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Replacement of the Anterior Cruciate Ligament

A Comparative Study of Four Different Methods of Reconstruction

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Summary. Eighty-seven patients have been examined 2 years on average after knee ligament reconstruction for a torn anterior cruciate ligament. The patients were divided into four groups according to the type of operation that had been carried out. In the first group an extra-articular lateral repair ("MacIntosh tenodesis") had been performed, in the second group an intra-articular "over-the-top" repair using the quadriceps and the patellar tendon, in the third group a modified "Eriksson" procedure using the patellar tendon, and in the fourth group a combined intra- and extra-articular repair using carbon fibres as a graft. The results of the operations in the different groups are compared. The best results were obtained with the "Eriksson" procedure, closely followed by the "over-the-top" repair. Limited range of motion and retropatellar pain resulting from changes in the alignment of the patella were the main problems. The results after the use of carbon fibres were less good. In two cases the graft tore without further trauma, and there were also problems because of restricted range of motion and retropatellar pain. The worst results were found after extra-articular lateral repair, due to insufficient stability in many cases. However, the best results with regard to the range of motion were found in this group.

Zusammenfassung. Es wurden 87 Patienten im Durchschnitt 2 Jahre nach Ersatzplastik bei zerrissenem vorderem Kreuzband und chronischer Instabilität nachkontrolliert. Die Patienten wurden in vier Gruppen eingeteilt. In jeder Gruppe war eine andere Art von Ersatzplastik durchgeführt worden. In der ersten Gruppe war es ein extraartikulärer „lateral repair" (sog. „MacIntosh-Plastik"), in der zweiten Gruppe eine intraartikuläre „over the top" geführte Plastik mit der Quadriceps- und der Patellarsehne, in der dritten eine modifizierte „Eriksson"-Plastik unter Verwendung der Patellarsehne und in der vierten Gruppe eine kombinierte intra- und extraartikuläre Plastik mit „Carbon fibres". Die Resultate der Operationen in allen vier Gruppen werden miteinander verglichen. Die besten Ergebnisse zeigte das Vorgehen nach „Eriksson", dicht gefolgt vom „over the top-repair". Probleme, die in diesen zwei Gruppen auftraten, betrafen eingeschränkte Kniebeweglichkeit und retropatelläre Schmerzen wegen veränderter Führung der Patella. Die Resultate in der Gruppe mit Verwendung der „carbon fibres" waren weniger gut. In zwei Fällen ist das Transplantat ohne Trauma gerissen, zudem traten auch hier Beschwerden auf wegen eingeschränkter Beweglichkeit und retropatellärer Schmerzen. Am wenigsten gut waren die Resultate nach extraartikulärem „lateral repair". In vielen Fällen konnte durch diese Methode keine genügende Stabilität erreicht werden. Andererseits war die Beweglichkeit des Kniegelenkes nach dieser Operation kaum je eingeschränkt.

Traumatic lesions of the ligaments of the knee caused by athletic activities and traffic accidents are becoming increasingly common. In the last decade, an extensive literature has been published on the anatomy and the mechanism of knee ligament injuries and on methods of repair. However, several questions in both diagnosis and treatment are still controversial. The type of treatment chosen is to some extent influenced by the interpretation of fundamental diagnostic questions. There is considerable confusion concerning the origin of the jerk sign, as first described by Hey-Groves in 1920 [13] and recently popularized by Galway et al. [12] under the term "lateral pivot shift". In his classical article in 1976, Hughston [14, 15] states

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that this sign is always associated with antero-lateral instability although the anterior cruciate ligament is not necessarily torn. Similar observations have been reported by Kennedy et al. [21, 22] and Slocum et al. [39]. Larson [23] reports that knee ligament injuries most often first lead to anteromedial instability, but if there is no adequate treatment, a *secondary* antero-lateral instability develops and the pivot shift sign then becomes positive. On the other hand, Fetto and Marshall [7] showed in their experimental study in 1979 that the pivot shift sign is positive in 89% of the cases, if *only* the anterior cruciate ligament is sectioned, but if it is intact, removal of the lateral structures does not create the pivot shift sign. The clinical equivalent to the pivot shift sign is the "giving way". The discomfort of the patient with chronic instability of the knee is closely related to the frequency of this unpleasant and uncontrollable occurrence. Reports on the natural history of untreated ruptures of the anterior cruciate ligament (McDaniel and Dameron [26] show that 68% of the patients are quite satisfied with their knee and 47% of them could take part in active sports without major restrictions almost 10 years after the trauma. However, if "giving way" occurs frequently, conservative treatment is of no help, and it does not disappear spontaneously. Therefore, the indication to operative treatment depends upon whether either the pivot shift sign can be produced and/or there is a history of giving way, or both signs are absent. The treatment should aim at eliminating these signs.

Many operations have been suggested for the treatment of chronic instability of the knee (Brückner [1], Campbell [3], Ellison [4, 5], Eriksson [6], Jenkins [17, 18], Jones [19], Lindemann [24], Losee et al. [25], MacIntosh [27], O'Donoghue [36], Palmer [37], Slocum [41]). They can be calssified into intra-articular, extra-articular, and combined repairs. In some respect, they reflect the authors opinion on the origin of the pivot shift sign. Hughston [14, 15] states that (except in hyperextension-trauma) the anterior cruciate ligament is only the "second line of defense". In all other mechanisms, the sprain occurs first in the lateral or medial structures, which are forming the "first line of denfense". The authors, who assume, that the pivot shift is caused by anterolateral instability and the anterior cruciate is not necessarily torn, propose an extraarticular repair (Ellison [4], Losee et al. [25], MacIntosh [16], Palmer [37]). They reinforce the "first line of defense". Those who assume that the pivot shift and the giving way are signs of a deficient function of the anterior cruciate ligament carry out an intra-articular repair, either with tendons (usually the patellar and eventually the quadriceps tendon) (Brückner [1], Campbell [3], Eriksson [6], Jones [19], Lindemann [24]), or with a free graft like autologous cutis (Willenegger and Baltensberger [43]) or carbon fibres (Jenkins [17], Jenkins and McKibbin [18]). MacIntosh (pers. commun.) recently started to use a combined intra- and extra-articular repair with a long strip of the iliotibial tract for anterolateral instability, thus replacing the anterior cruciate ligament as well as tightening the lateral compartment.

For most of these procedures, follow-up studies with large numbers of patients have been published, but few comparisons between the different methods have been reported. In this paper, results of the operative treatment of chronic instabilities of the knee with four different methods are reported. A follow-up time of 2 years seemed to be reasonable. All patients were examined by the same surgeon using the same criteria for all the patients. Although this is a retrospective study and the number of patients in each group is not large, we were able to make some interesting observations.

Material and Methods

Between 1975 and 1979 98 patients underwent reconstructive operations after knee ligament injury with rupture of the anterior cruciate ligament and chronic instability at the Dept. of Orthopaedics of the University of Basle. After 2 years on an average (between 1.2 and 4.1 years 87 of them were reviewed by one of the authors (F. H.).

Four different operative techniques have been used:

Extra-articular Lateral Reconstruction

Group 1 underwent an extraarticular lateral reconstruction as proposed by MacIntosh [11, 16]. This technique uses a strip of the iliotibial band based distally on Gerdy's tubercle. This strip is passed to the posterolateral corner of the knee through a tunnel deep to the fibular collateral ligament. A hiatus is created at the distal insertion of the lateral intermuscular septum. The strip is passed through it, looped back, and inserted near Gerdy's tubercle after being pulled taut with the knee flexed in 90° and the tibia externally rotated. The knee is then fixed in a long-leg cast in this position for 6–8 weeks (Fig. 1).

Intra-articular "Over-the-Top" Reconstruction

Group 2 had an intraarticular reconstruction of the anterior cruciate ligament as first described by Campbell in 1939 [3] and later popularized by Jones in 1963 [19]. An important additional element in this procedure is the "over-the-top" reconstruction as proposed by MacIntosh in 1974 [27]. For this operation a strip of the midportion of the quadriceps and patellar tendons was used. The strip was passed through a drill-hole from the tibial tuberosity to the anterior medial part of the intercondylar eminence. From here, the tendon was passed through the intercondylar notch and "over-the-top" of the lateral femoral condyle. Here the strip was fixed either with sutures or a small screw (Fig. 2).

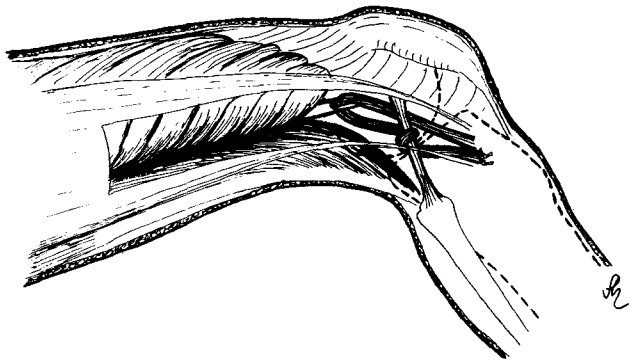

Fig. 1. Extra-articular lateral repair as proposed by MacIntosh viewed from the lateral side

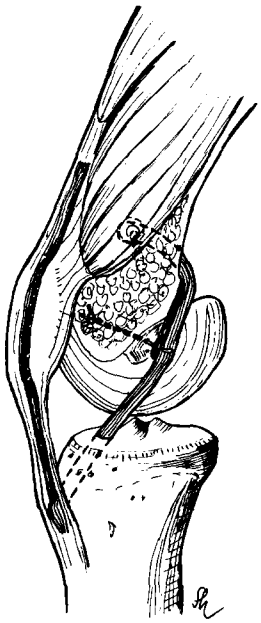

Fig. 2. Intra-articular "over-the-top" repair using a strip of the midportion of the quadriceps and the patellar tendon. View from the medial side. Sagittal section through the femur at the level of the intercondylar notch

Eriksson Procedure

In group 3 a modified Eriksson procedure was performed; basically, this is also an intra-articular replacement of the anterior cruciate, but without the "over-the-top" reconstruction. A strip of the midportion of the patellar tendon, beginning in the middle of the patella together with a bony piece of the surface of the patella is dissected free maintaining its base at the tibial tuberosity. The strip is passed through a drill-hole similar to the previous procedure. The bony piece of the patella is pressed into a small cleft in the bone (called "bec de canard"), made on the medial side of the lateral femoral condyle at the site of the original attachment of the anterior cruciate ligament. The end of the ligament outside the bec de canard is fixed with a thread that passes through a drill-hole to the external side of the lateral condyle ("through-the-top" method) (Fig. 3). The attachment must be situated far posteriorly on the lateral condyle. One can only reach this point, if the knee is flexed more than 90°. Although Eriksson [6] himself never observed the tendon being too short, we sometimes made this experience. In some patients the tendon was therefore detached from the tibial tubercle together with a bony piece and fixed with a screw. The drill-hole no longer started from the tibial tuberosity but from the medial tibial condyle.

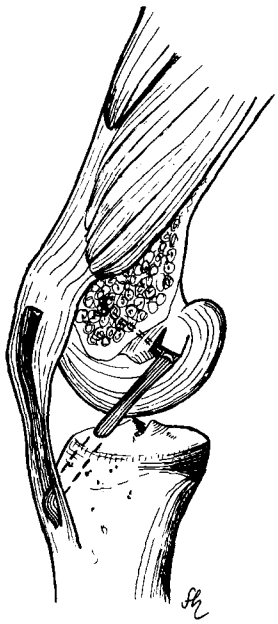

Fig. 3. Modified Eriksson procedure using a strip of the patellar tendon. View from the medial side. Sagittal section through the femur at the level of the intercondylar notch

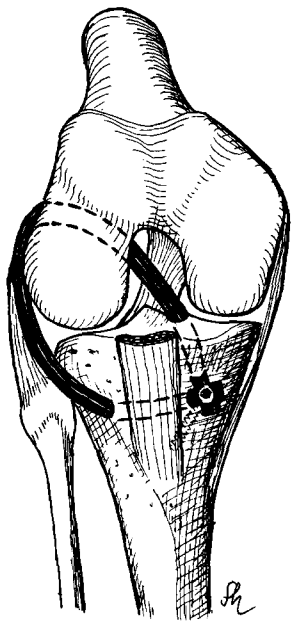

Fig. 4. Combined intra- and extra-articular repair using carbon fibres as a graft. Anterior view with knee in flexion

Table 1

Type of operation	Group				Total
	I. Lateral repair	II. "Over-the-top" repair	III. Eriksson-procedure	IV. Carbon fibres	
Number of patients operated on	13	31	29	25	98
Number of patients reviewed	12	27	25	23	87 (89%)
Time between trauma and operation	3.8 years (SD 3.3)	2.9 years (SD 3.6)	1.2 years (SD 2.1)	1.3 years (SD 2.3)	2.4 years
Age at operation	30.4 years (SD 9.2)	24.6 years (SD 7.2)	27.2 years (SD 7.3)	29.0 years (SD 11.6)	27.3 years

Table 2. Type of trauma

Professional activities	4 (5%)	
Vehicular trauma	9 (10%)	
Sports - soccer	71 (82%)	33 (47%)
- ski		13 (18%)
- handball		17 (24%)
- others		8 (11%)
Others	3 (3%)	
	100%	100%

Carbon Fibres

In group 4 carbon fibres were used as a graft, as introduced by Jenkins in 1978 [17]. The graft was passed from the medial side of the tibia through a drill-hole to the medial intercondylar eminence, then "over-the-top" of the lateral femoral condyle to the lateral side of the condyle. The fibres then passed down to Gerdy's tubercle and through a drill-hole under the tibial tuberosity to the medial side of the tibia, where both ends were attached with a screw, thus forming a ring (Fig. 4). This procedure represents a combined intra- and extra-articular repair. In the intra-articular portion, the fibres were usually covered by synovial membrane. In seven cases they were reinforced by residues of the original ligament. In six cases a strip of the patellar tendon was added to the carbon fibres.

Table 1 shows the *number of patients in each group*. Group 1 includes less patients than the others because we abandoned this method as an isolated repair in late 1977.

The *time lapse between trauma and operation* averaged 2.4 years (0.2–7 years). It was longer in the first two groups than in groups 3 and 4.

The *origin of trauma* (Table 2) was athletic injury in 82%, predominantly soccer, skiing and handball.

The *indication* for the operation was usually a history of "giving way". Ninety per cent of the patients complained about such disabling occurences, 70% were seriously limited in their athletic activities, 63% complained of at least occasional pain, and 45% of recurrent effusions or swelling. Limited range of motion or a history of locking was observed in 28%. The pivot shift sign was found positive in 72%.

The average *age* of the patients at the time of the operation was 27.3 years (14–52 years) and very similar in all four groups.

Table 3 lists the *additional operations* that have been carried out at the same time as the main reconstructive procedure. Frequent additional operations were medial and lateral meniscectomies, lateral releases, and *pes anserinus* transfers, the latter being considered a reinforcement procedure and not a reconstruction in its own right.

The *postoperative management* included cast fixation in all cases. Its duration was 8 weeks following lateral repair and 7 weeks following the "over-the-top" procedure, while it was only 5 weeks after the Eriksson procedure and the utilization of carbon fibres. Physiotherapy by isometric exercises for the quadriceps was initiated a few days after the operation. The average duration of assisted physiotherapy was 18 weeks; it was significantly longer after the lateral repair (23 weeks) than after the Eriksson procedure (15 weeks).

The *clinical examination at the time of follow-up* was made in accordance to the suggestions of Hughston et al. [14, 15] and later of Müller [31, 33], former coworker of our department, who had introduced most of the diagnostic methods in our clinic in the mid-seventies. The pivot shift sign was examined as proposed by Galway et al. [11, 12], and the Lachman test was examined as described by Torg et al. [42]. For evaluation we rated the knees according to the evaluation system of the Hospital for Special Surgery in New York as deviced by Marshall et al. [29, 30] and also used in other publications (e.g. MacDaniel and Dameron [26]). It is a rating which gives 50 points to a fully normal knee. A very good result has more than 45 points, a good result more than 40 points, a moderate between 36, and 40 points and a bad result less than 36 points.

Results

Postoperative Course (Table 4)

On average patients regained normal *walking* ability 5 months after surgery. They returned to *work* after a mean time of 4.1 months and returned cautiously to some *sporting activity* after 10 months.

A few patients had to undergo *secondary interventions* on the same knee. The most serious ones were in four patients, where new ligament reconstructions had to be carried out because of disabling instability without further trauma. In one patient several addi-

Table 3. Additional procedures

Type of operation	Group				Total
	I. Lateral repair	II. "Over-the-top" repair	III. Eriksson procedure	IV. Carbon fibres	
Patients reviewed	12	27	25	23	87
Med. meniscectomy	1	7	12	5	25
Lat. meniscectomy	2	3	3	4	12
Repair of the medial structure		5	4	2	11
Repair of the med. post. angle		3	2	5	10
Repair of the lat. post. angle		3	2		5
Suture of the post. cruc. lig.			1		1
Ellison procedure		4			4
pes anserinus transfer		2	9	14	25
O'Donoghue procedure		2			2
Use of patellar tendon				6	6
Use of parts of the cruc. lig.				7	7
Lateral release	2	3	14	15	34
Elmslie procedure			2	6	8
Shaving of the patella	1	2	1	3	7
Internal fixation of fracture of the tibial condyle				1	1

Table 4. History of the time between the operation and the follow-up

Type of operation	Group				Total	Significant differences between groups
	I. Lateral repair 12	II. "Over-the-top" repair 27	III. Eriksson procedure 25	IV. Carbon fibres 23	87	
Regained normal walking ability after (months)	4.9 (SD 4.8)	5.2 (SD 2.2)	4.0 (SD 2.5)	4.8 (SD 4.8)	4.7	–
Returned to work after (months)	5.8 (SD 2.5)	4.5 (SD 3.8)	3.0 (SD 1.6)	3.9 (SD 3.2)	4.1	I-III[a]
Started with sporting activity after (months)	8.8 (SD 7.0)	12.6 (SD 5.6)	8.2 (SD 4.3)	9.4 (SD 6.4)	10.0	II-III[a]
Secondary interventions on the same knee: Number of patients (number of interventions)						
Ligament reconstruction after significant trauma			2 (2)		2 (2)	
Ligament reconstruction without significant trauma	1 (5)	1 (1)		2 (2)	4 (8)	
Mobilization in general anaesthesia	1 (1)	5 (8)	2 (3)	4 (5)	12 (17)	
Arthroscopy		1 (1)	2 (2)	1 (1)	4 (4)	
Operation because of chondromalacia of patella		2 (2)	1 (1)		3 (3)	
Other interventions		1 (1)	1 (1)		2 (2)	

[a] = $P < 0.01$

Table 5. Activities and complaints at the time of follow-up

Type of operation	Group				Total
	I. Lateral repair	II. "Over-the-top" repair	III. Eriksson procedure	IV. Carbon fibres	
Patients reviewed	12	27	25	23	87
Time between operation and follow-up (years)	1.93 years (SD 1.1)	2.37 years (SD 0.8)	2.08 years (SD 0.9)	1.41 years (SD 0.5)	1.99 years
Working ability:					
– full	9 (75%)	24 (89%)	23 (92%)	19 (83%)	76 (87%)
– limited	1 (8%)	1 (4%)	2 (8%)	3 (13%)	6 (7%)
– unable to work	1 (8%)				1 (1%)
– change of profession	1 (8%)	2 (7%)		1 (4%)	4 (5%)
Sporting activity:					
– unlimited	1 (8%)	5 (19%)	8 (32%)	3 (13%)	17 (20%)
– limited	8 (67%)	16 (59%)	15 (60%)	13 (57%)	52 (60%)
– abandoned	3 (25%)	4 (15%)	1 (4%)	5 (22%)	13 (15%)
– never performed sports		2 (7%)	1 (4%)	2 (8%)	5 (5%)
Pain:					
– never	6 (50%)	8 (30%)	11 (44%)	9 (39%)	34 (39%)
– occasionally	4 (33%)	16 (59%)	14 (54%)	10 (43%)	44 (51%)
– frequently	2 (17%)	3 (11%)		4 (18%)	9 (10%)
Instability:					
– never	4 (33%)	16 (59%)	20 (80%)	15 (65%)	55 (63%)
– occasionally	4 (33%)	10 (37%)	4 (16%)	6 (26%)	24 (28%)
– frequently	4 (33%)	1 (4%)	1 (4%)	2 (9%)	8 (9%)
Giving way:					
– never	7 (58%)	24 (89%)	22 (88%)	20 (88%)	73 (84%)
– occasionally	3 (25%)	2 (7%)	3 (12%)	2 (8%)	10 (11%)
– frequently	2 (17%)	1 (4%)		1 (4%)	4 (5%)

tional stabilizing operations had to be performed after a lateral repair. Two patients needed a second knee ligament reconstruction after a new adequate trauma (ski injuries). The patellar tendon graft was torn in both cases. Histological examination, however, showed good vascularization of the graft. Twelve patients had to be mobilized in general anaesthesia because of limited range of motion. Three patients had additional operations because of retropatellar pain, and four patients underwent arthroscopies for diagnosis of residual pain.

Activities and Complaints at the Time of Follow-up (Table 5)

Two years after the reconstructive procedure 87% of the patients *worked* in their original profession without limitations, 7% were limited in their professional activities (mainly construction workers), 1% was still unable to work at the time of follow-up. Four patients (5%) had changed their profession to a physically less strenuous activity.

At the time of the review only 20% took part in *athletic activities* without any restriction, of those who had had lateral repairs only one patient. On the other hand, 80% of the patients were still taking part in sports, mostly in the same kind as before the accident, but 3/4 of them felt limitations for certain movements or they avoided specific movements because of a slight uncertainty. Five per cent of the patients had not had performed sports prior to the trauma, and only 15% did not return to athletic activities after the operation. The results in that respect are best for the Eriksson procedure and worst for the lateral repair.

Fifty-one per cent of the patients complained of occasional and 10% of frequent *pain or discomfort*

Table 6. Clinical examination at the time of follow-up

Type of operation	Group				Total
	I. Lateral repair	II. "Over-the-top" repair	III. Eriksson procedure	IV. Carbon fibres	
Patients reviewed	12	27	25	23	87
Circumference at the level of the knee joint space					
– equal	9 (75%)	12 (44%)	15 (60%)	12 (52%)	48 (55%)
– difference up to 2 cm	2 (17%)	14 (52%)	9 (36%)	9 (39%)	34 (39%)
– difference more than 2 cm	1 (8%)	1 (4%)	1 (4%)	2 (9%)	5 (6%)
Circumference 15 cm proximal to the knee joint space					
– equal	4 (33%)	9 (33%)	10 (40%)	8 (35%)	31 (36%)
– atrophy up to 2 cm	5 (42%)	14 (52%)	11 (44%)	12 (52%)	42 (48%)
– atrophy more than 2 cm	3 (25%)	4 (15%)	4 (16%)	3 (13%)	14 (16%)
Flexion					
– equal	10 (83%)	7 (26%)	8 (32%)	7 (30%)	32 (37%)
– limitation up to 20°	2 (17%)	15 (55%)	14 (56%)	12 (52%)	43 (49%)
– limitation more than 20°	–	5 (19%)	3 (12%)	4 (18%)	12 (14%)
Extension					
– equal	12 (100%)	24 (89%)	21 (84%)	18 (78%)	75 (86%)
– limitation up to 10°	–	2 (7%)	3 (12%)	4 (18%)	9 (10%)
– limitation more than 10°	–	1 (4%)	1 (4%)	1 (4%)	3 (4%)
Retropatellar pain					
– none	4 (33%)	10 (37%)	19 (76%)	13 (57%)	46 (53%)
– mild	7 (59%)	13 (58%)	6 (24%)	6 (26%)	32 (37%)
– marked	1 (8%)	4 (15%)	–	4 (19%)	9 (10%)
Anterior drawer sign					
– none	–	3 (11%)	1 (4%)	3 (13%)	7 (8%)
– up to 5 mm (+)	6 (50%)	19 (70%)	18 (72%)	11 (49%)	54 (62%)
– up to 10 mm (++)	3 (25%)	4 (15%)	4 (16%)	7 (30%)	18 (21%)
– more than 10 mm (+++)	3 (25%)	1 (4%)	2 (8%)	2 (8%)	8 (9%)
Posterior drawer sign					
– none	11 (92%)	27 (100%)	24 (96%)	22 (96%)	84 (96%)
– up to 5 mm (+)	–	–	1 (4%)	1 (4%)	2 (3%)
– up to 10 mm (++)	1 (4%)	–	–	–	1 (1%)
– more than 10 mm (+++)	–	–	–	–	–
Medial opening to valgus stress					
– none	6 (50%)	14 (52%)	16 (64%)	15 (65%)	51 (59%)
– mild in 30° flexion	4 (33%)	10 (37%)	8 (32%)	6 (27%)	27 (31%)
– moderate in 30° flexion	2 (17%)	3 (11%)	1 (4%)	2 (8%)	9 (10%)
– in extension	–	–	–	–	–
Lateral opening to varus stress					
– none	5 (42%)	16 (59%)	15 (60%)	12 (52%)	48 (55%)
– mild in 30° flexion	4 (33%)	10 (37%)	7 (28%)	7 (30%)	28 (32%)
– moderate in 30° flexion	3 (25%)	1 (4%)	3 (12%)	4 (18%)	11 (13%)
– in extension	–	–	–	–	–
Pivot shift sign positive	2 (25%)	1 (4%)	1 (4%)	2 (8%)	6 (7%)

Table 7. Overall rating of the results

Type of operation	Group				Total	Significant differences between groups
	I. Lateral repair	II. "Over-the-top" repair	III. Eriksson procedure	IV. Carbon fibres		
Patients reviewed	12	27	25	23	87	
Personal opinion of the patient:						
– very good	4 (33%)	10 (37%)	6 (24%)	8 (35%)	28 (32%)	
– good	3 (25%)	12 (44%)	17 (68%)	10 (43%)	42 (48%)	
– moderate	4 (33%)	4 (15%)	2 (8%)	5 (22%)	15 (16%)	
– unsatisfactory	1 (9%)	1 (4%)	–	2 (9%)	4 (4%)	
Assessment according to the score sheet of the "Hospital of Special Surgery" in New York: (46–50 points = very good; 41–45 points = good; 36–40 points = moderate; less than 36 points = bad)						
– very good	2 (17%)	7 (26%)	8 (32%)	5 (22%)	22 (25%)	
– good	5 (42%)	15 (55%)	13 (52%)	12 (53%)	45 (51%)	
– moderate	4 (33%)	3 (11%)	4 (16%)	6 (26%)	17 (19%)	
– bad	1 (8%)	2 (8%)	–	2 (9%)	5 (5%)	
Mean score	39.55 (SD 5.1)	42.75 (SD 4.4)	43.85 (SD 2.4)	40.15 (SD 5.2)	41.95	I-II[a]; I-III[b]; III-IV[a]

[a] = $P<0.05$; [b] = $P<0.01$

(usually after strenuous activities). Sixty-three per cent of the patients have not complained of any *instability* since surgery, 28% felt this occasionally, and 9% frequently; half of the patients in the latter group had undergone the lateral repair. Eleven per cent of the patients reported that some sort of giving way had occurred since the operation, 5% suffered this incident more frequently.

Clinical Examination at the Time of Follow-up (Table 8)

The *circumference* at the level of the *knee joint space* was equal on both the healthy and the operated side in 55%, there was an increase of up to 2 cm on the affected side in 39% and even more in 6%. The results here are best in the lateral repair group and worst in the group with the "over-the-top" repair.

The *circumference* of the *quadriceps muscle* (measured 15 cm proximal to the knee joint space) was equal on both sides in 36%, there was atrophy of up to 2 cm on the injured side in 48% and even more in 16%. The differences between the groups are negligible.

The *range of motion* for flexion was unlimited in 37%, there was a limitation of up to 20° in 49%, and even more than 20° in 14%. Full extension could be achieved in 80%, limited extension of up to 10° was found in 10% and over 10° in 4%. The results concerning the range of motion are clearly best in the group who had the lateral repair and quite equal in all the intra-articular procedures with a slight disadvantage for the "over-the-top" repair.

A noticeable finding was that 37% of the patients complained of slight *retropatellar discomfort* and 10% of severe retropatellar pain. The best results were achieved in those patients who had undergone the Eriksson procedure or the carbon fibre operation. In these groups, a lateral release had frequently been combined with the reconstructive procedure.

Examination of Stability

The anterior drawer sign was negative in 8%, there was an anterior drawer sign of up to 5 mm (+) in 62%, of up to 10 mm (++) in 21% and of more than 10 mm (+++) in 9%. Ninety-six of the patients had a negative posterior drawer sign, a sign of up to 5 mm (+) was found in 3% and only one patient had a more marked posterior drawer sign with a soft endpoint. On valgus or varus stress in full extension, there was no opening-up of the medial or lateral joint-space. In flexed position of 30°, there was no medial instability to valgus stress in 59%, a slight instability (+) in 31% and a marked one (++) in 10°. No lateral instability in 30° flexion to varus stress was found in 55%, a slight instability (+) in 31% and a more marked one (++) in 13%. The pivot shift sign and the jerk test were found positive in 7%. Although the Lachman test has proven its value for the examination of a recently injured knee, we do not find it very useful

Table 8. Patients with moderate or bad results and the main reasons for the failure

Lateral repair	
M. A.	instability
M. F.	instability
R. L.	instability
R. N.	retropatellar pain
H. Z.	instability
"Over-the-top" repair	
B. K.	retropatellar pain
B. M.	retropatellar pain
R. R.	limitation of the range of motion
E. R.	retropatellar pain
J. S.	limitation of the range of motion
Eriksson procedure	
E. G.	limitation of the range of motion
R. J.	limitation of the range of motion
H. S.	instability
R. S.	instability
Carbon fibres	
H. A.	retropatellar pain
S. A.	limitation of the range of motion
H. B.	retropatellar pain
M. G.	retropatellar pain
J. H.	instability
A. K.	instability
A. S.	limitation of the range of motion
D. V.	limitation of the range of motion

for following up patients after surgery. On physical examination stability was clearly worst in the group who had the lateral repair. The best results were obtained in the group with the "over-the-top" repair, closely followed by the group with the Eriksson procedure.

Overall Rating of the Results (Table 7)

The *personal opinion* of the patients upon the result of the operation was good or very good in 80%, 16% of the patients were satisfied with a moderate result and only 4% felt that the result was unsatisfactory.

According to the *evaluation system of the "Hospital for Special Surgery"* the result was rated very good in 25%, good in 51%, moderate in 19% and bad in 5%. Thus, the subjective opinion of the patients gives slightly better figures.

Comparing the average ratings in the four groups (Table 7), we clearly have the best results in the group with the Eriksson procedure, closely followed by the "over-the-top" repair. The overall results of the carbon-fibre group are markedly worse, and the lateral repair gave the lowest ratings. The difference between the first two groups and the latter ones is statistically significant. For statistical evaluation we used Student's *t*-test. The normal distribution of the variables was controlled.

Table 8 showes a listing of the patients with moderate or bad results and the main pathological symptom. In the lateral repair, this was obviously predominantly instability. In the "over-the-top" procedure the causes of failure were limitations of the range of motion or problems with the patella. The Eriksson procedure left a limited range of motion in two cases and instability in another two. After the implantation of carbon fibers all three reasons of failure appeared.

Discussion

The goal of our follow-up study was to compare the results of four different types of knee ligament reconstructions for a torn anterior cruciate ligament. Knee ligament injuries are usually very complex and the results are therefore difficult to compare. The only common preoperative finding was an anterior instability and a torn anterior cruciate ligament (which was usually confirmed arthroscopically in those patients, who underwent a lateral repair). In 90% of the patients there was also a history of "giving way". The pivot shift sign was found positive in only 72% of the patients preoperatively. Although Noesberger [34] states that the pivot shift sign is always positive with a torn anterior cruciate ligament this is no contradiction. Demonstration of the sign depends very much on the experience of the examiner and the actual muscular tension of the patient.

We were unable to classify the preoperative type of instability (straight or different types of rotatory or combined instabilities as described by Hughston [14, 15]) in all the cases, because the data on the medical records were not sufficiently reliable for a clear classification. The fact that many additional operations apart from the main reconstructive procedure had to be carried out reflects the complexity of the injuries. They can, of course, have an uncalculable influence on the results. Although we are aware of this problem, it is not possible to eliminate or to evaluate these uncalculable criteria.

The choice of the main operative procedure did not essentially depend on the type of injury. We used the same operative procedure for a limited period of time to collect experience with the method in patients

with a torn anterior cruciate ligament with a history of giving way and/or a positive pivot shift sign. The groups are comparable because the type of the injury did not influence the choice of the procedure. The methods of repair were used in patients with a very disabling instability. The patients therefore represented a negative selection of those in whom conservative treatment was not satisfactory.

Assessment of the Final Results in the Four Groups

The *lateral repair* showed the best results regarding the range of motion inspite of a long-term cast fixation in an unfavourable position (in 90° of flexion and externally rotated). To some extent this may be due to the fact that these patients had assisted physiotherapy for a longer period of time (23 weeks). It clearly reflects that the procedure is an extra-articular one and does not cause adhesions within the joint itself. The overall results of this method, however, are clearly the worst of all four groups. The main reason for the bad results is a remaining instability in most of the cases. Although the operation usually eliminates the pivot shift sign, it does not increase the stability of the joint to a significant extent. The patients still feel an uncertainty, some of them even report frequent episodes of giving way, and this often prevents them from athletic activities. MacIntosh (pers. commun.) himself has abandoned this procedure.

The *"over-the-top" procedure* produced good overall results. The remaining instability hardly ever caused problems. The less satisfactory results were either due to limitations of the range of motion or to retropatellar pain. The first symptom is certainly due to the fact, that the intervention is intra-articular. Furthermore, the site of attachment of the graft on the lateral condyle is of greatest importance; if the graft is placed too far anteriorly, limitations of the range of motion result. Limitations of extension cause much discomfort, but also the limitations of flexion are not negligible. Depending on the profession or on the type of athletic activity this can disturb the patient considerably. The patient is handicapped in squating down. We always controlled this position as well as "duck walking". Retropatellar pain is also quite common after this operation, possibly due to a change in the alignment of the patella after removal of a part of the patellar tendon. In this group, we did not carry out the lateral relase very often in contrast to the Eriksson group, and this might have an unfavourable influence.

In the *"Eriksson-group"* we observed the best overall results. The few moderate results were due to limitations of the range of motion and in two cases to instability. Here again, it is important that the graft is implanted far enough posteriorly on the medial side of the lateral femoral condyle. Although Eriksson [6] himself states that the graft is never too short, we quite often observed this difficulty. For this reason, we now no longer leave the patellar tendon strip in its original attachment at the tibial tuberosity, but we excise it with a large piece of bone and make a channel from the medial side. After the proximal insertion in the *bec de canard* we can now choose the length distally and insert the graft with the piece of bone in the channel through the tibia with a screw. Two of the patients had remaining instabilities, but these were not very pronounced. Two patients had to be reoperated after a new significant trauma. Both cases were satisfied with the result prior to the second injury and were performing strenuous athletic activities. In this group we hardly ever noted problems with retropatellar pain. We attribute this to the fact that the lateral release had often been carried out together with the reconstruction. An advantage of the Eriksson method as compared to the "over-the-top" repair lies in the fact that the procedure is easier to carry out and the operation time is shorter.

The results of the operations with *carbon fibres* are not much better than those with lateral repair. The best results were obtained where remaining parts of the anterior cruciate or a strip of the patellar tendon had been added to the carbon fibres. In two cases the carbon fibres were torn, which led to marked and disabling instability and the patients had to be reoperated. One of the joints was full of black debris. It might also be possible that this kind of foreign body material is responsible for retropatellar pain in some of the remaining cases because this discomfort was quite frequent in this group inspite of the lateral release. On the external side of the lateral femoral condyle, where the carbon fibres had been fixed, we often noted a very thick cord of fibrous tissue, which also occasionally caused some discomfort.

Our follow-up study does not answer all the controversial questions on knee ligament injuries with a torn anterior cruciate ligament, but it emphasizes the following points: In anterior instability with a torn anterior cruciate ligament and a positive pivot shift sign and/or a history of giving way, an extra-articular repair does not supply sufficient stability. Replacement of the anterior cruciate ligament with patellar tendon can furnish excellent stability in long-term follow-up. The use of foreign material, such as carbon fibres alone without addition of ligamentous or tendinous tissue, is not sufficient and can produce new problems. We therefore emphasize that the subjective feeling of instability and the positive pivot shift sign are closely related to the lack of a functioning anterior

cruciate ligament or its replacement. It is essential that the central pivot, which is the anterior cruciate ligament, is replaced. Attention should be paid to the correct attachment of the graft far posteriorly on the medial side of the lateral femoral condyle to avoid limitations of the range of motion and secondary laxity due to excessive tension on the graft, as well as to the alignment of the patella to avoid retropatellar pain. Carbon fibres should only be used together with tendinous or ligamentous tissue. Recently, the fibres have become available in woven strips, which diminishes the risk of early tear. We have recently started to use them wrapped up in a long strip, of the iliotibial tract. The course of the tendinous strip is similar to the one now used by McIntosh (pers. commun.); it is based on Gerdy's tubercle, goes "over-the-top" of the lateral femoral condyle, passes through a drill hole from the medial intercondylar eminence to the medial side of the tibia and then underneath the tibial tuberosity to the lateral side, where the strip is attached again at Gerdy's tubercle, thus forming a ring. This again is a combined intra- and extra-articular repair. We usually do not use such a large strip of the iliotibial tract as MacIntosh does, but we reinforce it, as already mentioned, by carbon fibres. The experience with this procedure has been favourable up to now.

We have to make high demands on the effect of a reconstructive procedure because reports on untreated patients with torn anterior cruciate ligaments also show good and satisfactory results in a high percentage [8, 26, 38]. Treated and untreated patients, of course, cannot be compared with each other without restrictions. Patients who ask for a treatment with a chronic unstable knee represent a negative selection. They might have a more serious injury, they obviously feel more discomfort and they probably are more active in athletics than those who are satisfied without treatment. This, however, does not reduce the high demands on the effect of the operation. In our experience, only intra-articular repairs (possibly combined with extra-articular substitution) meet all the requirements. It seems to be very important for good long-term results to have the central pivot reconstructed.

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