and in the popliteal fossa. Tenderness was marked along the line of the joint on the inner side, where a defect in the soft tissues could be felt with the fingers. Without anaesthesia abduction rock of 40° could be demonstrated, as well as hyperextension and posterior glide. X-ray examination was negative.

Operation - seven days after injury. Incision of the /

the skin permitted the cruciate ligaments to be inspected. The deep fascia was torn. The medial collateral ligament had ruptured along an oblique line from the posterior edge of the upper insertion to the anterior edge of the lower insertion. The capsule was split in front of the ligament and behind it, along the joint line. The anterior triangular flap of ligament, attached at the upper insertion, was turned into the joint and lay behind the patellar ligament. The posterior triangular flap, attached below, was turned in and lay behind the femoral condyle, both above the meniscus. The meniscus was entirely separated from peripheral attachments. The posterior cruciate ligament was ruptured from the tibia and lay free in the joint.

The meniscus and the posterior cruciate ligament were removed. The capsule and medial collateral ligament were repaired with interrupted fine silk sutures.

Post-operative treatment. Immobilisation in plaster for ten weeks was followed by physiotherapy for twelve weeks before the patient returned to work. Owing to slow recovery of flexion, manipulation of the knee under anaesthesia was performed on two occasions, at fourteen and eighteen weeks after operation.

Follow-up. Examined personally. August, 1948. Patient is employed in a brick works. He is on his feet /

feet all day and does ladder work with confidence. The knee has never given way, nor become swollen and painful, and he states there is no disability. Flexion is limited at ten degrees past the right angle (range 180° to 80°) and forced flexion causes a little pain behind the patellar ligament. There is no trace of lateral rock or antero-posterior glide.

Summary. Ruptured medial collateral ligament and medial capsule repaired. Ruptured posterior cruciate ligament and detached meniscus excised. Moderate limitation of flexion. Stable knee. Minor disability due to adhesions.

FIVE CASES OF ADDUCTION RUPTURE

Case 5.

February, 1945 - knocked down by a car. The bumper struck the inner side of the knee which was forced laterally and backwards.

Examination - two days later. Extensive bruising had developed over the lateral side of the knee, spreading to the popliteal fossa and up the thigh. A capsular defect could be felt along the lateral joint line and tenderness was marked at this point. Under pentothal anaesthesia, adduction rock of 25° hyperextension and posterior glide were found. X-ray examination was negative.

Operation - three days after injury. Through a vertical lateral incision, the postero-lateral capsule was found to be split along the joint line back to the intercondylar notch. The fibular collateral ligament was ruptured from the styloid process and retracted to the level of the meniscus. The popliteus tendon was ruptured at the margin of the femoral condyle. The biceps tendon was avulsed from the belly at the musculotendinous junction, the tear extending over some three inches. The lateral meniscus was intact but was separated from all but the horn attachments. The posterior cruciate ligament was ruptured at the tibial insertion.

The /

The lateral meniscus and posterior cruciate ligament were removed. The lateral capsule was repaired as far back as possible; the popliteus tendon and biceps tendon were repaired, and the fibular collateral ligament reattached to the styloid process.

Post-operative treatment. Immobilisation in plaster for eight weeks was followed by physiotherapy for eight weeks, and the patient was then returned to duty.

Follow-up by letter. December, 1947. Patient is employed as a storekeeper and packer. He is on his feet all day, handling heavy boxes, and has no trouble from the knee. There is no pain or swelling. His only complaint is an occasional feeling of insecurity if he turns round quickly, but the knee has never given way. Extension is full. Flexion is restricted by some ten to fifteen degrees. He claims there is no disability.

Summary. Ruptured fibular collateral ligament, lateral capsule, popliteus tendon and biceps muscle, all repaired. Detached meniscus and ruptured posterior cruciate ligament excised. Slightly limited flexion. Stable knee. No real disability.

Case 6.

June, 1945 - motor cycle accident. The knee was trapped /

trapped underneath the cycle.

Examination - three days later. The knee was considerably thickened and contained a moderate effusion. Subcutaneous bruising extended over the lateral side of the joint to the popliteal fossa. Tenderness was maximum along the lateral joint line, where a soft tissue defect could be felt. Abduction rock to 30° , hyperextension and posterior glide could be demonstrated easily without much pain. There was motor paralysis and sensory loss in the distribution of the lateral popliteal nerve. X-ray showed a small bone flake above the fibular styloid process.

Operation - seven days after injury. A vertical lateral incision through skin and fascia revealed the articular cartilage of the femoral condyle through a wide rent in the capsule. The tear followed the joint line along almost the whole extent of the tibial condyle. Fibular collateral ligament and biceps tendon were ruptured from the styloid process, the latter with a fragment of bone, and were retracted one inch upwards. The popliteus had ruptured through the muscle belly below the joint, and the tendon, with a mass of shredded muscle attached to it, was turned into the joint between the femoral condyle and the lateral meniscus. The meniscus was attached only by the horns. Posterior cruciate ligament was ruptured from the tibial attachment and lay loose in the joint. The lateral popliteal nerve /

nerve was frayed and stretched over three inches of its length.

The lateral meniscus, the torn distal part of popliteus muscle and the posterior cruciate ligament were excised. The capsular rent was closed with interrupted fine silk sutures, and the fibular collateral ligament and biceps tendon were reattached to the styloid process. The damaged nerve was left for future attention.

Post-operative treatment. Immobilisation in plaster was maintained for six weeks and was followed by physiotherapy for twelve weeks. Eighteen weeks after operation the nerve was explored, three inches were resected and suture was carried out with the knee fully flexed. Turnbuckles and hinged plaster were used for gradual extension.

Follow-up by letter. December, 1947. Patient is employed as a salesman in a store. He wears a drop foot iron as there is no recovery from the nerve injury. The knee occasionally catches and swells, and he describes an abnormal movement of the head of the tibia on the femur. Extension is limited by 5° , flexion to 15° beyond a right angle (175° to 75°). He receives an army pension for a disability of 40 per cent.

Summary. Ruptured lateral capsule, fibular collateral ligament and biceps tendon repaired. Posterior cruciate ligament, popliteus muscle and meniscus /

meniscus excised. Lateral popliteal nerve sutured later. Repair failed. Severe disability persists.

Case 7.

July, 1945 - football injury of uncertain nature. Patient was admitted immediately to hospital with a backward dislocation of the tibia on the femur.

Examination - two hours later. The dislocation was reduced under pentothal anaesthesia. After reduction the head of the tibia was very unstable and tended to redislocate. Abduction of the knee was firmly resisted by the intact medial capsule and medial collateral ligament. Adduction resulted in wide opening of the lateral side of the joint with an adduction angle of 35° . It was evident that the biceps tendon was ruptured. X-ray examination showed a bone flake lateral to the joint.

The damage was found to affect mainly the lateral capsular structures and the cruciate ligaments and it was therefore decided to explore from the lateral side.

Operation - six days after injury. A vertical incision through skin revealed a transverse tear of fascia lata and wide separation of the lateral capsule which was torn along the joint line from the patellar ligament to the intercondylar notch. Biceps tendon was ruptured with a flake of bone from its insertion. Fibular /

Fibular collateral ligament was torn from the styloid process and retracted above the joint. Popliteus muscle was ruptured through the belly, and a large fragment of ragged muscle tissue attached to the tendon had swung into the joint and lay between the meniscus and femoral condyle. It was this displaced muscle fragment which caused the tendency to redislocate. The meniscus was intact but separated from all peripheral attachments. Both anterior and posterior cruciate ligaments were ruptured at the femoral insertion.

The lateral meniscus was removed and both cruciate ligaments trimmed short. The capsule was closed as far back as possible. Biceps was reattached to the styloid process and fibular collateral ligament repaired and reinforced with the popliteus tendon from which the torn muscle fibres had been stripped. Fascia lata was repaired.

Post-operative treatment. Immobilisation in plaster for nine weeks was followed by physiotherapy and rehabilitation for six months.

Follow-up. Examined personally November, 1947. Patient is employed as a Customs Inspector. He is unable to play hard games. He complains of creaking in the joint in the mornings and aching pain after a long walk. The knee has occasionally become swollen. Flexion is limited at 5° less than a right angle (180° /

(180° - 95°) and forced flexion causes pain above the medial border of the patella, almost certainly due to a firm adhesion. There is retropatellar crepitus, probable due to articular cartilage injury. The joint is remarkably stable. No antero-posterior glide can be elicited and just a trace of adduction rock. Quadriceps tone is good and the biceps functions normally. He can lower himself on the bad leg to 80° flexion of the knee, and straighten up again with ease.

Summary. Dislocation of knee joint. Ruptured fascia lata, lateral capsule, fibular collateral ligament, biceps tendon and popliteus tendon - all repaired. Ruptured anterior and posterior cruciate ligaments and detached meniscus excised. Limited flexion due to adhesions. Stable knee. Considerable disability.

Case 8. (See case 3)

July, 1945 - thrown from a vehicle. The right knee sustained a severe adduction injury.

Examination - a few hours later. The knee was grossly swollen. 30° adduction rock and hyper-extension could be demonstrated without anaesthesia and the biceps tendon could not be felt. X-ray examination was negative. Later, severe bruising appeared /

appeared over the lateral side of the joint and the viability of a small area of skin became doubtful.

Operation - eleven days after injury. A lateral incision disclosed a transverse tear of the deep fascia and fascia lata. The fibular collateral ligament was curled up outside the rent, having torn from the lower insertion. Biceps tendon had given way at its junction to muscle, and separated some three inches. Popliteus was intact. The capsule was ruptured postero-laterally along the joint line, and in the same area the meniscus was separated from its peripheral attachments. Posterior cruciate ligament had parted at the femoral insertion.

The cruciate ligament was excised. The lateral meniscus was anchored back to the capsule which was repaired. Fibular collateral ligament, biceps tendon and fascia lata were repaired.

Post-operative treatment. Immobilisation in plaster for seven weeks was followed by hot air and massage for three weeks. Thereafter the patient carried out exercises himself at home. A small area of skin was found to have sloughed when the stitches were removed after fourteen days, but healing was complete on removal of the second plaster.

Follow-up by letter. Six months after operation there was a range of movement from 180° to 45° . He complained of occasional pain and a feeling of insecurity /

insecurity. January, 1948. Patient is employed as an Insurance Agent and is on his feet most of the day. He does not complain of any pain or swelling in the right knee which he states is firm and strong. The range of movement remains 180° - 45° . Assessment of activity is rather unsatisfactory due to disability in the other knee, and to the fact that follow up by letter, in a foreign language, was difficult.

Summary. Ruptured fascia lata, lateral capsule, fibular collateral ligament and biceps muscle, and detached meniscus repaired. Posterior cruciate ligament excised. Slight limitation of flexion, with apparently reasonable stability.

Case 9.

January, 1946 - buried by a fall of masonry. The right foot was crushed and required amputation. The left knee sustained an adduction injury.

Examination - seven days after injury. Subcutaneous bruising covered the lateral side of the joint. The joint was much thickened and contained a moderate effusion. Muscle spasm was marked and prevented movement. Tenderness was maximum along the lateral joint line. Under pentothal anaesthesia, 20° adduction rock was found with very slight anterior glide, mainly affecting the lateral condyle. X-ray examination was negative.

Operation /

Operation - nine days after injury. Through a lateral incision the fascia lata and lateral capsule were found to be torn from the margin of the tibial condyle for a distance of one inch in front of the ligament, opening the joint below the lateral meniscus. The fibular collateral ligament was ruptured from the styloid process. Popliteus, biceps tendon and meniscus were intact. The cruciate ligaments were not seen.

The capsular tear was repaired and the fibular collateral ligament reattached with a braided silk mattress suture. Tissues were not easily defined and were rather friable due to inflammatory reaction.

Post-operative treatment. The limb was immobilised in plaster for eight weeks. Removal of the plaster disclosed a small sinus in the wound from which the silk mattress suture was eventually discharged.

Follow-up. Examined personally, May, 1946. Patient was not yet walking due to amputation of the other foot. The range of movement was full, but there was some residual adduction rock of about 10° . Quadriceps tone was poor. In November, 1947, he reported by letter that the knee still feels a little unstable and occasionally swells.

Summary. Ruptured fibular collateral ligament and lateral capsule repaired. Mild infection interfered with healing. Moderate instability persists.

COMMENTARY

Clinical Features

When a severe rupture occurs either on the inner or the outer side of the joint, the capsule itself is involved and resulting effusion into the joint escapes into the tissues. The communication is usually through to the subcutaneous layer and therefore ecchymosis appears after a short interval over the site of the rupture. For the same reason effusion into the joint is never tense, but the presence of blood causes a reaction in the synovial layer which becomes palpably thickened. It is often possible to feel the rent in the capsule with the tips of the fingers, and tenderness is maximum over it. Pain is not usually a prominent symptom. Muscle spasm was found to be variable and was more pronounced in the cases of lesser severity, producing the usual limitation of extension. Where rupture was extensive, however, the spasm was absent, and it was quite possible to demonstrate wide lateral mobility without causing pain. If lateral mobility can be produced with the joint extended it is evidence that the posterior capsule is split, in addition to collateral and cruciate ligaments.

Examination under pentothal was invaluable in the assessment of the damage, particularly when spasm was present /

present, and it enabled the function of the cruciate ligaments to be tested with confidence. Novocaine infiltration has been suggested for this purpose, but in these severe injuries the damage is far too widespread for it to be efficacious and a general anaesthetic is to be preferred. X-ray is necessary to exclude fractures of the tibial condyles and to reveal detached bone flakes.

The high proportion of adduction ruptures is quite out of keeping with all other reports and must be regarded as fortuitous.

Abduction Ruptures

All four cases of abduction injury were found to have severe damage to the medial side of the joint, consisting of a complete rupture of the medial collateral ligament and a long horizontal tear through the capsule and the synovial membrane along the upper border of the meniscus. In association with the collateral damage, the anterior cruciate ligament was ruptured in two cases, the posterior cruciate in one case and both cruciates in one case. The medial collateral ligament was found to be coiled up outside the torn deep fascia in the two cases in which the lower end had parted, and where the tear was oblique the two long segments were both turned into the interior of the joint. There is
no /

no doubt that such distortion of tissue would prevent spontaneous healing.

At operation, replacement of the medial collateral ligament and approximation of the capsule were easy and a few interrupted silk sutures were sufficient to hold the tissues reasonably firmly in apposition.

The medial meniscus was never damaged in its substance, but its peripheral attachments were separated to a varying degree. In the one case in which the whole periphery was free, the meniscus was removed, but in the remainder it was preserved.

The cruciate ligaments presented a problem. When the joint is widely torn on one or other side, the cruciates are easily inspected and manipulated through the tear, but there is not enough room to insert sutures or to repair them. In the presence of a wide rent in the capsule, it seems rather drastic to inflict further damage by making the long parapatellar incision which is the only means of satisfactory access. In several recent papers it has been suggested that the cruciate ligaments are really of secondary importance in stabilisation of the knee joint, and that they are entirely subsidiary to the collateral ligaments. Horwitz and Davidson (1938), von Rosen (1941), Abbott et al. (1944) state that as long as a firm repair of the collateral ligament is obtained, a stable knee will result. There is a possibility that this opinion may be governed by the /

the technical difficulty of repairing the cruciate ligaments, and may be the result of wishful thinking. However, it was followed in treating all these cases. Rather than make further extensive capsular incisions, in each instance the torn cruciate ligaments which were apt to float across the joint, were trimmed short.

The results obtained by this procedure possibly support the argument. Cases 1 and 2 were discharged from the Army in category A1, and after two years they admitted no disability. There was a little antero-posterior glide in Case 1 and slight limitation of flexion in Case 2, but the results must be classified as good. Case 4, after a very severe injury, had a completely stable knee at twelve months, but limitation of flexion to 80° due to intra-articular adhesions. This was not sufficient to interfere with his normal activities. Case 3 is classified as a poor result, having instability and loss of flexion range. Three out of four cases can be regarded as very satisfactory in view of the severe damage they sustained.

Adduction Ruptures

Normal activities throw far less strain on the lateral side of the knee joint than on the medial. Perhaps for that reason the fibular collateral ligament is a much slighter structure than its medial companion /

companion. The ligament lies a little behind the centre of the joint axis and so is completely taut only in full extension of the knee. As flexion proceeds it relaxes.

Adduction violence to the flexed knee distorts the joint with the ligament relaxed, and the first strain comes on the lateral capsule reinforced by the ilio-tibial tract. This is especially so if the force thrusts the femur forwards as well as outwards on the tibia. Several cases of lesser severity have been seen in which rupture of the lateral capsule from the antero-lateral margin of the tibia has occurred as an isolated lesion with an intact ligament. Adduction when the knee is extended bears first on the taut ligament which parts at its fibular attachment, and then several other structures may go, including the lateral popliteal nerve which becomes stretched over the femoral condyle.

Platt (1940) describes a triad of lesions which accompanied traction injuries of the lateral popliteal nerve resulting from such violence. He found that the lateral capsule, the fibular collateral ligament and the biceps tendon were usually ruptured and he presumed there was also damage to the cruciate ligaments. In Palmer's series there was only one example of adduction injury, and here the popliteus tendon was torn.

This multiplicity of lesions on the outer side of the /

the joint is well demonstrated in the cases reported.

Besides the wide tear of the lateral capsule and the rupture of the fibular collateral ligament from the fibular styloid process that were discovered in every case, four out of the five presented a rupture of the biceps either at the insertion or at the musculotendinous junction, while three of the four had a tear of the popliteus muscle as well. The posterior cruciate ligament was torn in three cases and both cruciates in one. Twice it was found that a large remnant of popliteus muscle had turned into the joint. Separation and distortion of the torn structures were again regular features.

The association of a rupture of the biceps with the collateral ligament injury four times out of five is especially noteworthy. In the absence of a stable collateral ligament, the biceps is one of the main supports to the lateral side of the joint. If both are out of action, serious instability is bound to result.

Case 7 was interesting in that it was admitted with a dislocated knee. After reduction, the medial side of the joint was found to be stable and the damage affected the cruciate ligaments and the lateral side of the joint. Many of these severe capsular ruptures are virtually dislocations which have become spontaneously reduced, and although few surgeons would consider operating on a frank dislocation, exploration seemed /

seemed perfectly justifiable in this instance. The procedure at least yielded the satisfaction of removing a large fragment of popliteus muscle from the interior of the joint, besides enabling a repair of the biceps and lateral capsule to be effected.

Operative procedure followed the same lines as for the abduction ruptures. The capsule was repaired as far back as the lateral head of gastrocnemius would permit, and ligament and biceps tendon were reconstituted. Access to the cruciates for repair is even more difficult from the outer side of the joint, and again they were trimmed short. The lateral meniscus was removed on account of complete peripheral separation in three cases.

The post-operative results in the adduction ruptures are not so easy to assess. Case 9 - the least severe - was complicated by mild sepsis which prevented healing of the ligament, and lateral instability persists. Case 6 was complicated by nerve injury which necessitated secondary operation. This interfered with after-treatment and entailed a long period of immobilisation in full flexion. Again instability has resulted. Case 7 - the dislocation - after two years has a perfectly stable knee but only 85° flexion range, which is a considerable handicap. Adhesions about the patella, which may have sustained articular damage from the backward dislocation of the tibia, appear /

appear to be the cause. The collateral ligament and the biceps tendon are firmly healed. Case 5 can be classed as satisfactory. He has good stability and insignificant loss of flexion. Case 8 is a little uncertain, but apparently has a sound knee with slight limitation of movement. Of the five cases, therefore, two were failures, one due to local infection and one to nerve injury. Three obtained stable knees, though with some restriction of flexion which in one case was serious.

Although the functional results in the cases of adduction rupture are not so impressive, one cannot help wondering what the state would have been had foreign tissue not been removed from the interior of the joint, and biceps tendons repaired. In comparison with the seven cases reported by Highet and Holmes after conservative treatment, six of which remained grossly lax, they hold the advantage.

Limitation of flexion is one of the chief reasons for subsequent disability in both groups of cases. Immobilisation in plaster was continued, as a rule, for some eight or nine weeks after operation. The original injury causes extensive damage to synovial membrane, possibly local contusions of articular surfaces, and a haemarthrosis - conditions all conducive to adhesion formation which will certainly be favoured by a long period of inactivity. It seems probable, in view of the /

the experimental evidence described in Part I, that a much shorter period of complete immobilisation, followed by controlled non-weight bearing exercises, would yield better functional results without loss of stability.

CONCLUSION

In the introduction to this paper, the case for early surgical repair of severe ligament injuries to the knee joint was said to rest on the answers to four questions. These may now be considered.

(1) Abduction violence first ruptures the medial collateral ligament and then proceeds to open out the inner side of the joint so that the capsule and cruciate ligaments may tear. When the joint closes again the torn structures do not necessarily fall back into position. In particular, the medial collateral ligament frequently becomes curled up leaving a significant gap, or it may turn into the interior of the joint. Adduction violence, after tearing the fibular collateral ligament, often produces rupture of several other important structures which become distracted by the momentary angulation and may remain widely separated from their normal relationships. Anatomically, therefore, surgical exploration to reduce displacement and to maintain apposition is essential if restoration of function in the damaged structures is to be expected.

(2) Surgical repair of ruptured collateral ligaments, joint capsule and muscle insertions is technically easy provided operation is performed within a short time of injury. The surgeon is afforded a brief opportunity, during the first seven to ten days, of /

of achieving anatomical restitution of these structures. If he delays, organisation of haematoma, shrinkage and scar formation will render later repair impossible. Repair of ruptured cruciate ligaments in association with collateral damage is difficult and may be unwarranted until better technical methods of access and repair have been evolved. There is evidence, however, to support the theory that firm healing of the collateral structures will yield a stable joint even if the cruciate ligaments are absent.

(3) A ruptured ligament is capable of healing by the regeneration of regular collagen tissue which unites the torn ends and reproduces a virtually normal structure. Regeneration depends on reasonable apposition of the fragments and adequate blood supply to the tissue. By ensuring the former condition, operation favours the process, but it should be conducted with due regard for the blood supply which may have been already rendered precarious by the injury. Experimental evidence suggests that blood supply may be particularly liable to occlusion when the rupture affects the upper end of the medial collateral ligament, and that in this situation, ischaemia may sometimes vitiate regeneration whatever method of treatment is adopted. The majority of cases may be expected to heal and surgical repair should not be discredited on this account.

(4) The /

(4) The question of justification of operative repair by end results is one which cannot be answered by a small series of nine cases. In view of the scarcity of any reliable post-operative information, they have been presented as a contribution towards a problem which can only be solved after much careful observation by many surgeons over a long period of time. With knowledge at its present level, surgical experience of these injuries during the early stages is, unfortunately, uncommon. It will suffice to say that, considering the gravity of the injuries, the results are encouraging enough to warrant the continuation of operative endeavour.

The number of cases with permanent severe disability resulting from ligament injuries must be reduced, and for this to be achieved it is first necessary that both general practitioner and surgeon recognise more fully and promptly the probable nature of the lesions that may exist in the grossly swollen joint. Early surgery may not be able to restore all these lesions to normal. It may, in some cases, be doomed to failure. But by permitting anatomical restitution of the important collateral structures, it does at least afford the patient the best prospects of a stable knee joint.

References.

- Abbott, L. C., Saunders, J. B. de C. M., Bost, F. C. and Anderson, C. E. (1944), "Injuries to the Ligaments of the Knee Joint," J. Bone & Joint Surg., 26, 503.
- Bircher, E. (1933), "Über Binnenverletzungen des Kniegelenkes," Arch. f. klin. Chir., 177, 290.
- Brantigan, O. C. and Voshell, A. F. (1941), "The Mechanics of the Ligaments and Menisci of the Knee Joint," J. Bone & Joint Surg., 23, 44.
- Brantigan, O. C. and Voshell, A. F. (1943), "The Tibial Collateral Ligament; its function, its bursae and its relation to the Medial Meniscus," ibid., 25, 121.
- Carleton, H. M. (1934), Schafer's Essentials of Histology, 13th edn., Longmans Green & Co., London.
- Felsenreich, F. "Kreuzbandverletzungen," Wien. klin. Wschr., 48, 1058.
- Folliason, A. (1934), "Entorse grave du genou," Bull. et Mém. Soc. Nat. de Chir., 60, 1218.
- Gardner, E. D. (1942), "Nerve terminals associated with the knee joint of the mouse," Anat. Rec., 83, 401.
- Highet, W. B. and Holmes, W. (1943), "Traction Injuries to the Lateral Popliteal Nerve," Brit. J. Surg., 30, 212.
- Horwitz, M. T. (1938), "Investigation of the surgical anatomy of the ligaments of the knee joint," Surg. Gynec. Obstet., 67, 287.
- Horwitz, M. T. and Davidson, A. J. (1938), "Newer concepts in the treatment of injuries to the ligaments of the knee joint," Surgery, 3, 407.
- Johnston, T. B. (1935), Gray's Anatomy, 26th edn., Longmans Green & Co., London.

- Leger, L. and Olivier, C. (1945), Entorses du coup du pied et entorses du genou, Masson et Cie, Paris.
- Mason, M. L. and Shearon, C. G. (1932), "The Process of Tendon Repair," Arch. Surg., 25, 615.
- Maximov, A. A. and Bloom, W. (1938), Textbook of Histology, 3rd edn., W. B. Saunders Company, Philadelphia.
- Merle d'Aubigné, R. (1935), "Entorse externe du genou avec fracture de la tête du péroné traitée par l'intervention immédiate," Bull. et Mém. Soc. Nat. de Chir., 61, 1070.
- Mitchell, G. A. G. (1947), Fletcher's Medical Disorders of the Locomotor System, E. and S. Livingstone, Edinburgh.
- Oda, M. (1935), "Über die Nervenendigungen im Gelenkkapsel und in der Synovialhaut," Tr. Soc. path. Jap., 25, 587.
- Palmer, I. (1938), "On the Injuries to the Ligaments of the Knee Joint," Acta Chir. Scand., Vol. 81, Suppl. 53.
- Payr, E. (1927), "Der heutige Stand der Gelenkchirurgie," Arch. f. klin. Chir., 148, 404.
- Platt, H. (1940), "Traction Lesions of the External Popliteal Nerve," Lancet, 2, 612.
- von Rosen, S. (1941), "Zur Diagnose und Behandlung der Bandverletzungen des Kniegelenks," Acta Orth. Scand., 12, 117.
- Sfameni, P. (1902), "Recherches anatomiques sur l'existence des nerfs dans les tissus qui renforcent les articulations," Arch. ital. Biol., 38, 49.
- Valls, J. (1939), "Ruptures of the Lateral Ligaments of the Knee Joint," Amer. J. Surg., 43, 486.