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The outcome at 15 years of endoscopic anterior cruciate ligament reconstruction using hamstring tendon autograft for 'isolated' anterior cruciate ligament rupture

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The purpose of this study was to report the outcome of 'isolated' anterior cruciate ligament (ACL) ruptures treated with anatomical endoscopic reconstruction using hamstring tendon autograft at a mean of 15 years (14.25 to 16.9). A total of 100 consecutive men and 100 consecutive women with 'isolated' ACL rupture underwent four-strand hamstring tendon reconstruction with anteromedial portal femoral tunnel drilling and interference screw fixation by a single surgeon. Details were recorded pre-operatively and at one, two, seven and 15 years post-operatively. Outcomes included clinical examination, subjective and objective scoring systems, and radiological assessment. At 15 years only eight of 118 patients (7%) had moderate or severe osteo-arthritic changes (International Knee Documentation Committee Grades C and D), and 79 of 152 patients (52%) still performed very strenuous activities. Overall graft survival at 15 years was 83% (1.1% failure per year). Patients aged < 18 years at the time of surgery and patients with > 2 mm of laxity at one year had a threefold increase in the risk of suffering a rupture of the graft (p = 0.002 and p = 0.001, respectively). There was no increase in laxity of the graft over time.

ACL reconstructive surgery in patients with an 'isolated' rupture using this technique shows good results 15 years post-operatively with respect to ligamentous stability, objective and subjective outcomes, and does not appear to cause osteoarthritis.

Long-term outcomes (> ten years) of endoscopic anterior cruciate ligament (ACL) reconstruction with the bone–patellar tendon–bone (BPTB) graft have been reported,[1,2] but the outcome of endoscopic ACL reconstruction with the hamstring tendon (HT) graft beyond ten years has not.

A variety of ACL reconstruction techniques have been shown to be successful in restoring stability to the knee, but questions remain over their role in preventing osteoarthritis (OA). A recent review article has concluded that the available literature is not sufficient to answer this question with certainty.[3] Several authors have recorded that the rate of OA is greater in ACL-reconstructed knees than those treated conservatively,[4-6] suggesting that the surgery itself might be a cause of degenerative change. It is known that concomitant soft-tissue damage at the time of the initial injury contributes to the development of OA[7-9]; therefore, by longitudinally evaluating patients who have had an ACL reconstruction without significant other intra-articular injuries, we hope to understand the natural history of the procedure, in particular regarding the onset of OA.

The choice of graft in ACL reconstruction is still a matter of surgeon preference. HT graft

has traditionally been thought of as prone to increasing laxity compared with other graft types. Some prospective studies have shown increased laxity following ACL reconstruction with HT on clinical and instrumented testing compared with reconstruction using BPTB.[10,11] We are unaware of any long-term clinical studies with clear information on this matter.

Patients and Methods

All patients undergoing primary ACL reconstruction performed by the senior author (LAP) were considered for the study. We defined 'isolated' ACL ruptures by excluding: 1) associated ligamentous injury requiring surgical treatment; 2) significant chondral damage (any full-thickness cartilage defect) or degeneration; 3) previous meniscectomy; 4) excision of one-third or more of one meniscus and no significant root avulsion or meniscal instability; 5) abnormal radiological findings; 6) abnormality in the contralateral knee; 7) those seeking compensation for their injuries; and 8) those who did not wish to participate. Ethical approval was granted.

A total of 1131 patients had a primary ACL reconstruction performed with HT autograft

in our unit between October 1993 and March 1996. In all, 215 met the inclusion criteria, and of these the first consecutive 100 men and 100 women were included in the trial. Their mean age at surgery was 25.8 years (14 to 62), and 152 patients (76%) had their reconstruction performed within 12 weeks of injury. There were 99 left-sided reconstructions and 101 right-sided. All associated injuries were documented at the time of operation. Reconstruction was performed in the subacute (after four weeks) or chronic phase (more than 12 weeks), when the knee was pain free and mobile.

Surgical technique. All operations were performed by the senior author (LAP). The technique[12] and post-operative rehabilitation[13] have previously been reported in detail. We used a 'single-incision' endoscopic technique, using a four-strand ipsilateral HT autograft. Anatomical femoral tunnel drilling was performed via the anteromedial portal. Graft fixation in both tunnels was performed using 7 mm × 25 mm titanium round cannulated interference (RCI) screws (Smith & Nephew, Andover, Massachusetts). If required, meniscal repair was performed with a non-absorbable monofilament suture using an inside-out technique. Patients were permitted to bear weight using crutches immediately after surgery, and no brace was used. An accelerated rehabilitation programme was instituted. Return to competitive sport was prohibited until six months after the operation, and only after rehabilitation goals had been met.

Clinical assessment. Patients were assessed pre-operatively and at one, two, seven and 15 years after surgery, including the Lysholm knee score[14] and the International Knee Documentation Committee (IKDC) score.[15] The Lysholm knee score is a subjective evaluation questionnaire designed specifically for injuries of the knee ligaments. It includes questions on symptoms such as pain, stability and locking, to assess the impact of the injury on the patient's daily activities. It is a 100-point scoring system with between 84 and 90 graded as 'good' and > 90 graded as 'excellent'. The IKDC score is an instrument designed to measure symptoms, function and sports activities in patients who have had knee injuries. Grade A is considered to be a 'normal' knee, grade B a 'nearly normal' knee, grade C an 'abnormal' knee and grade D is considered a 'severely abnormal' knee.

Ligamentous laxity was measured using a KT-1000 arthrometer (MEDmetric Corp., San Diego, California) and clinical examination with Lachman[16] and pivot-shift tests was undertaken. All assessments were graded as a difference from the normal contralateral side. The Lachman test was graded as 0 (< 3 mm), 1 (3 to 5 mm), or 2 (> 5 mm); the pivot-shift test was graded as 0 (negative), 1 (glide), 2 (clunk) or 3 (gross). All clinical examinations were performed by the senior author (LAP), an orthopaedic fellow or a research physiotherapist.

Radiological assessment. Pre-operatively and at two, seven and 15 years post-operatively, weight-bearing anteroposterior, 30° flexion posteroanterior, lateral and patellofemoral

view radiographs were taken. Radiographs were graded by an independent musculoskeletal radiologist (JL) using the IKDC radiological grading system.[15] A mild grade (B, nearly normal) indicates minimal changes (small osteophytes, slight sclerosis or flattening of the femoral condyle) and narrowing of the joint space that is just detectable. A moderate grade (C, abnormal) may have those changes and joint space narrowing (such as a joint space of 2 mm to 4 mm or narrowing of up to 50%). Severe changes (grade D, severely abnormal) include a joint space < 2 mm or narrowing of the joint space > 50%.[17] Tunnel position was assessed in the sagittal and coronal planes, and the inclination angle of the graft was measured.[18] Ideal positioning of the graft was defined as the tibial tunnel being 40% to 50% posterior on the tibial plateau in the sagittal plane, and the femoral tunnel being > 80% posterior along Blumensaat's line[19] in the sagittal plane, and a graft inclination angle of > 15° in the coronal plane.

Radiological assessment for osteoarthritis was only made from radiographs taken at 15-year follow-up. Tunnel position was assessed from any available post-operative radiograph to maximise the number of assessments available for this part of study.

Statistical analysis. The outcomes were compared between selected subgroups using the Mann-Whitney U test for continuous measurements (mean KT-1000 arthrometer, Lysholm score, radiological tunnel placement) and ordered categorical variables (IKDC categories, Lachman, pivot-shift test). Changes over time in related data were assessed with the Wilcoxon signed rank test. Logistic regression was used for the relationship between radiological outcomes and the variables of further surgery and tunnel placement. Survival of the ACL graft and contralateral ACL was calculated using the Kaplan-Meier survival method with 95% confidence intervals (CI). Survival curves were compared with log-rank tests and univariate Cox's regression. Factors that were significant (p < 0.05) on univariate survival analysis were entered into multivariate Cox regression and then eliminated in a stepwise fashion, until only the independent significant factors remained. Statistical significance was set at 5%.

Results

The mean follow-up was 15 years (14.3 to 16.9). The participant flow is shown in Figure 1. In all, 14 patients were lost to follow-up; of the remaining 186 patients, 33 were excluded because of rupture of their ACL graft and one was excluded due to rupture of the posterior cruciate ligament. This left a total of 152 patients available to provide a subjective opinion on the outcome at a mean of 15 years. However, 15 of these patients had ruptured their contralateral ACL and so could not participate in an objective assessment.

Operative findings. The lateral meniscus was intact in 176 patients (88%) and in 184 patients (92%) the medial meniscus was intact at the time of surgery. In 20 patients (10%) meniscal tears required suturing, and 20 (10%) required excision of less than one-third of the meniscus. Of

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                        ┌─────────────────────────┐
                        │  Primary ACL reconstructions │
                        │        n = 1004         │
                        └─────────────────────────┘
                                    │
                                    ▼
                        ┌─────────────────────────┐
                        │     Enrolled in study   │
                        │        n = 200          │
                        └─────────────────────────┘
                                    │
                                    │────────────────────────►  ┌─────────────────────┐
                                    │                            │  Lost to follow-up  │
                                    │                            │       n = 14        │
                                    ▼                            └─────────────────────┘
                        ┌─────────────────────────┐
                        │     Outcome known       │
                        │     n = 186 (93%)       │
                        └─────────────────────────┘
                                    │
                                    │────────────────────────►  ┌──────────────────────────────┐
                                    │                            │ Excluded due to ACL graft rupture │
                                    │                            │            n = 33            │
                                    │                            └──────────────────────────────┘
                                    │
                                    │────────────────────────►  ┌──────────────────────────────┐
                                    │                            │    Excluded due to PCL       │
                                    │                            │      rupture n = 1           │
                                    ▼                            └──────────────────────────────┘
                        ┌─────────────────────────┐
                        │  Patients with subjective │
                        │  15 year review n = 152 │
                        └─────────────────────────┘
                          │                      │
                          ▼                      ▼
      ┌──────────────────────────┐   ┌──────────────────────────────────────────┐
      │ Intact contralateral ACL │   │ Contralateral ACL rupture n = 15 excluded from │
      │        n = 137           │   │         objective clinical review          │
      └──────────────────────────┘   └──────────────────────────────────────────┘
                  │
                  ▼
      ┌────────────────────────────────────────┐
      │ Intact contralateral ACL and objective review │
      │                n = 114                 │
      └────────────────────────────────────────┘
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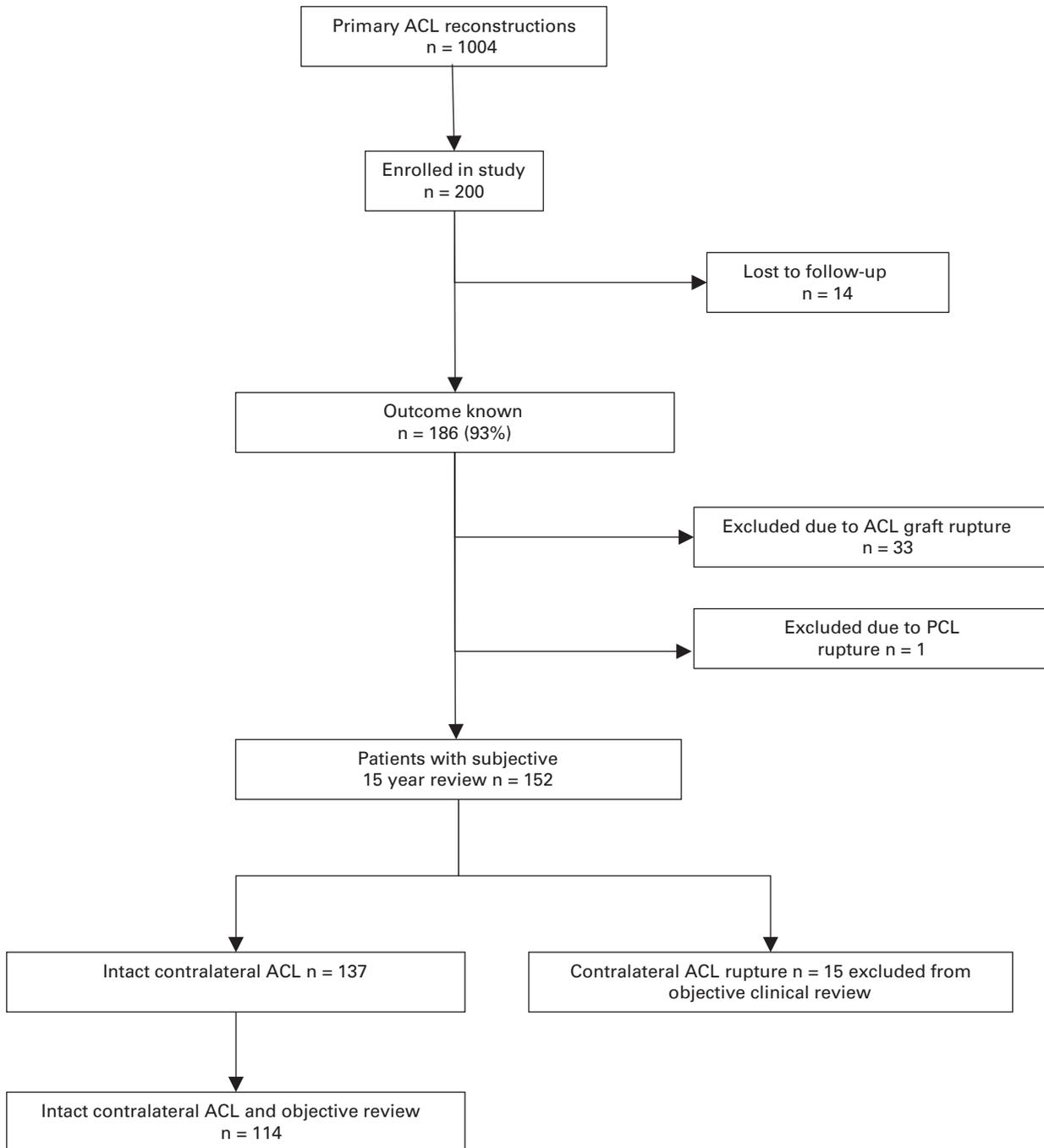
Fig. 1

Participant flowchart (ACL, anterior cruciate ligament; PCL, posterior cruciate ligament).

the 20 patients who underwent meniscal suture, seven went on to have a further arthroscopic meniscectomy at a mean of 57 months (7 to 150).

Subjective knee scores. A total of 152 patients underwent subjective assessment at 15 years. The mean Lysholm knee score at 15 years was 93 (41 to 100); a total of 143 patients (94%) had a good or excellent Lysholm score at one year and 134 (88%) had good or excellent scores at 15 years

(p = 0.25, Wilcoxon). The mean IKDC subjective score at 15 years was 90 (44 to 100). At 15 years after surgery 79 of 152 patients (52%) reported they were regularly participating in very strenuous activities such as side stepping and pivoting team ball sports.

IKDC grade. A total of 114 patients with an intact contralateral ACL underwent objective review at 15 years (Fig. 1). Of these, 112 patients (98%) had a normal or nearly

Table I. The International Knee Documentation Committee (IKDC) radiological grade in each compartment of the knee at 15 years (n = 118)

	IKDC grade (n, %)			
	A	**B**	**C**	**D**
Medial	69 (*59*)	45 (*38*)	4 (*3*)	0 (*0*)
Lateral	92 (*78*)	23 (*20*)	2 (*2*)	1 (*1*)
Patellofemoral	104 (*88*)	13 (*11*)	0 (*0*)	1 (*1*)
Overall IKDC grade	60 (*51*)	50 (*42*)	6 (*5*)	2 (*2*)
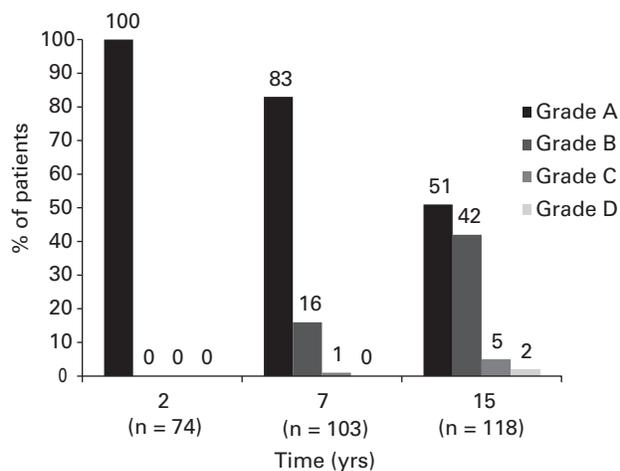
Fig. 2

Histogram showing the proportion of patients with a normal overall International Knee Documentation Committee (IKDC) radiological examination. There was a significant decrease in the number of patients with a Grade A (normal) radiological examination result between seven and 15 years (p = 0.001, Wilcoxon).

Fig. 3a

Fig. 3b

Weight-bearing 30° flexion radiographs a) laterally, showing measurement of tunnel placements, and b) posteroanteriorly, showing the measurement of the graft inclination angle.

normal overall IKDC examination (grades A and B). If those with an ACL graft rupture are assumed to have an abnormal grade, then the proportion of patients with a normal or nearly normal grade was 112 of 147 (76%).

Radiological assessment. A total of 118 patients with intact ACL grafts had knee radiographs performed at 15 years. Results are shown in Table I and Figure 2. The most degenerative compartment determines the overall IKDC radiological grade. Pre-operatively and at two years, no patient had an abnormal radiological examination. There was a significant decrease in the proportion of patients with a normal radiological examination result between seven and 15 years (p < 0.001, Wilcoxon). There was a poor correlation between radiological grade and subjective scores (r = -0.11).

Of the 33 patients who sustained a rupture of the ACL graft, radiographs at 15 years were available for 24; these were normal in six patients; there were grade B changes in 14 and grade C changes in four. Compared with patients with intact ACL grafts, those with ruptures of the graft had a significantly greater incidence of abnormal radiological changes (p = 0.02, Mann-Whitney).

Regression analysis of radiological assessment. Any further knee surgery was associated with abnormal radiographs at 15 years (odds ratio (OR) 18 (95% CI 4 to 88, p < 0.001). Non-ideal tunnel placement was not signifi-

cantly associated with abnormal radiographs at 15 years (OR 0.99; 95% CI 0.2 to 4.5, p = 0.75).

Radiological tunnel placement. A total of 186 patients (93%) had a suitable post-operative radiograph available for review. In these patients, the tibial tunnel was a mean of 48% (SD 6%) posteriorly along the tibial plateau and the femoral tunnel was a mean of 86% (SD 5%) posteriorly along Blumensaat's line. The mean coronal graft inclination angle was 19° (SD 5°). In all, 69 of 186 patients (37%) were thought to have ideal tunnel placement, an example of which is shown in Figure 3.

Of these 186 patients with post-operative radiographs available, there were 30 who sustained a rupture of the ACL graft. These 30 patients had more posteriorly placed tibial tunnels than those with intact grafts (p = 0.04, Mann-Whitney). There was no difference between those with a

Table II. Comparison of the parameters of tunnel placement between patients with ruptured and those with intact grafts at 15 years

	Intact graft	Ruptured graft	p-value[*]
Number of patients (n)	156	30	
Mean (SD) tunnel placement			
Sagittal femoral (%)	*86* (4)	*85* (6)	0.47
Sagittal tibial (%)	*47* (6)	*49* (7)	0.04
Mean (SD) coronal graft inclination (°)	19 (5)	18 (5)	0.64

*Mann-Whitney U test
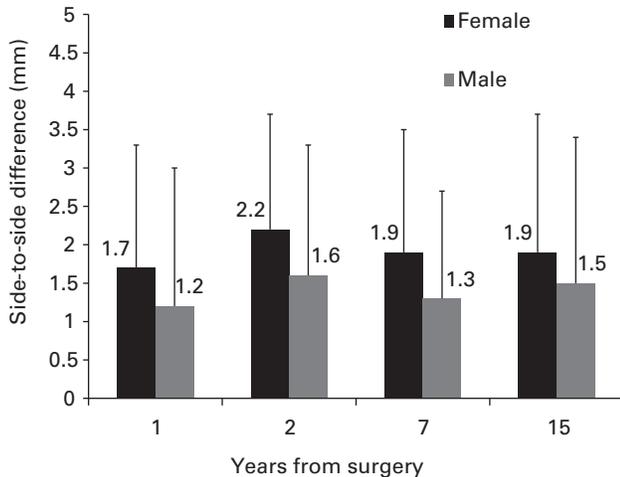
Fig. 4

Histogram showing the mean (SD in error bars) side-to-side difference in KT-1000 instrumented testing at each review by gender. Females had a significantly higher KT-1000 side-to-side difference at one (p = 0.03), two (p = 0.04) and seven years (p = 0.02), but no significant difference at 15 years (p = 0.44, all Mann-Whitney U test).

rupture of the graft and those with an intact graft in femoral placement (p = 0.47, Mann-Whitney) or graft angle (p = 0.64, Mann-Whitney) (Table II). If the tibial tunnel was outside the ideal placement, the incidence of rupture was 18 of 79 patients (23%), compared with 12 of 107 (11%) of those with intact ACL grafts (p = 0.03, Mann-Whitney).

Instrumented ligament testing. Testing was performed on 150 patients at one year, 156 patients at two years, 125 patients at seven years, and 112 patients at 15 years. The mean manual maximum side-to-side difference for men was 1.6 mm (SD 1.9) and for women was 1.9 mm (SD 1.8). There was no statistically significant difference between the two-year and the 15-year results of patients who attended both sessions (p = 0.96). At 15 years there were no significant gender differences (p = 0.44, Mann-Whitney) (Fig. 4).

Lachman test. The Lachman test was performed in 114 patients at 15 years. There were no Lachman tests greater than grade 1, and 85 patients (75%) patients had a grade 0. There was no difference between the two-year and the 15-year results (p = 0.96, Wilcoxon). Significant differences were identified between males and females at one, two

and seven years, where females had greater laxity, but there was no significant gender difference at 15 years (p = 0.23, Wilcoxon).

Pivot-shift test. Pivot-shift tests were undertaken in 114 patients at 15 years. There were no pivot-shift tests greater than grade 1, and 98 of 114 patients (86%) were a grade 0. Significant differences were identified between males and females at one, two and seven years, but there was no significant gender difference at 15 years (p = 0.09, Mann-Whitney). There was no difference between the two-year and the 15-year results (p = 0.96, Wilcoxon).

Rupture of the ACL graft. A total of 33 of the 186 (18%) patients with a known outcome at 15 years had sustained a rupture of the graft at a mean of 53 months (2 to 180) postoperatively. In total, 25 of these patients had a revision procedure; the remaining eight chose not to have further surgery. A non-ideal graft position was identified in 21 of 30 patients with appropriate radiographs, and in 14 patients the rupture of the graft occurred in the first two years.

The Kaplan–Meier survival rate for the ACL reconstruction in all patients was 93% at two years, 89% at five years, 85% at ten years and 83% at 15 years. There was no significant difference between males and females (p = 0.74, Cox regression), or between those with HT graft diameter ≤ 7 mm and those with graft size > 7 mm (p = 0.81, Cox regression).

The results of the univariate and multivariate regression analyses on graft rupture are shown in Tables III and IV, respectively.

In all, 18 (9%) patients suffered a contralateral ACL rupture at a mean of 66 months (6 to 176) post-operatively. Three males (1.5%) suffered both a contralateral ACL rupture and a rupture of the graft.

A total of 11 patients sustained a medial meniscal tear and underwent arthroscopic meniscectomy at a mean of 44 months (7 to 150) post-operatively. Three patients required subsequent lateral meniscectomy at 22, 36 and 123 months post-operatively, respectively. One patient subsequently underwent high tibial osteotomy.

Discussion

In the knowledge that concomitant injuries can have a deleterious effect on outcomes,[20,21] the purpose of this study was to determine the 15-year outcomes of 'isolated' ACL ruptures reconstructed using hamstring tendon autograft.

Table III. Univariate Cox's regression of potential risk factors for anterior cruciate ligament (ACL) graft rupture (CI, confidence interval)

Factor and category	Number	2-year survival (%)	5-year survival (%)	10-year survival (%)	15-year survival (%)	Hazard ratio (%)	95% CI	p-value
Age at surgery (yrs)								
≤ 18	38	82	71	68	66	3.0	1.5 to 6.0	0.002
> 18	148	95	93	89	86			
Laxity on 1-year instrumented KT-1000 manual maximum testing								
> 2 mm	51	84	80	73	71	2.9	1.4 to 5.9	0.004
≤ 2 mm	129	98	94	91	88			
Radiological tibial tunnel placement*								
Non-ideal	117	92	85	79	76	2.1	1.1 to 4.6	0.035
Ideal	69	94	93	90	88			
Age and gender								
Male; ≤ 18	13	62	62	54	54	4.0	1.6 to 9.7	0.002
Female; ≤ 18	25	92	76	76	72			
Male; > 18	79	95	91	87	86			
Female; > 18	69	96	96	90	87			

* ideal ACL graft tibial tunnel position defined as: tibial tunnel 40% to 50% posterior along the tibial plateau in the sagittal plane

Clinical assessment and level of activity. At 15 years the mean IKDC subjective score was 90 and the mean Lysholm score was 93. If those patients who sustained an ACL rupture were assumed to be 'abnormal', the overall objective IKDC scores were 'normal' or 'nearly normal' in 76%. There are no other long-term reports using HT, but long term BTPB studies have shown similar results, with between 74% and 100% of patients being graded 'normal' or 'nearly normal'.[1,2]

Radiological assessment. On radiological assessment at 15 years we found an incidence of 7% of patients with moderate or severe degenerative change. This is low compared with other series: Kessler et al[6] reported an incidence of moderate or severe changes osteo-arthritic changes of 43% at 11 years after reconstruction, von Porat, Roos and Roos[22] found an incidence of 41% at 14 years, and Lohmander et al[23] found an incidence of 51% at 12 years. The low incidence in our series may due in part to the exclusion of patients with other injuries to the joint from our series, so we have a group with the best chance of having a 'near normal' knee again. The effect of concomitant intra-articular damage at the time of injury is well known, and it contributes unquestionably to post-traumatic degeneration.[24,25] Having intact menisci is known to be protective against osteoarthritis[26] and to enhance the stability of the knee.[27] This is further reinforced in this series by the finding that the biggest predictor of degenerative changes in the 15-year radiographs was further knee surgery.

Secondly, although it is accepted that ACL reconstruction causes an alteration to normal knee kinematics,[28] we suspect that the extent to which this happens will depend upon the quality of the reconstruction. Non-anatomical reconstructive techniques are likely to 'over-constrain' the knee and thus create abnormal shear forces within the joint. A recent study on articular cartilage and ACL reconstruction has shown that abnormal shear stresses following this procedure will lead to early cartilage matrix degenera-

Table IV. Multivariate Cox's regression of significant risk factors for anterior cruciate ligament graft rupture (CI, confidence interval)

Risk factor	Hazard ratio (95% CI)	p-value
Age (yrs)		
≤ 18 years *versus* > 18 years	2.3 (1.1 to 4.9)	0.03
Laxity on 1-year instrumented testing		
MMT < 3 mm *versus* ≥ 3 mm	2.6 (1.3 to 4.9)	0.009

tion.[29] We suspect that the high incidence of OA previously reported[6,22,23] is due to more invasive surgery being performed through larger incisions and a non-anatomical graft position.

Recording the true incidence of OA following ACL reconstruction is difficult owing to the many confounding factors. According to the Framingham Osteoarthritis Study,[30] the incidence of OA in the tibiofemoral joint in patients over the age of 25 years is 13.8%. In our study the incidence of moderate or severe OA in patients with a mean age of 41 years was 7%. In addition, patients who had a rupture of the graft had a higher incidence (17%) of grades C and D degenerative changes at 15 years than those with intact grafts (7%) (p = 0.02). The data suggest that ACL reconstruction using this technique does not cause osteoarthritis, but is likely to have a protective effect on the joint.

Ligament testing. There was no change in the Lachman tests, pivot-shift tests or KT-1000 examinations between two and 15 years (p = 0.96), suggesting that HT graft does not elongate over this time. An early laxity of > 2 mm on manual maximum testing at one year increased the odds of rupture of the graft by a factor of 3 (p = 0.001). These high, early rates of rupture of the graft may be related to the ligamentisation process,[31] where the graft tissue remodels from a ten-

dinous to a ligamentous biochemical and histological form, specific to the native ACL. This process is thought to take up to two years to complete.[32,33] During this time the graft may be vulnerable to rupture as it remodels. Biochemical and histological analyses have shown that the graft does not gain sufficient mechanical strength for at least one year.[33] The clinical relevance of this is to be cautious if there remains laxity one year post-operatively. With a threefold increased rupture rate it may be advisable to delay a return to high-level activity in these patients and prolong their rehabilitation until ligamentisation is complete.

There have been minor changes to our surgical technique during the course of this study in an ongoing attempt to optimise fixation of the graft. The 7 mm × 25 mm interference screws used for all fixations in this study were the only size available at the time (1993 and 1994). Subsequent analysis of these patients revealed some laxity in right knees[34] and in females with soft tibial bone.[12] These findings have been incorporated into current practice using undersized-diameter screws in hard bone such as on the femoral side, and oversized-diameter and longer screws in soft bone, which is usually on the tibial side.

Graft survival. Rupture of the graft occurred in 17% of patients over 15 years (1.1% per year). Between ten and 15 years, the rates of rupture of BPTB grafts of 6% to 13% have been reported.[1,2] As graft rupture is relatively rare, only a study involving a very large number of patients will determine whether a true difference exists between graft types.

An important finding from this study was that patients ≤ 18 years of age at the time of ACL reconstruction were over three times more likely to rupture their graft than those > 18 years (p = 0.03). This finding has been reported previously[35] and may be due to the exposure of younger patients to higher-risk activities and at a greater intensity than older patients. Young males in this study group presented the greatest risk and were found to have four times the risk of rupture of the graft than other subgroups. This has highlighted the importance of additional advice for these patients. More careful attention should be paid to their rehabilitation, expectations, and the possible use of neuromuscular and proprioceptive training programmes.[36]

Tunnel placement. Non-ideal tunnel placement has previously been reported to have an adverse effect on the outcome,[37] and our study confirms this. In 79% of patients who sustained a rupture of the graft we were able to find an error in graft position. Most of these errors were in the placement of the tibial tunnel, which was mostly too posterior and was associated with graft rupture (p = 0.04). Although the biomechanical reason for this is unclear, we suspect this finding does not prevent any other malposition, either on the tibial or the femoral side, from having a detrimental effect on the graft. Unfortunately, the numbers in this study are too low to allow us to draw any conclusions about other non-ideal tunnel placements. Any non-isometric positioning is likely to have an adverse effect on the graft owing to abnormal forces during activity.

There has been much recent work on the anatomy of the footprint of the ACL[38,39] in an attempt to restore normal knee kinematics as closely as possible. However, given that the cross-sectional area of the ligament is about 40 mm^2, and that the cross-sectional area of the insertions is about 150 mm^2, it is clear that ACL fibres splay out, creating parabolic curves at their insertion. This anatomical arrangement results in recruitment of fibres when the ACL is placed under load. However, it is not possible to recreate such anatomy, and one must consider the functional insertion of longitudinal fibres with a direct course from femur to tibia. These would appear to be in the posteromedial tibial footprint and the proximal and lateral femoral footprint in the intercondylar notch. These are the sites that are associated with the radiological 'ideal' tunnels that we aimed to obtain.

At examination at 15 years after surgery with this technique, three in four patients can expect to have a normal or nearly normal knee. Contrary to previous studies, ACL reconstruction does not appear to cause osteoarthritis and 93% of patients will have normal or only subtle changes on radiographs at 15 years. Hamstring tendons proved to be a reliable graft and did not show evidence of elongation with time. It is important to obtain the correct tunnel placement to ensure a good outcome in the long term.

Supplementary material

ë A table giving details of the 33 patients who sustained an anterior cruciate ligament (ACL) graft rupture over the 15 years, and five Kaplan-Meier survival curves for a) all patients, b) age ≤ 18 years *versus* > 18 years, c) male and female patients aged ≤ 18 years and > 18 years, d) instrumented laxity > 2 mm *versus* ≤ 2 mm, and e) ideal *versus* non-ideal tunnel placement, are available with the electronic version of this article on our website www.jbjs.boneandjoint.org.uk

References

1. **Lebel B, Hulet C, Galaud B, et al.** Arthroscopic reconstruction of the anterior cruciate ligament using bone-patellar tendon-bone autograft: a minimum 10-year follow-up. *Am J Sports Med* 2008;36:1275–1282.

2. **Shelbourne KD, Gray T.** Minimum 10-year results after anterior cruciate ligament reconstruction: how the loss of normal knee motion compounds other factors related to the development of osteoarthritis after surgery. *Am J Sports Med* 2009;37:471–480.

3. **Øiestad BE, Engebretsen L, Storheim K, Risberg MA.** Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. *Am J Sports Med* 2009;37:1434–1443.

4. **Daniel DM, Stone ML, Dobson BE, et al.** Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med* 1994;22:632–644.

5. **Fithian DC, Paxton LW, Goltz DH.** Fate of the anterior cruciate ligament-injured knee. *Orthop Clin North Am* 2002;33:621–636.

6. **Kessler MA, Behrend H, Henz S, et al.** Function, osteoarthritis and activity after ACL-rupture: 11 years follow-up results of conservative versus reconstructive treatment. *Knee Surg Sports Traumatol Arthrosc* 2008;16:442–448.

7. **Beynnon BD, Johnson RJ, Abate JA, Fleming BC, Nichols CE.** Treatment of anterior cruciate ligament injuries, part I. *Am J Sports Med* 2005;33:1579–1602.

8. **Laxdal G, Kartus J, Ejerhed L, et al.** Outcome and risk factors after anterior cruciate ligament reconstruction: a follow-up study of 948 patients. *Arthroscopy* 2005;21:958–964.

9. **Shelbourne KD, Gray T.** Results of anterior cruciate ligament reconstruction based on meniscus and articular cartilage status at the time of surgery: five- to fifteen-year evaluations. *Am J Sports Med* 2000;28:446–452.

10. **Anderson AF, Snyder RB, Lipscomb AB Sr.** Anterior cruciate ligament reconstruction: a prospective randomized study of three surgical methods. *Am J Sports Med* 2001;29:272–279.

11. **Feller JA, Webster KE.** A randomized comparison of patellar tendon and hamstring tendon anterior cruciate ligament reconstruction. *Am J Sports Med* 2003;31:564–573.

12. **Corry IS, Webb JM, Clingeleffer AJ, Pinczewski LA.** Arthroscopic reconstruction of the anterior cruciate ligament: a comparison of patellar tendon autograft and four-strand hamstring tendon autograft. *Am J Sports Med* 1999;27:444–454.

13. **Salmon LJ, Refshauge KM, Russell VJ, et al.** Gender differences in outcome after anterior cruciate ligament reconstruction with hamstring tendon autograft. *Am J Sports Med* 2006;34:621–629.

14. **Tegner Y, Lysholm J.** Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res* 1985;198:43–49.

15. **Hefti F, Müller W, Jakob RP, Stäubli HU.** Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sports Traumatol Arthrosc* 1993;1:226–234.

16. **Torg JS, Conrad W, Kalen V.** Clinical diagnosis of anterior cruciate ligament instability in the athlete. *Am J Sports Med* 1976;4:84–93.

17. **Mehta VM, Paxton LW, Fornalski SX, Csintalan RP, Fithian DC.** Reliability of the International Knee Documentation Committee radiographic grading system. *Am J Sports Med* 2007;35:933–935.

18. **Pinczewski LA, Salmon LJ, Jackson WF, et al.** Radiological landmarks for placement of the tunnels in single-bundle reconstruction of the anterior cruciate ligament. *J Bone Joint Surg [Br]* 2008;90-B:172–179.

19. **Blumensaat C.** Die Lageabweichungen und Verrenkungen der Kniescheibe. *Ergebn Chir Orthop* 1938;31:149–223 (in German).

20. **Neuman P, Englund M, Kostogiannis I, et al.** Prevalence of tibiofemoral osteoarthritis 15 years after nonoperative treatment of anterior cruciate ligament injury: a prospective cohort study. *Am J Sports Med* 2008;36:1717–1725.

21. **Wu WH, Hackett T, Richmond JC.** Effects of meniscal and articular surface status on knee stability, function, and symptoms after anterior cruciate ligament reconstruction: a long-term prospective study. *Am J Sports Med* 2002;30:845–850.

22. **von Porat A, Roos EM, Roos H.** High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann Rheum Dis* 2004;63:269–273.

23. **Lohmander LS, Ostenberg A, Englund M, Roos H.** High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis Rheum* 2004;50:3145–3152.

24. **Kartus JT, Russell VJ, Salmon LJ, et al.** Concomitant partial meniscectomy worsens outcome after arthroscopic anterior cruciate ligament reconstruction. *Acta Orthop Scand* 2002;73:179–185.

25. **Salmon VJ, Russell VJ, Refshauge K, et al.** Long-term outcome of endoscopic anterior cruciate ligament reconstruction with patellar tendon autograft: minimum 13-year review. *Am J Sports Med* 2006;34:721–732.

26. **Church S, Keating JF.** Reconstruction of the anterior cruciate ligament: timing of surgery and the incidence of meniscal tears and degenerative change. *J Bone Joint Surg [Br]* 2005;87-B:1639–1642.

27. **Wojtys EM, Chan DB.** Meniscus structure and function. *Instr Course Lect* 2005;54:323–330.

28. **Tashman S, Collon D, Anderson K, Kolowich P, Anderst W.** Abnormal rotational knee motion during running after anterior cruciate ligament reconstruction. *Am J Sports Med* 2004;32:975–983.

29. **Haughom B, Schairer W, Souza RB, et al.** Abnormal tibiofemoral kinematics following ACL reconstruction are associated with early cartilage matrix degeneration measured by MRI T1rho. *Knee* 2011:Epub.

30. **Felson DT, Naimark A, Anderson J, et al.** The prevalence of knee osteoarthritis in the elderly: The Framingham Osteoarthritis Study. *Arthritis Rheum* 1987;30:914–918.

31. **Amiel D, Kleiner JB, Roux RD, Harwood FL, Akeson WH.** The phenomenon of "ligamentization": anterior cruciate ligament reconstruction with autogenous patellar tendon. *J Orthop Res* 1986;4:162–172.

32. **Claes S, Verdonk P, Forsyth R, Bellemans J.** The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. *Am J Sports Med* 2011;39:2476–2483.

33. **Marumo K, Saito M, Yamagishi T, Fujii K.** The "ligamentization" process in human anterior cruciate ligament reconstruction with autogenous patellar and hamstring tendons: a biochemical study. *Am J Sports Med* 2005;33:1166–1173.

34. **Musgrove TP, Salmon LJ, Burt CF, Pinczewski LA.** The influence of reverse-thread screw femoral fixation on laxity measurements after anterior cruciate ligament reconstruction with hamstring tendon. *Am J Sports Med* 2000;28:695–699.

35. **Shelbourne KD, Gray T, Haro M.** Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med* 2009;37:246–251.

36. **Gilchrist J, Mandelbaum BR, Melancon H, et al.** A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. *Am J Sports Med* 2008;36:1476–1483.

37. **Khalfayan EE, Sharkey PF, Alexander AH, Bruckner JD, Bynum EB.** The relationship between tunnel placement and clinical results after anterior cruciate ligament reconstruction. *Am J Sports Med* 1996;24:335–341.

38. **Iriuchishima T, Ingham SJ, Tajima G, et al.** Evaluation of the tunnel placement in the anatomical double-bundle ACL reconstruction: a cadaver study. *Knee Surg Sports Traumatol Arthrosc* 2010;18:1226–1231.

39. **Han Y, Kurzencwyg D, Hart A, Powell T, Martineau PA.** Measuring the anterior cruciate ligament's footprints by three-dimensional magnetic resonance imaging. *Knee Surg Sports Traumatol Arthrosc* 2011:Epub.