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Experimental Study on Repair of Collateral Ligament

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Introduction

Among the growing incidence of factory accidents and sports traumas, the changes of encountering cases of digital collateral ligament impairment, with the main sign of instability of the ulnar collateral ligament of the thumb, represented by the so-called game-keepers' thumb[3,8,13], have been increasing.

However, there has been no definite theory, for its therapy, and some advocate conservative therapy[6], while others maintain surgical treatment[20] to be more beneficial. So, controversies on therapy as well as on periods for fixation have been brisk.

In this paper the authors present the results of the comparison between the conservative and the surgical treatments for digital collateral ligament impairments at an acute stage, using rabbit elbows as experimental models.

Formerly, various methods have been used on inveterate cases and those where end-to-end anastomosis was not possible. The authors also studied the usefulness of the tendon allograft, which we have previously used in the repair of the tendon, by comparing it with the use of tendon autograft.

Experimental Methods

One hundred and ten rabbits each weighing 2.0–3.0 kg were used in the experiment. Sodium pentobarbital was injected into the ear vein of the animals. With a lateral transverse incision at the elbow, the lateral collateral ligament, looking like a whitish-yellow band, and the site of the attachment of the extensor muscle were exposed. Then, the ligament including the attached muscle was cut transversely to incise the joint capsule. The unstable elbow was produced by applying the repeated force of supination and ulnar deviation of the elbow (Fig. 1).

Key words: Game-keepers' thumb, Collateral ligament, Scalloped edge, Autogenous tendon, Allogeneic tendon.
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Fig. 1. Unstable joint was produced by cutting lateral collateral ligament of the elbow.

The animals were divided into six groups and the following repair-work was made:

1) This group was left untreated after the cutting of the ligament and joint dislocation (Group-I).

2) In this group the ligament was fixed with cylindric cast after being cut, dislocated and reduced (Group-II).

3) For this group, the ligament was sutured with Kessler's modified method[10], using 6–0 prolene, and was fixed with cast (Group-III).

4) In this group the deep digital flexor-muscle tendon was extracted from the hind leg, and holes were put with the dental barr through the upper part of the capitulum of the humerus and the ulna, thus putting the tendon through the bones in the shape of a figure "8"[21] and then fixed with cast (Group-IV).

5) In this group, the cut parts of the ligament were repaired with processed allogeneic tendon (Group-V)[12,17–19]. The tendon was produced by the following procedure: The deep digital flexor-muscle tendon removed from the hind legs of rabbits was deproteinized with ficin, cross-linked with 0.05% glutaraldehyde, coated with atelocollagen, lyophilized, and irradiated with electron beams. Ligament reconstruction was performed similarly with that of Group-IV, and was fixed with cast.

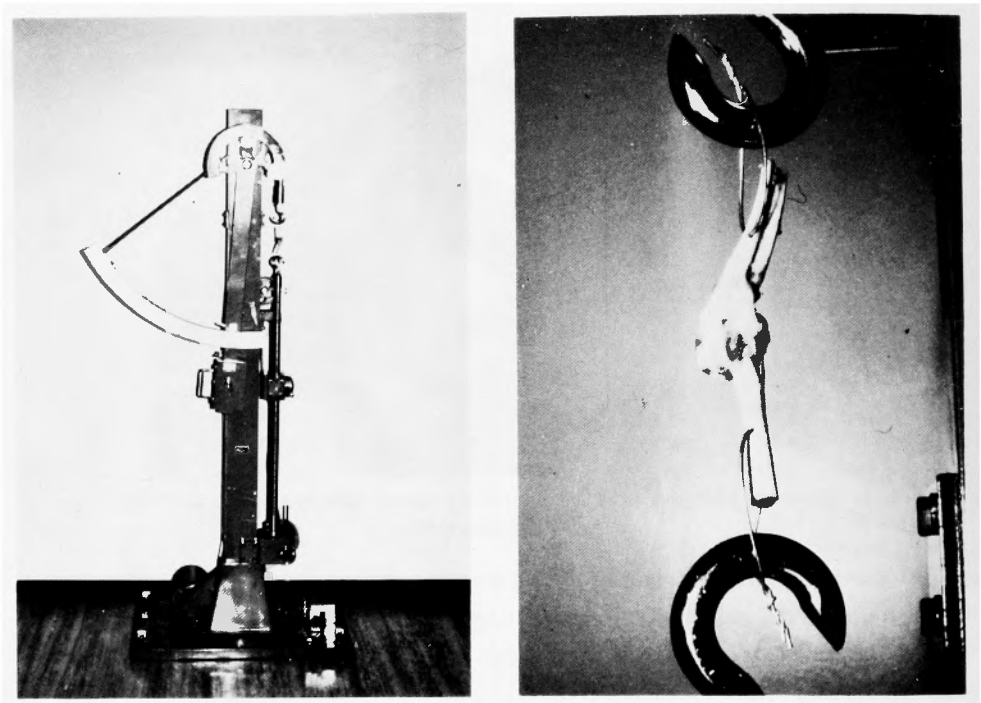
6) The group having a normal ligament (N), was made the control.

Methods of Observation

The animals were sacrified 3 or 6 weeks after the treatment and the following examinations were done.

(A) For histological examinations, haemotoxylon-eosin staining and AZAN staining were used, and further observation was made with micropolariscopy in order to investigate the alignment of collagen fibers.

(B) For biomechanical examinations[7,22,23], the physiological strength test, using the intro-



2-a 2-b

Fig. 2-a & b. Distraction strength test using Schopper's fiber tensile testor.
a: Testor, b: Elbow in the testor.

vertive tensive strength and the distraction strength test, using the 40-kg level Schopper's fiber tensile testor, were conducted (Fig. 2).

Results (Table 1)

(A) Histological examination[1]: In Group-I after 3 weeks, gaps were found macroscopically[4,9]. Histologically, the formation of granulation, vascularization, fibrocartilage[5] at the site where bones were attached, and bone resorptions were noted (Fig. 3). Micropolariscopy detected

Tabel 1. Results of histological examination.

Results

group / histological view	3 weeks' group					6 weeks' group				
	GI	GII	GIII	GIV	GV	GI	GII	GIII	GIV	GV
fibroblast infiltration in tendon				±	−				++	±
orientation of collagen fiber	−	−	±	±	−	±	±	+	++	±
continuity of collagen fiber at insertion	+	±	+	±	±	−	−	±	−	−
bony resorption at insertion	±	±	±	±	±	+	++	+	++	++

−: none ±: minimal +: moderate ++: severe
(GI): transection only, (GII): transection and plaster cast immobilization,
(GIII): suture and plaster cast immobilization, (GIV): using autogenous tendon graft,
(GV): using processed tendon allograft.



Fig. 3. Group I. Fibroblast proliferation was observed with bone resorption at bony insertion, after 3 weeks. (Azan, ×1000)

irregular connections of collagen fibers within bones.

After 6 weeks, regular alignment of fibers in some parts (Fig. 4) and scalloped edges due to bone resorption, were observed (Fig. 5).

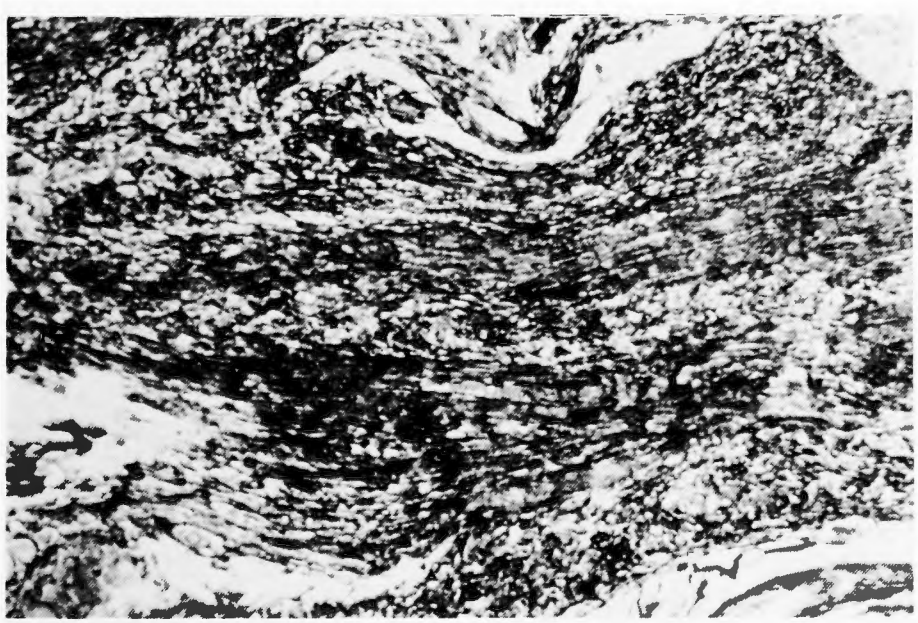


Fig. 4. Group I. Relatively parallel arrangement of collagen fibers was observed, after 6 weeks. (Azan, ×100)



Fig. 5. Group I. Scalloped edge due to bone absorption was observed at the bone insertion, after 6 weeks. (Azan, ×100)

In Group-II after 3 weeks, stronger resorption of bone at the site where bones were attached were noticed (Fig. 6), and after 6 weeks, better orientation of collagen fibers, similar to that in Group-I after 6 weeks was observed. Very strong resorption of bone were noted at the site attached to the bone, showing complete disconnection of collagen fibers between the bone and



Fig. 6. Group II. Marked bone absorption was observed, after 3 weeks. (Azan, ×100)

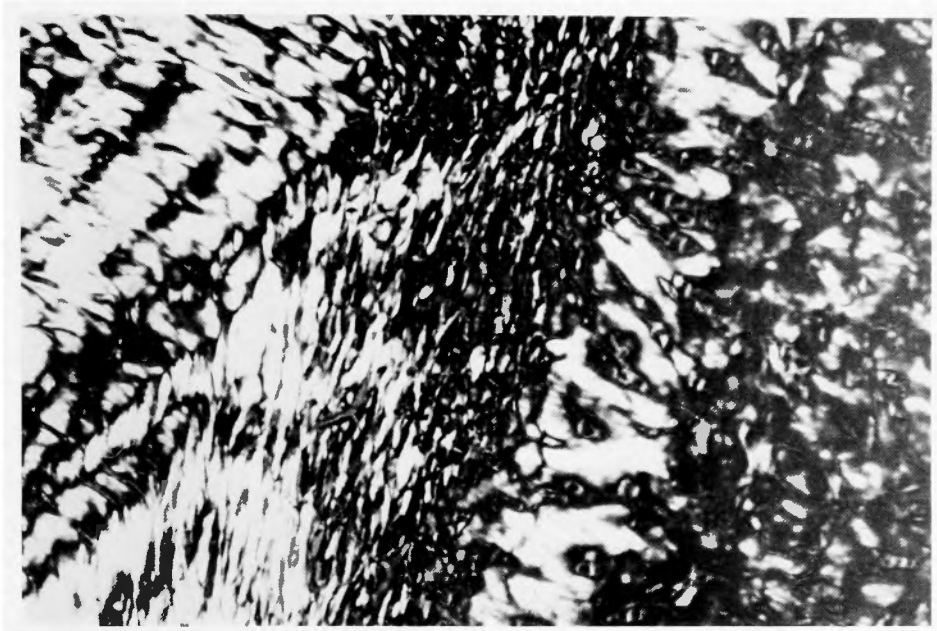


Fig. 7. Group III. Alignment of collagen was continuous, but was partly interrupted by fibrous tissue, at the bony insertion, 3 weeks after operation. (H & E stain, ×200, polarization)

ligament.

In Group-III after 3 weeks, similar to Group-I and Group-II, regular and partly parallel alignment of collagen fibers was observed, but at the insertion to the bone, the alignment of

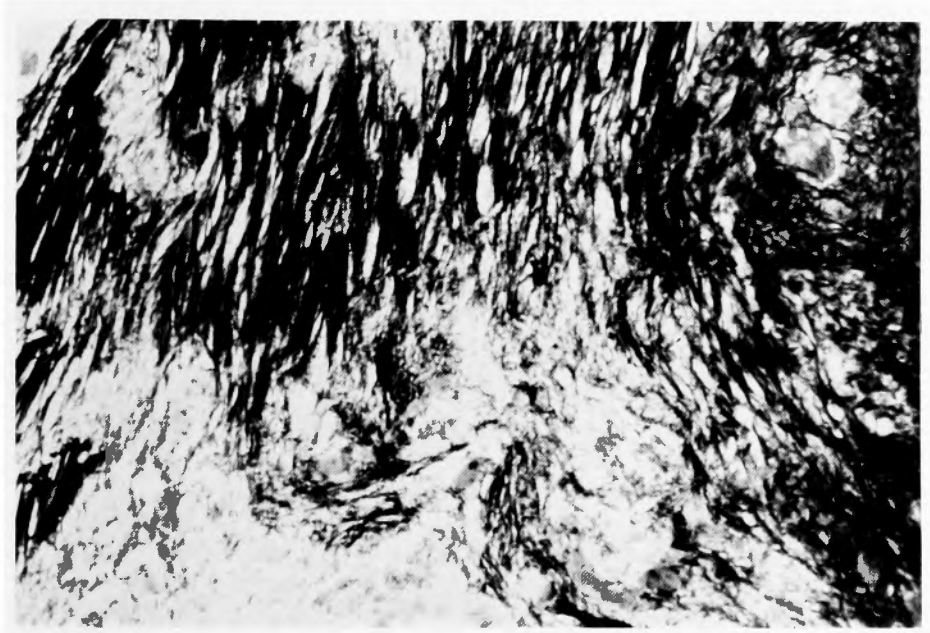


Fig. 8. Group III. Continuity of collagen fibers preserved at the site of bone insertion, after 6 weeks. (Azan, ×100)



Fig. 9. Group IV. Micropolariscopy revealed parallel alignment of collagen fibers in the grafted tendon, after 6 weeks. (H&E, ×100, polarization)

collagen fibers was continuous but irregular (Fig. 7). After 6 weeks, the alignment of collagen fibers was considerably stabilized (Fig. 8), and continuity of fibers at the site of bone insertion was preserved.

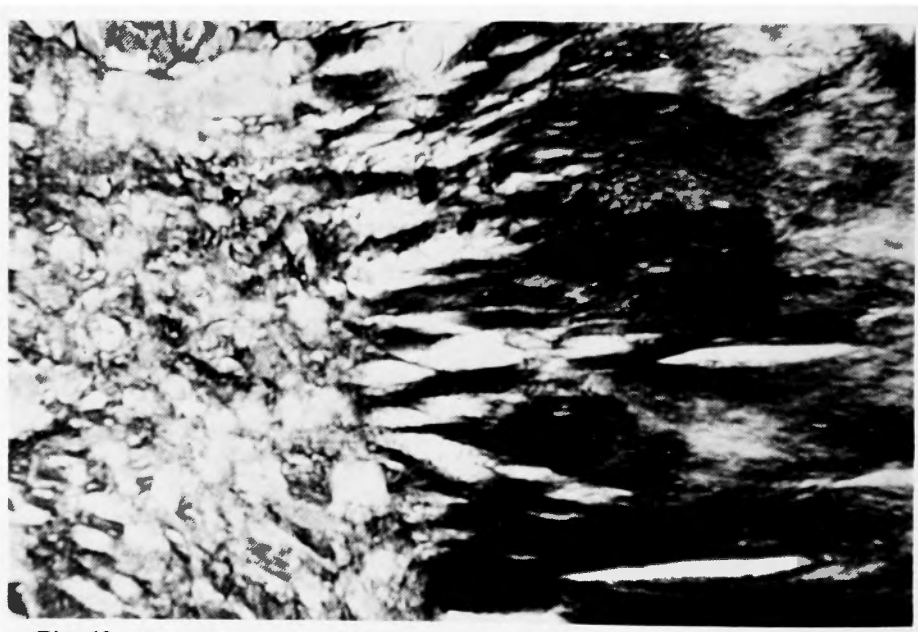


Fig. 10. Group V. At the junction between graft and host, infiltration of fibroblasts was observed to infiltrate into the graft. (Azan, ×400)

In Group-IV after 3 weeks, invasion of fibroblasts into the tendon from the surrounding regions, and preserved fiber cells within the tendon were detected, while after 6 weeks, regeneration of collagen fibers and invasion of affluent fibroblasts were noted. Furthermore, micropolariscopy clearly revealed parallel allignment of collagen fibers (Fig. 9).

In Group-V after 3 weeks, partial fragmentation of the treated tendon and infiltration of round cells and fibroblasts were noted, whereas after 6 weeks, fibroblasts aligned from the periphery to the center were noticed (Fig. 10).

(B) Biomechanical examinations: The physiological strength test found that avulsion fracture occurred at the normal ligament insertion to the ulna at a mean weight of 5 kg, but rupture of the ligament did not occur.

The strength in Group-IV after 3 weeks was 70% of that of the normal ligament, followed by 50% in Group-V, 30% in Group-III and 30% in Group-II and 20% in Group-I. The sites of rupture were the cut and suture sites.

After a lapse of 6 weeks, the strength of Group-IV and Group-III was 70% that of the normal ligament, followed by 50% in Group-V, 50% in Group-I, and 40% in Group-II. Rupture was noted at the injured site in Group-I and Group-II. In the other groups, ruptures were found at the distal bone insertion.

The distraction strength test using Schopper's fiber tensive strength testor, showed that avulsion fracture at bone insertion took place in the normal ligament by a mean weight of 10 kg. The strength was 45% of the normal ligament in Group-IV after 3 weeks, followed by 25% in Group-V, 20% in Group-III, 20% in Group-II and 15% in Group-I. With respect to the site of rupture, it was noted in Group-V that some distal regions at bone insertion, but almost all others occurred at the cut and sutured sites. After 6 weeks, the strength in Group-III was 70%

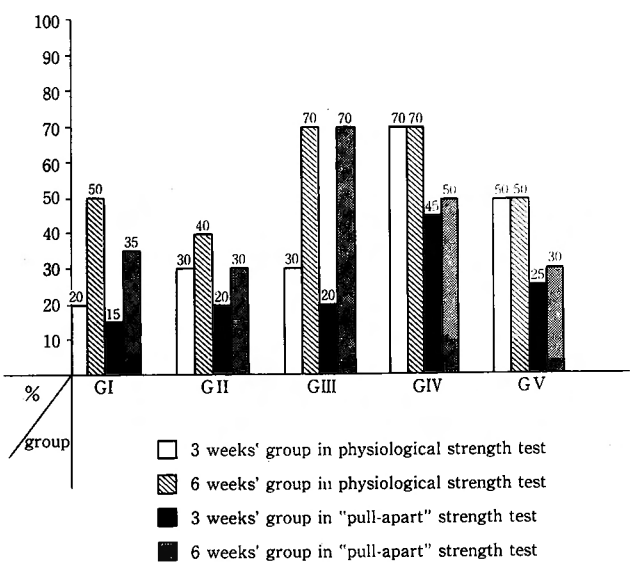


Fig. 11. Results of mechanical test.

that of the normal ligament, followed by 50% in Group-IV, 35% in Group-I, 30% in Group-V and 30% in Group-II. Although in Group-I and Group-II, rupture occurred at the cut sites, in other groups, it took place at the sites of bone insertion (Fig. 11).

Discussion

Rabbits' cubital joints were used as the experimental models for digital collateral ligament impairments. This was because 1) the rabbits' radio-ulnar joint presents syndesmosis, and no rotation is made, only movement of the sagittal surface, which closely resembles the movements of the human thumb MP and digital PIP, and 2) the size of the rabbits' cubital joint is nearly the size of the human digital joint, and the strength of the collateral ligament resembles one another.

One of the purposes of the present experiment was to compare the effects of conservative therapy to surgical therapy for digital collateral ligament impairments at an acute stage.

Sterner (1965)[20] recommends to restorting to surgical therapy for impairment of the thumb MP collateral ligament on the ulnar side in the acute stage, in consideration of the turning of the disrupted-end and the interposition of the adductor aponeurosis, whereas Coonrad et al. (1968)[6] reported that they obtained satisfactory results in many cases by fixing the joint with cast for 4 weeks. In our present experiment, histological studies revealed that Group-III was superior to Group-I and Group-II in the alignment of collagen fibers and the changes in the bone insertion, while dynamic examinations revealed that Group-III, an experimental model of surgical therapy, indicated the largest strength of 70% that of the normal ligament. All of this leads us to conclude, that Group-III was the best therapy at an acute stage. The results of the comparison of the strengths between Group-II, an experimental model of conservative therapy, and Group-I, in which no therapy was given, revealed that after 6 weeks Group-I was stronger than Group-II, whereas after 3 weeks, the outcome was the reverse.

In other words, fixation for 6 weeks in conservative therapy[14,15] was too long, and so, 4 to 5 weeks fixation was appropriate.

With regards to the site of rupture in experimental models in the acute stage, i.e. in Group-I, Group-II and Group-III, we found after 3 weeks rupture occurred at the cut and sutured sites, but after 6 weeks, they were noted at the site of insertion to the bones. Histological examination also confirmed disuse bone atrophy and disorganized alignment of collagen fibers without connection to the bone. Noyes (1977)[16] referred to this finding and reported that the strength became 61% that of the normal ligament after 8 weeks fixation, pointing out the enfeeblement of the ligament strength at the insertion site to the bone after a long-term fixation.

On the other hand, Laros et al. (1971)[11] stated that disuse atrophy occurred at the site of insertion to the bone which was replaced with a fibrous tissue, after 6 weeks, fixation, thus, the connection of collagen fibers to the bone was disrupted, simultaneously by bone resorptions. It is considered therefore that rehabilitation program after the removal of 6 weeks fixation should be given quite cautiously in clinical practice, since the insertion sites were much enfeebled.

Our other reason for the current experiment was the comparison of the uses of the autogenous

tendon and that of allogeneic and processed tendons in the reconstruction technique in chronic and inveterate cases, in order to examine the usefulness of the treated tendon.

The outcome showed that the autogenous tendon was stronger by 20% than the allogeneic tendon, both after 3 and 6 weeks. The finding was confirmed histologically in that the cell components were preserved in the autogenous tendon, while invasion of fibroblasts in the periphery alone was noted in the allogeneic tendon. In other words, the difference of the quantities of cell components may be represented in the difference of the strengths. The fragmented sites in both Group-IV and Group-V after 6 weeks were the regions into which the tendons were inserted.

Arnoczky et al. (1982)[2] reported that in the ligament reconstruction technique vascularization would start from the surrounding soft tissue, so that the invasion of blood vessels and fibroblasts into the tendon would be delayed. Accordingly, fixation of the tendon is the figure "8" shape through the bone would delay to the utmost the repair in the bone at the site through which the tendon was inserted, thus causing the resultant rupture.

Summary

An experiment was conducted in order to decide the therapeutic principles for fresh and chronic cases of digital collateral ligament impairments, using rabbit's lateral cubital collateral ligament impairment as the model.

Observations by tissue staining and strength tests revealed the following results:

1) In Group-III (sutured Group), regular alignment of collagen fibers at the repaired regions and bone insertion was found after 6 weeks' observation. Resorption of bone and interrupted connection of collagen fibers were noted at the bone insertion of ligament after 6 weeks fixation, and rupture was also detected in these region by distraction test.

In Group-III (sutured Group), as compared to Group-I (No-treatment Group) and Group-II (Fixed Group), satisfactory repairs were observed.

2) In Group-IV (Autogenous Tendon Group), invasion of affluent fibroblasts and parallel alignment of collagen fibers after 6 weeks were found.

In Group-V (allogeneic Tendon Group), invasion of fibroblasts only around the tendon was observed. Biomechanically, the strength was reduced to 50% in Group-V, whereas Group-IV revealed 70% of the strength of the normal tendon.

These findings suggest that in future improvement of preparation for allogeneic tendon was necessary in order to facilitate the regeneration of the tissue of the tendon.

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和文抄録

外側側副靱帯損傷の修復に関する実験的研究

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工場災害およびスポーツ外傷の多発とともに手の外傷，なかでも母指尺側々副靱帯の不安定性が主徴で，いわゆるゲームキーパーサムで代表される指側副靱帯損傷の症例に遭偶する機会が増えた．しかしその治療法についてはいまだ定説がなく，保存的療法，外科的療法など固定期間を含めて議論が多い．今回われわれは指側副靱帯損傷の急性期における治療で保存的治療と外科的治療の成績を比較するため家兎の肘を用い指側副靱帯損傷の実験モデルを作成し比較検討した．また従来より陳旧例および端々縫合が不可能な症例に対しては種々の方法が試みられているが，われわれは以前より腱修復の実験に用いてきた同種処理腱の有用性について検討を加えた．

本実験により以下のような結論がえられた．

① 内反抗張力による生理的テストとショッパー引張り試験器を用いた引き離し強度テストの二方法で力学的検索を行った．その結果，縫合群が最良である事が分った．② 固定群より放置群の方が6週で強度が大きかった事より6週間の固定は長すぎると考えられた．③ 自家腱修復群，同種処理腱修復群は3週と6週の間に強度の増加が少かった．このことは遅い血管新生，線維芽細胞の侵入によるものと考えられた．④ 3週群では主に切断部及び縫合部より切離され，6週群では骨付着部で切離され，廃用性萎縮により骨付着部が弱くなり切離されるものと考えられた．⑤ 同種処理腱修復群は力学的テストで自家腱群より低値を示した．この事は周辺部にのみ線維芽細胞の浸潤を示した組織学的所見と一致しており，今後長期の観察が必要であると考えられる．