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20 Year Outcomes of ACL Reconstruction with Hamstring Tendon Autograft. The Catastrophic Effect of Age and Posterior Tibial Slope.

Background: No well controlled studies have compared the long term outcome of anterior cruciate ligament (ACL) reconstruction with hamstring tendon (HT) autograft between adolescents and adults. Increased posterior tibial slopes (PTS) have been reported in ACL injured versus controls but the effect of PTS on the outcome after reconstruction is relatively unexplored.

Purpose: To compare the prospective longitudinal outcome of 'isolated' ACL ruptures treated with anatomical endoscopic ACL reconstruction using hamstring tendon autograft over 20 years in adolescent and adult cohorts, and the examine factors for repeat ACL injury.

Study Design: Case series, Level of evidence 4

Methods: A single surgeon series of 200 consecutive patients undergoing isolated primary ACL reconstruction with hamstring tendon autograft were prospectively studied. Subjects were assessed pre-operatively and 2, 7, 15 and 20 years post-operatively. Outcomes included: IKDC Knee Evaluation, IKDC subjective scores, KT1000 Instrumented laxity testing and radiological evaluation of degenerative change and medial tibial slope. 20 year outcomes were compared between those who underwent surgery at the age of 18 years or less (adolescent group n=39) and those who underwent surgery >18 years (adult group n=161).

Results: At 20 years 179 of 200 subjects were reviewed (89.5%). ACL graft rupture occurred in 37 subjects, and contralateral ACL injury in 22 subjects. Of those with intact ACL grafts at 20 years, outcomes were not statistically different between adolescents and adults for the variables of IKDC subjective score (p=0.29), return to preinjury activity level (p=0.84), current activity level (p=0.69) or degree of radiological degenerative change at 20 years (p=0.51). The adolescent group had a higher proportion with grade 1 ligamentous laxity testing compared to the adult group (p=0.003). Overall ACL graft survival at 20 years was 86% for adults and 61% for adolescents (HR 3.3; p=0.001). The hazard for ACL graft rupture was increased by 4.8 in adolescent males and 2.5 in adolescent females, compared to adults. At 20 years the ACL survival for adolescents with a PTS of $\geq 12^0$ was 22%. The hazard for ACL graft rupture was increased by 11 in adolescents with a PTS of $\geq 12^0$ (p=0.001), compared to adults with a PTS $<12^0$.

Conclusions: Repeat ACL injury after isolated ACL reconstruction is common, occurring in 1 in 3 over 20 years. In the absence of further injury, isolated ACL reconstruction using this technique was associated with good long term outcomes with respect to patient reported outcomes and return to sports, regardless of age. However, mild ligament laxity and ACL graft rupture after ACL reconstruction is significantly more common in the adolescents, especially adolescent males, compared to adults. PTS of 12 degrees or more is the strongest predictor of repeat ACL injury, and its negative effect is most pronounced in adolescents.

What is known about this subject:

The short and medium term outcomes of ACL reconstruction is well documented but little evidence exists for the long term outcomes of modern ACL reconstruction techniques with hamstring tendon autograft. Young age and the sagittal slope of the tibial plateau has recently become recognised as a significant contributor to primary ACL injuries[22, 44, 47, 54], but few studies examine the effect of these factors on long term outcomes After ACL reconstruction.

What this study adds to existing knowledge:

This study represents the longest prospective longitudinal examination of ACL reconstruction with hamstring tendon autograft currently available in the literature and specifically examines differences between adults and adolescents. Significant factors for repeat ACL injury have been identified which are highly topical.

Introduction

ACL injuries are being seen with increasing frequency in the young. Factors contributing to this increase include higher rates of sports participation, sports specialisation occurring at a younger age, increasing intensity of training and play, and improved rates of diagnosis of ACL injury[19]. It is now accepted that ACL reconstruction should be advocated in the young, even before skeletal maturity, and anatomic transphyseal ACL reconstruction can be safely performed to restore functional stability[19, 26]. After ACL reconstruction, there is considerable recent evidence that 2nd ACL injuries occur more frequently in the young [1, 21, 29, 34, 37, 52].

The sagittal slope of the tibial plateau has only recently become recognised as a significant contributor to primary ACL injuries[22, 44, 47, 54]. It is suggested that high sagittal posterior tibial slopes increase the relative anterior translation of the tibia relative to the femur[17, 20], and recent robotic models have demonstrated that this is associated with higher flexion and adduction torques on landing tasks, a known contributor to ACL injuries[7]. It has been reported that the mean tibial slope of ACL injured individuals is higher than uninjured control subjects on both radiographic and MRI measures[15, 47, 49 48]. Relatively less attention has been paid to the effect of high tibial slopes on further ACL injuries after ACL reconstruction[18, 50]. The combined effect of high tibial slope and a young age on reinjury rates after ACL reconstruction is currently unreported.

While it is accepted that rates of second ACL injury are higher in the young, relatively little is known about differences in clinical, radiographic and subjective outcomes between adolescents and adults over the long term. In this study we prospectively followed a cohort of 200 subjects undergoing ACL reconstruction without significant chondral or meniscal pathology over a 20 year period. At 20 years we compared clinical, subjective and radiographic outcomes of ACL reconstruction between an adolescent cohort (aged 18 or less) and an adult cohort (age >18 years) and examine the combined effect of age and tibial slope on repeat ACL injuries. We hypothesised that over 20 years adults and adolescents would have equivalent patient reported and clinical outcomes, but a higher incidence of repeat ACL injury would be seen in adolescents over adults, and those with tibial slopes 12 degrees or more, compared to <12 degrees.

Materials and Methods

Patient Selection

Subjects who underwent ACL reconstruction with hamstring tendon autograft between October 1993 and March 1996 under the care of the senior surgeon were eligible for inclusion (n=1131 subjects). The following exclusion criteria were applied (1) associated ligament injury requiring surgical treatment, (2) evidence of significant chondral damage or degeneration, (3) previous meniscectomy, (4) excision of more than one third of one meniscus at the time of reconstruction, (5) abnormal radiographic findings, (6) any abnormality in the contralateral knee, (7) those seeking compensation for their injuries, and (8) those who did not wish to participate in a research programme. The first consecutive 100 men and 100 women who met the inclusion criteria formed the study group. Ethical approval was obtained from a local independent human research ethics committee (St Vincent's Human Research Ethics Committee, Sydney). Reconstruction was performed once the knee had recovered from the acute trauma of the ACL injury and patients had a pain-free, mobile joint.

Operative Technique:

A standardised surgical technique, and postoperative rehabilitation protocol was followed for all patients. The technique and rehabilitation regimen has previously been reported in detail [14, 42]. This was a 'single-incision' endoscopic technique, using a 4-strand ipsilateral hamstring autograft. Anatomical femoral tunnel drilling was performed via the anteromedial portal. Graft fixation was achieved with a 7 × 25mm titanium RCI interference screw in all subjects (Smith and Nephew, Andover, MA) in both the femoral and tibial tunnels. Surgery was performed as a day procedure. Subjects were permitted to weight bear as tolerated on crutches immediately after surgery and no brace was used. An accelerated rehabilitation programme was instituted, supervised by a physical therapist with aim of achieving full extension by two week and full range of motion by 6 weeks. At the time of post operative rehabilitation of these subjects, intensive plyometric, agility and sports specific training was not routinely instituted. Return to competitive sport involving jumping, pivoting or side-stepping was prohibited until 6 months after the reconstruction after clinical confirmation of ligamentous stability by the surgeon.

Patient Reported Outcome Measures & Clinical Evaluation

Subjects were evaluated preoperatively and at 6 months, 12 months, annually till 5 years then at 7, 15 and 20 years following surgery. Assessment included the IKDC Knee Ligament Evaluation Form in its early version until the 7 year review [23, 27], and then using the updated version at 15 and 20 years [27]. Ligament laxity was assessed with Lachman, Pivot-shift tests and the KT 1000 arthrometer (Medmetric Corp., San Diego, California) using the side to side difference of manual maximum anterior displacement between knees. The single legged hop test was used for functional assessment.

Radiological Evaluation

Before surgery and a 2, 7, 15 and 20 years after surgery weight bearing anteroposterior, 30^0 flexed posteroanterior, patellofemoral and lateral knee radiographs were performed. All radiographs were assessed by an independent musculoskeletal radiologist (JL) for radiographic features of osteoarthritis. Osteoarthritis was graded as per IKDC radiological grading system [27] where A is normal; B indicates minimal changes (small osteophytes, slight sclerosis or flattening of the femoral condyle) and narrowing of the joint space that is just detectable, C is moderate changes and joint space narrowing of up to 50% and grade D is severe changes such as include a joint space < 2 mm or narrowing of the joint space > 50%. The worst compartment of the medial, lateral and patellofemoral compartments determines the overall IKDC radiological grade.

Sagittal femoral and tibial osseous tunnel position was measured on lateral knee radiographs and graft inclination was measured in the coronal plane on AP radiographs using a method previously described [40]. Ideal radiological tunnel position was defined as the tibial tunnel being 40-50% posterior along the tibial plateau in the sagittal plane, femoral tunnel >80% posterior along Blumensaat's line in the sagittal plane and a graft inclination angle of greater than 15 degrees in the coronal plane [40].

Sagittal tibial slope was measured by 2 knee fellowship trained orthopaedic surgeons using OsiRix software on the best available digitised lateral radiograph of the knee using a method previously described[50]. The tibial slope was calculated by measuring the angle between a line drawn tangentially to the medial tibial plateau and the Proximal Anatomical Axis (PAA) of the tibia. The PAA is determined by a line connecting the mid-cortical diameters of the tibia at a point 5 and 15 centimetres distal to the knee joint. One assessor repeated the measures after a period of 2 weeks to assess intraobserver reliability.

Statistical Analysis

The outcomes were compared between selected subgroups using the students t-test for continuous measurements (mean KT-1000 arthrometer, radiological tunnel placement) and Chi Squared tests for categorical variables (IKDC categories, Lachman, pivot-shift test). Changes in mean instrumented laxity testing over time were assessed with paired t-tests. Multiple logistic regression was performed to assess the relative contribution of age, gender and side on the 2 and 20 year ligament laxity testing. Intra-observer and inter-observer reliability of the tibial slope measures was assessed with intraclass correlations. 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 univariate Cox's regression. Factors that approached significance ($p < 0.10$) 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%.

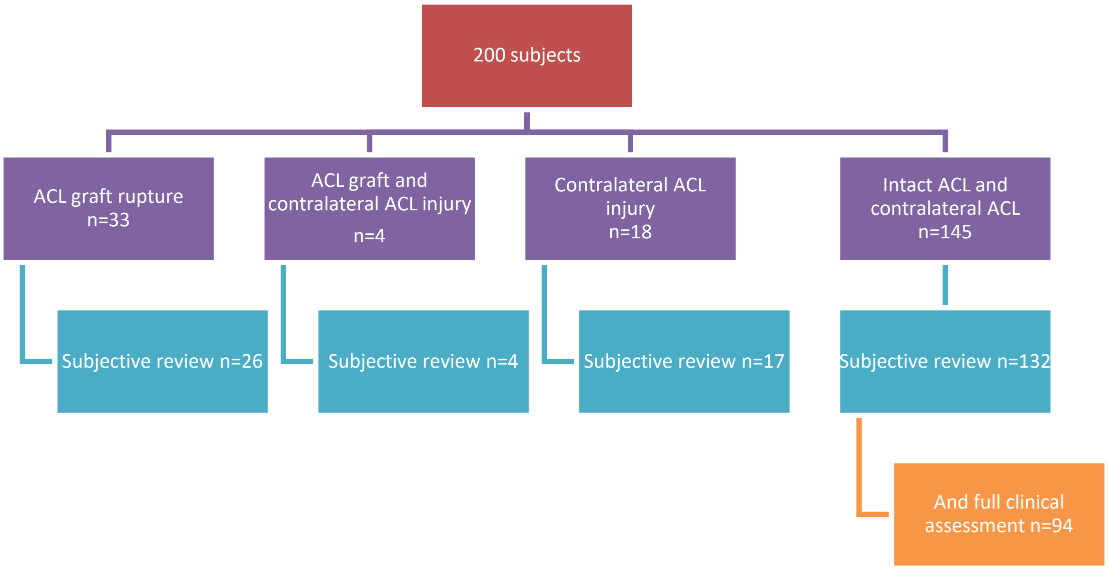
RESULTS

Study Group

100 male and 100 female consecutive participants undergoing isolated ACL reconstruction with HT autograft under the care of the senior surgeon who met the inclusion and exclusion criteria formed the study group. The mean age at surgery was 25.8 years and 152 patients (76%) had their reconstruction performed within 12 weeks of injury. There were 99 left-sided reconstructions and 101 right-sided. 176 patients (88%) had intact lateral menisci and 184 (92%) intact medial menisci at the time of surgery. 20 (10%) had meniscal tears requiring suturing and 20 (10%) required excision of less than one third of the meniscus. Mean follow-up was 236 months (range 212 – 257 months).

The participant flow is shown in Figure 1. Of the 200 participants recruited to the study, 179 (90%) were reviewed at 20 years. Of the 21 patients not reviewed, 5 refused continuing participation in the study, 8 did not respond to review requests, and 8 were unable to be located. Subjects with intact ACL graft and contralateral ACL completed full IKDC, clinical and radiographic assessment. Subjects who had a contralateral ACL injury completed subjective review and radiographic assessment only as IKDC clinical review requires comparison to a 'normal' contralateral knee. Of the 37 subjects who sustained an ACL graft rupture, 32 underwent revision ACL reconstruction. All 37 subjects who sustained an ACL graft rupture were excluded from the analysis of full clinical assessment, radiological and subjective review. For the purposes of the survival analysis all 200 subjects were included in the analysis, in the case of those lost to follow up subjects were included but censored after their last attendance. This model assumes that censored patients are considered to have survival prospects similar to the participants who continued to be followed.

Figure 1: Participant Flow



Study participants were divided into 2 groups – those who had surgery at the age of 18 or less (adolescent group, n=39) and those who were >18 years at the time of surgery (adult group, n=161). There was a higher proportion of females in the adolescent group, compared to the adult group (p=0.01). The mean age of the adolescent group was 16 years (range 14-18) and the mean age of the adult group was 28 years (range 19-52). There were no subjects in this study with open growth plates at the time of surgery.

Patient-Reported Outcomes

At 20 years, there were 163 participants with intact ACL grafts and patient reported outcomes were completed on 149 (91%). There were no significant differences between the adolescent and adult groups for patient reported outcome at 20 years as seen in Table 1.

Table 1: Selected Demographics and Comparison of Patient Reported Outcomes Measures for Adolescent and Adult Groups

	Adolescent	Adult	P
No of subjects with intact ACL at 20 years	24	139	
No of subjects reviewed at 20 years	23 (96%)	126 (91%)	
No of females	17 (74%)	57 (45%)	0.01*
No of right knees	14 (61%)	66 (52%)	0.453
Mean Graft Diameter (mm)	6.8	6.8	0.531
Mean Sagittal Tibial Slope (^{0})	8.6	8.9	0.584
IKDC Subjective Score/100 at 20 yrs, Mean	87	89	0.292
Regular Activity Level at 20 years, n(%)			
Strenuous / Very Strenuous	14 (61%)	77 (61%)	0.691
Moderate	6 (26%)	30 (24%)	
Light	3 (13%)	19 (15%)	
Return to preinjury level of sport at any time, n(%)	18 (78%)	101 (80%)	0.835
Current Knee related decrease in activity level, n(%)	5 (22%)	20 (16%)	0.489
Current Knee Function mean/10	8.7	8.9	0.671
No or minimal kneeling difficulty, n(%)	18 (78%)	101 (80%)	0.904

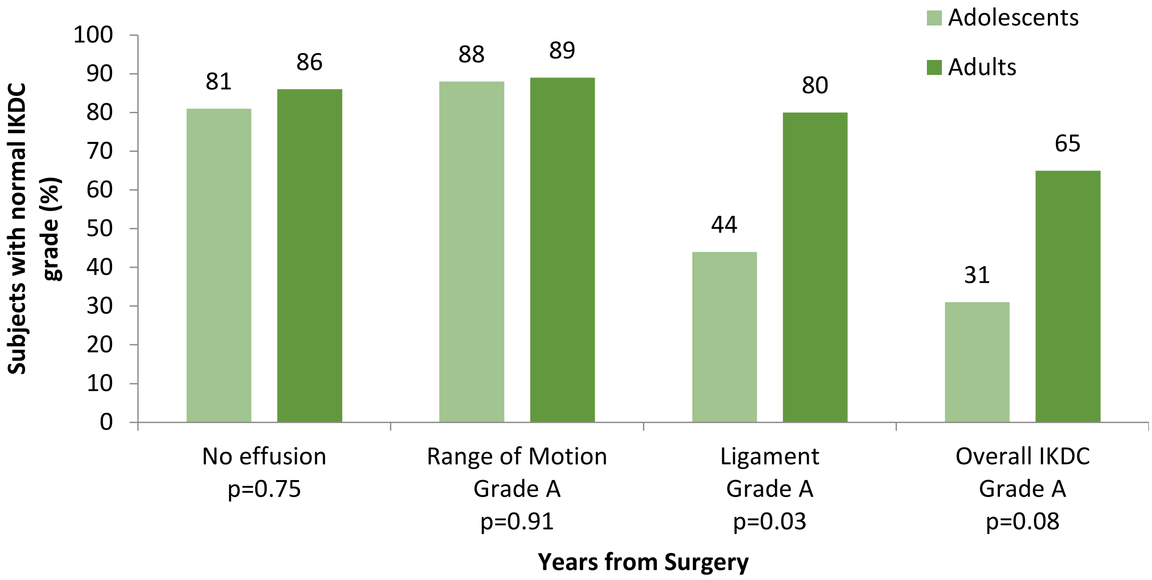
Clinical Assessment

Clinical examination with the IKDC Evaluation requires comparison to a normal contralateral knee. Clinical IKDC evaluation was performed at 20 years on 97 of the 145 (67%) participants with an intact ACL graft and contralateral ACL.

IKDC Evaluation

The IKDC evaluation includes subcategories of effusion, range of motion, ligament evaluation and overall IKDC grade. The percentage of subjects with a normal IKDC grade for each IKDC subcategory is shown in Figure 2. There was no significant difference between the adolescent and adult groups for the variables of effusion and range of motion. When compared to adults, significantly fewer adolescents had a normal ligament evaluation (p=0.003) and overall IKDC evaluation (p=0.07).

Figure 2: Percentage of adolescents and adults with 'normal' subgroup and overall IKDC grades at 20 years



If those with an ACL graft rupture are attributed with an abnormal grade, then the proportion of patients with a normal or nearly normal overall IKDC grade at 20 years was 15/31 (48%) in the adolescent group and 77/98 (79%) in the adult group (p=0.006).

Ligament Evaluation

The adolescent group has significantly lower proportion of subjects with normal laxity on pivot shift testing (p=0.003), instrumented laxity p=0.03) and overall IKDC ligament grade (p=0.003), (Figure 3). The comparison of adolescent and adult laxity testing is shown over time in Figure 4. The mean manual maximum side-to-side difference in KT1000 instrumented testing was 2.6mm (SD 1.7) in the adolescent group and 1.2mm in the adult group (p=0.02).

Figure 3: Percentage of adolescents and adults with 'normal' IKDC Ligament grades at 20 years

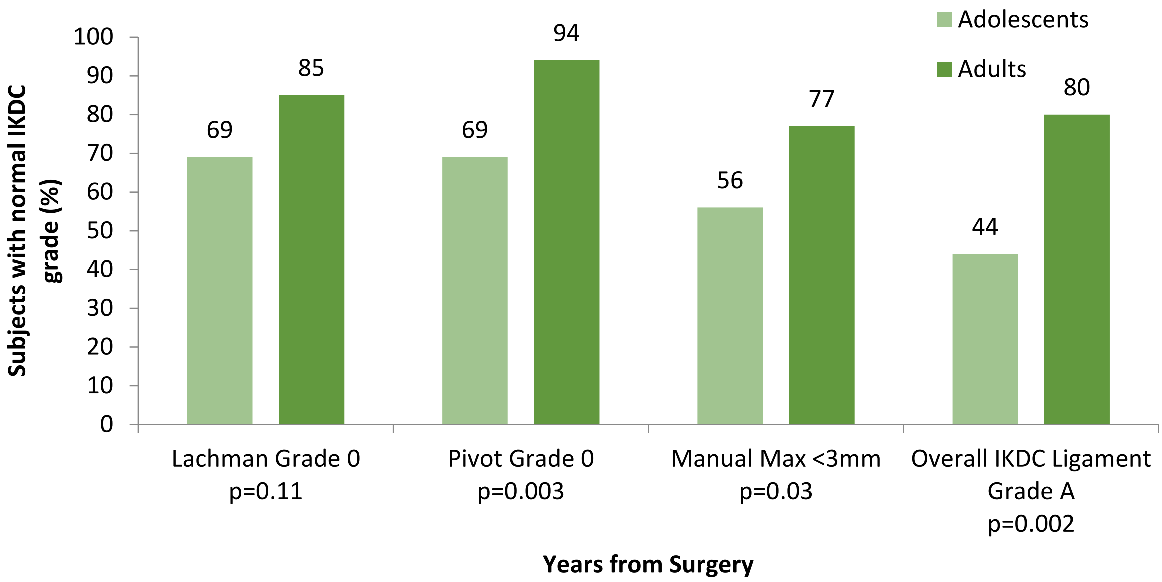
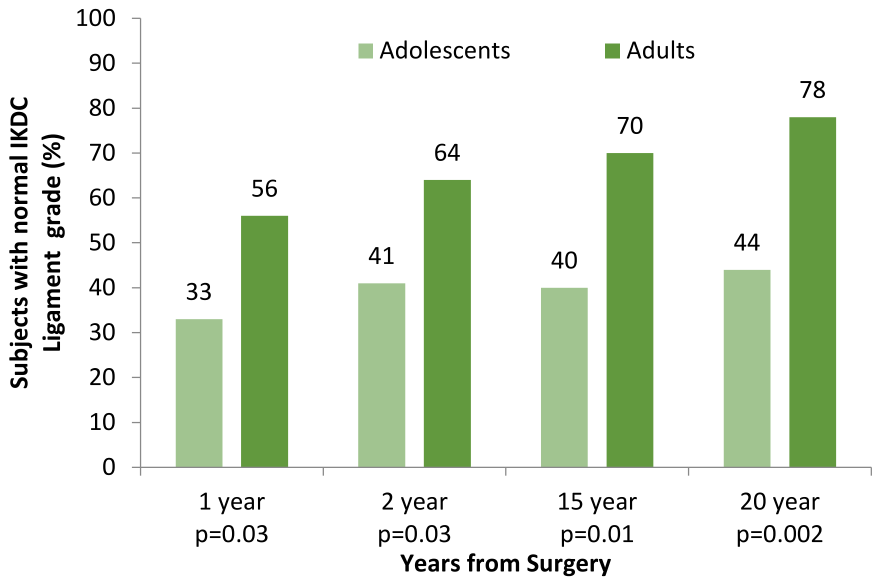


Figure 4: Percentage of adolescents and adults with 'normal' overall IKDC Ligament grade over time



Multiple logistic regression was performed to assess the relative contribution of age, gender and side on the 20 year IKDC ligament laxity grade. The results are shown in Table 2. Ligament laxity testing performed at 2 years after surgery was also examined with the same multiple regression analysis. At 2 years greater ligamentous laxity was associated with female gender (OR 4.0, 95%CI 2.0-8.0, p=0.001), not adolescents (OR 1.7, 95%CI 0.7-4.1, p=0.23) or right knees (OR 1.5, 95% CI 0.7-2.9, p=0.27).

Table 2: Results of Regression Analysis: The Relationship between 20 year IKDC Laxity grade and Age, Gender and Side of Reconstruction

Factor	Adjusted Odds Ratio	95% Confidence Interval	P
Age 18 or less	4.6	1.4-14.7	0.010
Female Gender	1.2	0.4-3.3	0.710

Single Leg Hop Test

Hop testing was performed on 82 patients at 20 years. 8 patients did not complete hop testing due to pregnancy or injury to other joints. 9 of 15 adolescents (60%) and 56 of 67 adults (84%) were able to hop within 90% distance of their contralateral limb at 20 years (p=0.08).

Radiological Assessment

Assessment of radiological degenerative change was assessed with the IKDC Radiological grade. A total of 99 adults and 22 adolescents had radiographs available for evaluation at 20 years. The worst compartment of the medial, lateral and patellofemoral compartments determines the overall IKDC radiological grade. Pre-operatively and at two years, no patient had an abnormal radiological examination. No significant difference was found in the incidence of radiological osteoarthritis between the adolescent and adult groups at 20 years (p = 0.28). Moderate to severe radiological degenerative change was evident in 20 of the 121 subjects (17%) at 20 years. The results are shown in Table 3.

Table 3: Comparison of IKDC Radiological Grade for Adolescent and Adult Groups

	Adolescent		Adult		
No of subjects	22		99		
Grade A	17	77%	56	57%	0.283
Grade B. Minimal changes	3	14%	25	25%	
Grade C. Joint space narrowing of up to 50%	2	9%	12	12%	
Grade D. Include a joint space of less than 2 mm or > 50% joint space narrowing.	0	0%	6	6%	

Radiological Tunnel Placement

Radiological tunnel placement was determined in 191 of the 200 patients. The mean sagittal femoral tunnel placement was 84% posterior (SD 7), the mean sagittal tibial tunnel placement was 47% (SD 6) and the mean graft angle was 18 degrees (SD 5). The ideal tunnel position has been defined as being a sagittal tibial tunnel 40% to 50% anterior, sagittal femoral tunnel 80% to 90% posterior, and coronal graft inclination greater than 17 degrees. [9, 39] Ideal tunnel position was evident in 43 of the 191 subjects' radiographs (23%). There was no significant difference between adolescents and adults with respect to sagittal femoral tunnel position (0.68), sagittal tibial tunnel position (p=0.288), or graft angle (p=0.387). The tunnel position could be assigned 'ideal' in 7 of the 39 adolescents (18%), and 36 of the 152 adults (24%, p=0.444).

Radiological Tibial Slope

Measurement of radiological tibial slope was possible in 182 of the 200 subjects using lateral radiograph. Measurement was performed by 2 orthopaedic fellows, and one orthopaedic fellow repeated the measurements 2 weeks apart. The interobserver reliability was 0.64 (intraclass correlation) and the intraobserver reliability was 0.75 (intraclass correlation). This represents substantial reliability according to the guidelines of Landis and Koch[31]. The mean tibial slope was 8.9 degrees (SD 2.9). There was no significant difference between adults and adolescents for mean tibial slope (mean 8.6 for adolescents and mean 8.9 for adults, p=0.672). 37 subjects (20%) (inclusive of 9 adolescents- 26%), had a tibial slope of 12 or more degrees and 147 (80%) had a tibial slope of <12 degrees. Tibial slope measures were distributed in a similar pattern for adults and adolescents (Figure 5).

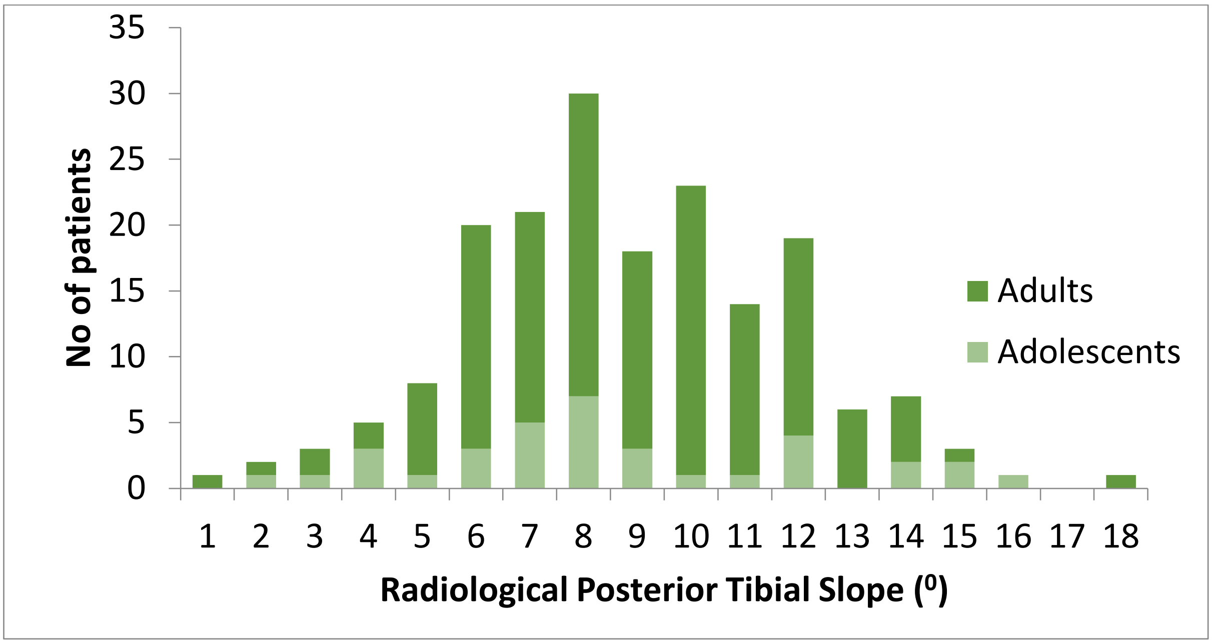


Figure 5: The distribution of tibial slope in adults and adolescents

ACL Graft Rupture

Over 20 years, 15 of the 39 adolescents (38%) and 22 of the 161 adults (14%) sustained a rupture of the ACL graft (p=0.001). The Kaplan–Meier survival for the ACL reconstruction in all patients was 93% at 2 years, 89% at 5 years, 85% at 10 years and 83% at 15 years and 80% at 20 years. Survival of the ACL graft survival was examined with univariate Cox regression as a factor of age < 18 years, gender, tibial slope, radiological tunnel placement and family history of ACL injury (Table 4). Independent factors that were significantly associated with ACL graft rupture on univarate regression analysis (Age and Tibial Slope) are demonstrated with Kaplan–Meier survival curves in Figures 7-10 and included in a stepwise multiple regression analysis to determine the relative contribution of each variable. On multiple regression analysis, ACL graft survival was significantly affected by the factor of age <18 years at the time of reconstruction (Hazard Ratio 3.3; 95% CI 1.7-6.4, p=0.001) and a posterior tibial slope of 12 or more degrees (Hazard Ratio 3.1; 95% CI 1.5-5.9, p=0.001).

Contralateral ACL Rupture

Contralateral knee ACL (CACL) rupture occurred in 5 of the 39 adolescents (13%) and 17 of the 161 (11%) of adults (p=0.59). Three adolescents and 1 adult suffered both a CACL and ACL graft rupture. Details of univariate analysis of contralateral ACL (CACL) survival at 20 years are presented in Table 5 and the Kaplan–Meier survival curve for tibial slope are shown in Figures 9 and 10. Independent factors that trended towards significance (p<0.10) with contralateral ACL rupture on univarate regression analysis (Family History of ACL injury and tibial slope) were included in a stepwise multiple regression analysis to determine the relative contribution of each variable. On multiple regression analysis, contralateral ACL injury was significantly affected only by the factor of posterior tibial slope of 12 or more degrees (HR 7.3; 95% CI 3-18, p=0.001).

Table 4: Univariate analysis of ACL Graft Survival at 20 years

Factor and Category	N	No of ACL Graft Ruptures	ACL Graft Survival					Hazard Ratio	95% CI	p-value
			2yrs	5yrs	10yrs	15yrs	20yrs			
All subjects	200	37	93	89	85	83	80			
Age at ACL Reconstruction										
Adolescent	39	15	85	77	72	64	61	3.3	1.7-6.3	**0.001**
Adult	161	22	96	93	89	88	86			
Age and Gender										
Male adolescent	13	7	77	77	62	54	46	4.8	1.8-12.7	**0.001**
Female adolescent	26	8	88	77	77	69	69	2.6	1.0-6.5	**0.048**
Male adult	87	12	97	92	88	87	86	1.0	0.4-2.3	0.995
Female adult	74	10	96	95	90	89	87	Ref		
Posterior Tibial Slope										
12 or more	37	14	84	72	67	67	62	3.0	1.6-5.9	**0.001**
< 12 degrees	147	23	96	93	89	86	84			
Age and Posterior Tibial Slope (PTS)										
Adolescent & PTS 12 or more	9	7	78	44	33	33	22	11.1	4.5-27.5	**0.001**
Adolescent & PTS <12	26	8	92	85	81	73	69	2.7	1.2-6.5	**0.02**
Adult & PTS 12 or more	28	7	93	85	78	74	74	2.3	0.9-5.7	0.07
Adult & PTS <12	119	15	97	95	91	90	88	Ref		
Family History of ACL Rupture										
Yes	42	11	90	86	79	74	74	1.7	0.9-3.6	0.127
No	146	24	95	92	88	86	85			
ACL Graft Diameter										
<7mm	92	21	92	85	82	80	83	1.7	0.9-3.2	0.126
7mm or more	107	16	95	94	89	86	85			
Radiological Tunnel Placement										
“non ideal”	148	29	95	89	84	82	79	1.1	0.5-2.4	0.848
“Ideal”	43	8	93	93	88	88	84			

Table 5: Univariate analysis of Contralateral ACL Survival at 20 years

Figure 6: Cumulative survival of the reconstructed ACL and contralateral ACL according to age

Factor and Category	N	No of CACL Injuries	Contralateral ACL Survival					Hazard Ratio	95% CI	p-value
			2 yr	5 yr	10 yr	15yr	20 yr			
All subjects	200	22	97	95	92	90	89			
Posterior Tibial Slope										
12 or more	37	12	84	78	72	72	66	7.3	3.0-18.0	**0.001**
< 12 degrees	147	9	99	98	97	94	94			
Age and Gender										
Male Adolescent	13	3	85	85	85	85	77	2.7	0.7-10.5	0.15
Female Adolescent	26	2	96	92	92	92	92	0.9	0.2-4.3	0.88
Male Adult	87	10	95	93	91	89	88	1.2	0.5-3.2	0.70
Female Adult	74	7	99	97	96	92	92	92		
Age and Posterior Tibial Slope										
Adolescent & PTS 12 or more	9	3	89	78	78	78	65	7.3	1.9-28.2	**0.004**
Adolescent & PTS<12	26	1	96	96	96	96	96	0.7	0.1-5.4	0.70
Adult & PTS 12 or more	28	9	86	82	71	71	67	6.7	2.5-17.9	**0.001**
Adult & PTS <12	119	8	99	99	97	94	94	Ref		
Family History of ACL Rupture										
Yes	42	8	93	86	83	81	81	2.2	0.9-5.1	0.08
No	146	14	97	96	95	92	91			
Age at ACL Reconstruction										
18 years or less	39	5	92	90	90	90	87	0.75	0.3-2.0	0.589
> 18 years	161	17	97	95	93	90	90			

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Figure 7: Cumulative survival of the reconstructed ACL according to age and gender.

INSERT Figure7a1.eps and Figure7b1.eps

Figure 8: Cumulative survival of the reconstructed ACL and Contralateral ACL according to Radiographic Sagittal Tibial Slope

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Figure 9: Cumulative survival of the reconstructed ACL and Contralateral ACL according to Age and Radiographic Sagittal Tibial Slope

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Other Subsequent Surgery/Complications

75 subjects underwent further knee surgery. Revision ACL reconstruction was performed on 32 of the 37 subjects who sustained an ACL graft rupture. Contralateral ACL reconstruction was performed on 17 patients. Subsequent meniscectomy was performed in 14 subjects on the ipsilateral knee and 6 on the contralateral knee. Osteotomy was performed in 2 subjects. 3 underwent excision of cyclops lesion, 1 underwent excision of tibial ganglion and screw and 1 underwent removal of loose body. There were no deep infections or post operative thrombosis in this series.

Discussion

In this study, we compared the outcomes in adolescents and adults after isolated endoscopic ACL reconstruction with hamstring tendon autograft and interference screw fixation over 20 years. We found that adolescents (aged 18 or less) had significantly greater clinical laxity, and a higher rate of ACL graft rupture, compared to their adult counterparts. No significant differences were found between adults and adolescents for activity level, patient reported outcomes, radiological osteoarthritis or functional assessments. While both young age and posterior tibial slope $\geq 12^0$ were independent predictors of second injury, the combined effect of these factors on ACL graft rupture was marked.

High posterior tibial slope had a catastrophic effect on further ACL injury, especially in the adolescent cohort, and especially in the first few years after surgery. Adolescents with a tibial slope of $\geq$12 degrees were 11 times more likely to rupture their ACL graft and 7 times more likely to rupture their contralateral ACL than adults with tibial slopes of <12 degrees. The steep incline of the survival curve shown in Figure 9 demonstrates that these injuries occur within first few years after an ACL reconstruction, with more than half of the adolescents sustaining a graft rupture within 5 years. Adults with a PTS of more than 12 degrees were 7 times more likely to injure their contralateral ACL and trended towards a higher rate of graft rupture that did not reach statistical significance (p=0.07), compared to adults with a PTS or <12 degrees. While these findings are alarming, it must be realised that tibial slopes of more than 12 degrees are only seen in about 20% of the study cohort, so for the vast majority of the population the rate of repeat ACL injury is conversely low over 20 years. High posterior tibial slopes may be responsible for those rare patients for whom multiple ACL injuries occur, despite an anatomical ACL reconstruction and appropriate rehabilitation, which many ACL surgeons and therapists may be anecdotally familiar.

The body of literature substantiates that mean tibial slopes are higher in primary ACL injured individuals than uninjured controls[15, 47-49, 54]. After ACL reconstruction there are fewer studies that examine tibial slope, but nevertheless the findings of a positive association with further injury is consistent[12, 50]. What is less clear is how to best manage those active individuals that have a very high posterior tibial slope. A recent study of 1090 cadaveric tibiae report that the mean osteological posterior slope of the medial tibial plateau is 7^0 and the lateral tibial plateau is 5^0.[51] Some authors have recently advocated correction of 'pathological' tibial slopes (defined as >12 degrees) in athletes with multiple ACL injuries using anterior closing wedge osteotomies at the time of revision ACL reconstruction[16, 18, 45]. However, the reported outcome of this procedure is limited to 2 series, with 5[45] and 9[16] subjects in each, followed for a minimum of 2 years. Both studies report no recurrent instability or further ACL injuries, but this limited data is currently insufficient to support this approach. The alarming finding of only a 22% ACL graft survival for adolescents with tibial slopes of 12 or more warrants careful consideration and our findings raise many questions we cannot answer. When examining this cohort previously, we have concluded that more consistent anatomical tunnel placement would improve outcomes[9, 40]. Whether further modifications to the surgical technique or advice regarding return to sports should be considered, or even whether the ACL reconstruction is indicated in this cohort remains open to debate. The solution to this difficult clinical problem remains unsolved.

Despite the strong association between posterior tibial slope and further injury we would advise caution in interpreting radiographic tibial slope measures. There is a lack of consistency regarding whether the medial or lateral tibial plateau slope is most relevant, which is the most robust measurement method, and whether radiographs or MRI scans are more reliable[18]. Testing performed in this study demonstrated substantial reliability in this study for both interrater (ICC 0.64), and intraobserver (ICC 0.75), but we remain concerned that the radiological method of measuring tibial slope is highly reliant on the quality of the radiograph, the rotation of the tibia[51], and the experience of the measurer. While tibial slope is certainly a contributing factor to ACL injuries, a more accurate, robust and relevant measurement method is needed[54].

Over 20 years, adolescents were 3 times more likely to have an ACL graft rupture than adults. This is a consistent finding in the literature. Younger age has been identified as a risk factor for ACL graft rupture of a magnitude of 2-7 times in large multi-centre registries from the US [29, 34], Sweden [1, 3], Scandanavia[21], Denmark[33] and Norway[38]. Wiggins et al recently reported that subjects younger than 20 years at the time of ACL reconstruction were 6 times more likely to sustain a graft rupture than patients 20 years and older in a large series of 750 patients over the first 3 years[52]. Young age may well be a proxy for other factors[52]. Although there was no significant difference in reported activity levels between the adolescents and adults at 20 years in our series, others have found that the young returned to sports after rehabilitation harder, faster and for longer than their adult counterparts [10, 43] which could also contribute to this elevated risk of injury. Other potential contributors to the elevated risk of injury in adolescents may include a genetic predisposition, anatomic, biomechanical and neuromuscular considerations of the adolescent knee.

ACL reconstruction in active subjects is frequently performed with the explicit aim of returning to pivoting and jumping sports. Reassuringly, both adolescent and adults over 20 years reported consistently high mean IKDC scores (87 and 89 respectively at 20 years), a very high proportion reported returning to their pre-injury sports (78 and 80% respectively) and continued to participate in strenuous sports (61%). These rates of return to sports are higher than other some other series. Ardern reported that <50% returned to their preinjury level of sport in a survey of 314 subjects [4], and 65% returned to their preinjury level of sport in a meta-analysis of 7556 subjects [5]. The longer period of follow up of this series may favor a return to preinjury sport, as well as the selection criteria which includes only those without significant meniscal or cartilage injury at the time of surgery. This selection criteria was applied in order to exclude the confounding negative effects of meniscal and chondral injuries and account for 1 in 3 subjects undergoing ACL reconstruction during the study period. This group therefore constitute the 'best case scenario' after ACL reconstruction, which may account for this cohort's favorable long term outcomes.

Clinical ligament laxity testing demonstrated greater ligamentous laxity in the adolescent group compared to the adult group at 20 years. However the magnitude of the difference was small – a mean of 1.4mm, with adolescents demonstrating a higher proportion with mild laxity (grade 1, 3-5mm) rather than pathological grade 2 laxity. This may account for the finding that this mild laxity did not translate to lower patient reported outcomes or rates of sports participation in the adolescents. Indeed others have shown that instrumented laxity and Lachman tests were poor predictors of subjective and functional outcome after ACL reconstruction [30, 32]. If when interpreting the overall IKDC grade at 20 years we categorise all subjects who had an ACL graft rupture as abnormal, then at 20 years a normal or nearly normal overall IKDC grade was seen in 77% of adults and only 48% of adolescents. It can be concluded that adolescents have inferior outcomes to adults after ACL reconstruction over 20 years in this series.

Previous studies have demonstrated a relationship between greater ligamentous laxity with female gender[42] and righted sided reconstructions[14] over short term follow up. The adolescent group in this series did have a higher proportion of females compared to the adults, which may bias the results. In order to address this we examined the relative contribution of gender, side and laxity on 20 year laxity testing and found that young age was a stronger predictor of ligamentous laxity (OR 4.6), than female gender (OR 1.2) or side of surgery (OR 1.3). However we also repeated multiple regression testing on the 2 year laxity testing data and found that gender was a significant factor for 2 year laxity over young age. Figure 4 demonstrates that adolescents had consistently higher laxity testing, but this only achieved statistical significance at 15 and 20 year reviews. In summary, female gender may predict short term laxity and young age may predict long term laxity.

There have been significant advances over the last decade in the field of rehabilitation after ACL reconstruction, and prevention of ACL injuries. While the population studied in this series may be representative of current surgical techniques, they did not receive a rehabilitation program consistent with current practices. A greater understanding of timing of second ACL injuries [8] and the biology of the remodelling of the ACL graft[13] has altered our practice to advise delaying a return to competitive sports for 12 months after reconstruction. This is in contrast to a 6 month delay in returning to competitive sports that was applied to this study cohort. The advent of far greater understanding and implementation of neuromuscular training, positive movement patterns and landing techniques, sports specific programmes, a focus on plyometrics and agilities has great potential to positively effect both rates of return to play and rates of second ACL injury [5, 25, 35, 53]. Hewett and Myer et al reported that neuromuscular training programs may be most beneficial in adolescents for preventing primary ACL injuries[24, 36] and these programmes can been successfully incorporated into rehabilitation after ACL reconstruction [35]. Given that 44% of the adolescents studied in this series had a second ACL injury over 20 years, that ACL graft rupture was increased by a factor of nearly 5 times in adolescent males, and 2.6 times for adolescent females compared to adults, the importance of completing successful criteria based rehabilitation and returning to sports at *both* a suitable time *and* at an optimal level of performance for the adolescent population is imperative. Particular attention to adolescents and those with tibial slopes of 12 or more with regard to education, delaying a return to play and completing an effective and complete rehabilitation may be warranted to reduce the high rate of reinjury in these populations.

The majority of subjects in this series (60%) displayed no evidence of radiological degenerative change 20 years after their ACL reconstruction. Mild changes were seen in 23% and moderate to severe radiological osteoarthritis was evident in only 17%. There was no significant difference in radiological grade between the adolescent and adult groups at 20 years (p=0.51). Since the mean age of study participants was 45 years at the 20-year review, the incidence of OA after ACL reconstruction with regard to moderate to severe degenerative change may be considered comparable with the normal population[46]. The prevalence of knee OA has been reported in the literature as 26% in the age group 55-65 years[28]. Few studies examine ACL reconstruction over 20 years, but Risberg recently reported very similar findings of radiographic OA observed in the tibiofemoral compartment in 42% and patellofemoral compartment in 21%, 20 years after ACL reconstruction in 168 subjects[41], with a higher prevalence of OA evident in those with combined injuries. Higher rates of radiographic osteoarthritis have been reported by others at 14 years after ACL reconstruction with a transtibial approach[6] and a recent systematic review and meta-analysis of 615 subjects reported moderate to severe radiologic changes evident in 20% 10 years after ACL injury [2]. Our study may reveal lower rates of degenerative change compared with other series, owing to the selection of participants without significant concurrent injuries to the menisci and articular cartilage. Our radiological findings should be interpreted with caution as only 61% of the original cohort completed radiological examination at 20 years. Like other authors [11] we are unable to conclude that ACL reconstruction prevents osteoarthritis in this series.

The strengths of this study lie in the prospective longitudinal nature over a 20-year period and the very low rates of loss to follow-up. The surgical technique was reproduced by a single experienced surgeon, eliminating multiple operator bias, utilizing a modern ACL reconstruction technique. However significant limitations should be acknowledged. As previously stated, the population studied represents only those without significant meniscal or articular cartilage pathology at the time of surgery, which is associated with considerably worse outcomes and survival[37]. The high proportion of subjects with a second ACL injury to either the reconstructed or contralateral limb meant that clinical examination, which assumes a normal contralateral limb and the primary ACL graft in situ, was invalidated for >25% of the population studied. With respect to follow up, although 91% of subjects completed self-reported outcomes at 20 years, only 65% attended for full physical clinical assessment, and 61% underwent radiological examination at 20 years introducing the possibility of bias. However, for the purposes of survival analysis, all subjects were censored at the time of the last examination. Additionally it should be noted that although we compare adolescents and adults in this study, the adolescent cohort is not representative of the juvenile skeletally immature subject, as only 4 subjects were aged <15 at the time of surgery and none had open growth plates. Furthermore, the number of subjects in the adolescent group was smaller than the adult group. Finally, this study was initially designed as a prospective case series of all ACL reconstructions, not specifically designed to compare adolescents and adults. A more robust study design would involve a prospective design with appropriate power and large sample sizes for both cohorts. Despite this limitation we were able to detect statistical significant and important clinically relevant differences between cohorts.

Conclusions

At 20-year evaluation, isolated anterior cruciate ligament reconstruction using hamstring tendons autograft is a reliable and reproducible procedure associated with good long term outcomes. Adolescents had inferior outcomes compared to adults with respect to ACL laxity testing, but the magnitude of this difference was small and had no effect on activity level, patient reported outcomes or return to sports. Adolescents, especially male adolescents, had an unacceptably elevated rate of ACL graft rupture compared to adults. Sagittal tibial slope appears to be a strong predictor of both reconstructed and contralateral ACL injury after reconstruction, and its negative effect is even more pronounced in adolescents.

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