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1 **Twenty-Year outcome of a longitudinal prospective evaluation of isolated endoscopic**
2 **anterior cruciate ligament reconstruction with patella tendon autograft**

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22

23

24 **Abstract**

25 **Background:** Long term prospective follow up studies of single-incision endoscopic anterior cruciate
26 ligament reconstruction are limited and may include confounding factors.

27 **Objectives:** This longitudinal prospective study reports the outcome of isolated anterior cruciate
28 ligament (ACL) reconstruction using middle-third patellar tendon autograft in 90 patients over 20
29 years.

30 **Study design:** Case series; Level of evidence, 4.

31 **Methods:** Between January 1993 and April 1994, 90 patients met study inclusion criteria, evaluation
32 1,2,3,4,5,7,10,15 and 20 years post surgery. Exclusion criteria: associated ligamentous injury
33 requiring surgery, previous meniscectomy; meniscal injury meniscectomy more than 1/3; chondral
34 injury; and an abnormal contralateral knee.

35 **Results:** At 20 years, 32(36%) patients had sustained another ACL injury, 8(9%) to the index limb and
36 27(29%) to the contralateral limb (3 injuring both knees). Mean IKDC score was 86, 50% participated
37 in strenuous/very strenuous activities, kneeling pain was present in 63%. Radiographic degenerative
38 change was found in 61%, 20% IKDC Grade C, 0% Grade D. IKDC clinical examination revealed 95%
39 had a normal/nearly normal knee. Significant gender differences existed: females were less likely to
40 re-injure the reconstructed ACL (18%v2%, $p=0.01$), reported poorer IKDC subjective score (90v83,
41 $p=0.03$), had more activity related pain (57%v20%, $p=0.02$), and less likely to participate in strenuous
42 activity (35v66, $p=0.01$). ACL graft survival was not related to age. Patients <18years old had an
43 increased odd ratio (3.2) for rupturing the contralateral ACL. Coronal graft angles <17 degrees had
44 increased risk of failure compared to those over 17 degrees (96% v 77%), by a factor of 8.5.

45 **Conclusion:** Injury commonly occurred in the contralateral ACL than the reconstructed ACL graft, the
46 most significant predictor of contralateral ACL injury is age under 18yrs. The most significant

47 predictor of ACL graft rupture is a coronal graft angle of less than 17 degrees. Females had lower re-
48 rupture rates, poorer subjective scores, decreased participation in strenuous activity, putting the
49 graft at less risk of failure. Kneeling pain remained persistent over 20 years. Radiographic
50 osteoarthritis was evident in 61% of subjects but symptomatic osteoarthritic symptoms were rarely
51 reported.

52 **Keywords:** knee; anterior cruciate ligament (ACL); reconstruction; long-term outcome

53

54 **Clinical Relevance:** The literature suggests that there is not enough evidence to determine
55 the long-term outcome of ACL reconstructive surgery using patella tendon, specifically with
56 regards to arthritis and functional outcome. This study reports the outcomes of ACL and
57 contralateral ACL knee injury at 20 years, allowing patients to better understand the long
58 term effects of ACL reconstruction and the possibility of further injury to the uninjured
59 knee.

60 What is known about the subject: There is a paucity of long-term outcomes of single
61 incision, endoscopic reconstruction of the ACL. This prospective study excludes confounding
62 factors and reports the 20 year results of isolated ACL rupture treated with patella tendon
63 autograft.

64 **What this study adds to existing knowledge:** We report the long term outcome of both the
65 reconstructed knee and the natural history of further injury to the contralateral ACL. This is
66 the longest prospective follow up study of endoscopic ACL reconstruction in the literature.

67

68

69 INTRODUCTION

70 Injury to the anterior cruciate ligament may lead to recurrent episodic instability, pain,
71 meniscal injury, osteoarthritis, poor quality of life and adversely affect long-term function of
72 the knee.^{6, 7, 10, 11, 21, 28, 30, 39} Endoscopic reconstruction aims to provide the patient with a
73 stable knee, by means of reproducing the anatomy of the ACL, thereby reducing the
74 potential for adverse long term intra-articular sequelae²¹. Arthroscopic reconstruction is
75 considered the gold standard for the treatment of ACL rupture^{9, 14, 23, 27}. The literature would
76 tend to suggest that there is not enough evidence to determine whether reconstruction of
77 the ACL prevents arthritis in the long-term^{13, 16, 21, 29}.

78 Few studies have reported long-term outcomes of single incision, endoscopic reconstruction
79 of the ACL without the associated other pathologies including meniscal, collateral ligament
80 and chondral surface damage^{7, 22, 27, 37, 38}. This prospective study excludes these confounding
81 factors, and has been reported in the literature at 2,5,7,10,15 years post-surgery^{12, 33-36}. The
82 purpose of this study is to report the 20-year outcomes of isolated ACL rupture treated with
83 endoscopic reconstruction using middle-third patellar tendon autograft.

84

85 METHODS

86 *Patient Selection*

87 Between January 1993 and April 1994, 333 consecutive patients underwent ACL
88 reconstruction. All patients had an ACL rupture diagnosed on clinical examination and
89 confirmed at arthroscopy and wished to return to sports involving pivoting, cutting or
90 sidestepping; or they had repeated episodes of instability despite non-operative treatment
91 and appropriate rehabilitation. Exclusion criteria included: any associated ligament injury

92 requiring surgery, evidence of chondral damage or degeneration, previous meniscectomy or
93 meniscal injury requiring more than one-third meniscectomy at the time of reconstruction,
94 abnormal radiograph, abnormal contralateral knee, patients seeking compensation for their
95 injury and patients who did not wish to participate in a research study. Therefore, the study
96 group consisted of 90 patients with an essentially isolated ACL injury. Ethical approval was
97 obtained from an independent ethics committee.

98

99 ***Surgical Technique***

100 The operative technique was standardized in all patients and has previously been described
101 in detail⁴¹. The senior author performed all procedures. Examination under anaesthesia
102 confirmed anterolateral rotary instability and positive Lachman testing in all patients. Under
103 general anaesthesia, a single dose of intravenous cephalosporin was administered. The limb
104 was exsanguinated using an esmarch bandage and a high thigh tourniquet was used.
105 Diagnostic arthroscopy was performed first, using high anterolateral and low anteromedial
106 portals. Suturing of appropriate meniscal lesions was carried out using an inside-out
107 technique. A central-third patellar tendon autograft was harvested through two 2cm
108 longitudinal incisions at the distal aspect of the patella and just medial to the tibial tubercle.
109 The femoral tunnel positioned 5mm anterior to the posterior capsule insertion and was
110 drilled through the low anteromedial portal with the knee in maximum flexion. The tibial
111 tunnel was positioned on the line between the anterior tibial spine and the anterior horn of
112 the lateral meniscus, immediately anterior to the PCL. The graft was fixed on the femoral
113 side with a 7 x 25 mm round-headed cannulated interference (RCI) screw (Smith and
114 Nephew Acufex, Mansfield, MA) through the low anteromedial portal and a 7 x 25 mm RCI

115 screw on the tibial side. The osseous tunnels were drilled 1mm less than the diameter of the
116 graft. The mean diameter of the tunnel was 9.6mm (range 8-11mm). Final tibial graft
117 fixation was performed in full extension. Full hyperextension, stable Lachman and anterior
118 drawer tests were achieved under anaesthetic in all patients.

119

120 ***Post-operative Protocol***

121 Patients were admitted to hospital for a median of 2 nights (1-5 nights). Immediate weight
122 bearing with the aid of crutches was encouraged. The median time of crutch use was 10
123 days (2-21 days). An accelerated rehabilitation program commenced on post-operative day
124 1 to reduce pain and swelling with the goal of achieving full extension by 6 weeks. The
125 rehabilitation program included closed-chain exercises with an emphasis on proprioceptive
126 training. At 6 weeks, patients began jogging in straight lines. From 12 weeks, general
127 strengthening exercises were continued with agility work and sporting activities
128 encouraged. Return to competitive sport involving jumping, pivoting or sidestepping was
129 not permitted until 6 to 9 months after surgery.

130

131 ***Clinical Assessment***

132 Assessments were performed by independent physical therapists or researchers with
133 extensive experience in knee assessment. Clinical assessment included: ROM, ligament
134 stability, instrumented knee testing using the KT-1000 arthrometer (MEDmetric Corp, San
135 Diego, Ca) using the manual maximum test, the International Knee Documentation
136 Committee (IKDC) Knee Ligament Evaluation Form^{4, 8}. Ligament stability was measured by
137 the Lachman and pivot-shift tests²⁵. The Lachman was graded as: 0 (negative), 1 (1-5mm

138 laxity), 2 (6-10mm laxity) or 3 (>10mm laxity) and the pivot-shift test as: 0 (negative), 1
139 (glide), 2 (clunk) or 3 (gross). Subjective assessment included: the Lysholm knee score and
140 IKDC subjective knee function score.^{4, 8} The single-legged hop test was used for functional
141 assessment. Evaluation was conducted pre-operatively, annually for 5 years, then at 7, 10,
142 15 and 20 years after surgery, these were side to side comparisons.

143

144 ***Radiographic Assessment***

145 Radiographic examination was performed as a side to side comparison, using bilateral
146 weight bearing 35-45° postero-anterior (PA), antero-posterior (AP), lateral, and patellar
147 skyline views. Radiographs were classified according to the IKDC guidelines as follows: A =
148 normal, B = minimal changes and barely detectable joint space narrowing, C = moderate
149 changes and joint space narrowing of up to 50% and D = severe changes and more than 50%
150 joint space narrowing. This grading has been shown to be both reliable and reproducible
151 with longitudinal data²⁵. An experienced musculoskeletal radiologist graded all radiographs.
152 Tunnel position was assessed in the sagittal and coronal planes and the graft inclination
153 angle was measured using a method that has previously been described in detail³⁵.

154

155 ***Statistical Analysis***

156 All data was assumed to be non-parametric. The Wilcoxon signed ranked test was used to
157 assess change over time. Comparisons between subgroups were performed with the Mann-
158 Whitney U test. Logistic regression analysis was used to assess the relative contribution of
159 selected variables on dichotomous outcomes. Statistical significance was set at p=0.05.
160 SPSS 11.0 for Windows (SPSS Science Inc., Chicago, IL) was used for all the above statistical

161 analysis. The outcomes were compared between sexes using the Mann-Whitney U test for
162 continuous measurements (mean KT-1000 arthrometer, Lysholm score) and the χ^2 test for
163 ordered categorical variables (IKDC categories, Lachman, pivot-shift test). Logistic regression
164 was used for the relationship between radiologic outcomes and the variables of further
165 surgery and tunnel placement. Survivorship of the ACL graft and contralateral ACL was
166 calculated using the Kaplan-Meier survival method. Comparisons of survival curves were
167 made with log-rank tests and univariate Cox Regression. The influence of the factors of age
168 <18 years, family history, gender and graft angle on ACL graft survival were assessed. The
169 influence of the factors of age <18 year and gender on contralateral ACL survival were
170 assessed. Factors that were significant ($p<0.05$) on univariate survival analysis were entered
171 into multivariate Cox regression and then eliminated in a step-wise fashion, until only the
172 independent significant factors remained. Statistical significance was set at a 5% level.

173

174 **RESULTS**

175 ***Study Group***

176 Ninety patients met the inclusion criteria. There were 46 men (51%) and 44 women (49%).
177 The left side was involved in 35 patients (39%) and the right in 55 (61%). Mean age at the
178 time of reconstruction was 25 years (15-42 years). Reconstruction was performed within 3
179 weeks of injury in 3 patients (3%), between 3 and 12 weeks in 64 (71%) and after 12 weeks
180 in 23 (26%). All patients had a preoperative Lachman test of grade 1 or 2 and 94% had a
181 positive pivot-shift; the remainder had locked knees and a pivot shift could not be
182 performed. Three patients (3%) with an acute injury had grade 2 laxity of the medial
183 collateral ligament; all were successfully treated by a preoperative hinged ROM brace with

184 an extension block at 30° for 6 weeks. Seventy-seven patients (86%) had intact menisci at
185 the time of ACL reconstruction. Seven (8%) required meniscal suture at the time of surgery
186 and 6 (7%) required excision of less than one-third of the meniscus.

187

188 ***Further ACL Injury***

189 Overall, **32 patients (36%)** sustained a subsequent ACL injury, either ACL graft rupture or
190 contralateral ACL (CACL) injury, at 20 years. Eight patients (9%) ruptured the ACL graft at a
191 median time of 82 months (12-240 months) post-operatively. These patients subsequently
192 underwent revision ACL reconstruction. ACL graft rupture occurred in 7 males and 1 female.

193

194 Twenty-seven patients had a contralateral ACL rupture at a mean of 82 months post-
195 operatively (22-165 months). These patients were excluded from subsequent instrumented
196 testing and single-legged hop test data, which assumes a normal contralateral knee. 25 of
197 27 contralateral ACL ruptures underwent ACL reconstruction. There were significantly more
198 contralateral ACL ruptures than graft ruptures over the 20-year follow-up period ($p=0.01$). 3
199 patients sustained both an ACL graft and contralateral ACL injury.

200

201 ***Complications***

202 There was 1 superficial wound infection in the proximal wound of the graft harvest that was
203 treated successfully with oral antibiotics. Two patients developed patellar tendonitis at 9
204 and 23 months post-operatively and were treated successfully with analgesia and
205 physiotherapy. 37 patients had further surgery. In 22 patients, surgery was performed on

206 the contralateral knee. 13 patients had surgery to the reconstructed knee and 6 required
207 surgery to both the reconstructed and the contralateral knee, Table 1. In total there were 9
208 meniscectomies performed after ACL reconstruction over the 20-year period. All meniscal
209 tears occurred during sporting activities. One patient died of unrelated causes at 9 years
210 post-operatively. 4 patients had contralateral meniscectomies. These occurred at 44, 72, 96
211 and 99 months in each patient respectively.

212

213 ***Follow-up***

214 Mean follow-up time was 245 months (231-259 months). 80 subjects were reviewed at 20
215 years. Of the 10 subjects not reviewed, 1 died of unrelated causes, 3 refused research
216 participation, 2 were unable to be located and 4 did not attend. The participant flow is
217 shown in Figure 1.

218 Patients who sustained rupture of the ACL graft were reviewed and a summary of their
219 results is shown in Table 2. Reviews were therefore performed on 72 of a possible 81
220 patients (89%) at 20 years.

221

222 ***Self-reported Assessment***

223 Lysholm Knee Score

224 The Lysholm knee score is designed to evaluate specific symptoms relating to knee function
225 (limp, need for support, locking, instability, pain, swelling and impairment of stair-climbing
226 or squatting ability). The best score is 100. Pre-operative median Lysholm knee score was 64
227 (range 6-97). At 20 years, the median Lysholm knee score was 95 (range 55-100).

228 Subjective Knee Assessment (IKDC)

229 At 20 years post-surgery the mean subjective IKDC score at 20 years was 86 out of a possible
230 100 (range 28-100).

231 Activity

232 At 20 years after surgery, the average age of the patients was 45 years. Regular participation
233 was: 35% (n=25) in very strenuous activities such as soccer and basketball, 15% (n=11) in
234 strenuous activities such as skiing or tennis, 38% (n=27) in moderate activities such as
235 running or jogging and 13% (n=9) in light activities such as walking.

236 Symptoms with activity

237 At 20 years after surgery, very strenuous or strenuous activities could be performed:
238 without pain in 78% (n=56) of patients, without swelling in 76% (n=55) of patients and
239 without giving way in 88% (n=63) of patients.

240 Kneeling pain

241 The proportion of patients with kneeling pain or difficulty is reported in Figure 2. There was
242 a significant increase in the incidence of kneeling pain between 2 and 20 years (p=0.001).

243

244 ***Gender analysis***

245 Females demonstrated significantly lower incidence of ACL graft rupture compared to
246 males, but also poorer subjective outcomes and lower reported activity levels as shown in
247 Table 3.

248 The proportion of males and females participating in strenuous activities at each review is
249 shown in Figure 4. Greater proportion of males reported participating in strenuous sports at
250 2 years ($p=0.09$), 15 years ($p=0.01$) and 20 years ($p=0.009$)

251 Males had higher mean Lysholm score than females at 2 years ($p=0.05$), 5 years ($p=0.06$), 10
252 years ($p=0.09$), 15 years ($p=0.008$) and 20 years ($p=0.20$) (Figure 5).

253

254

255 ***Clinical Assessment n=44***

256 IKDC clinical assessment assumes a normal contralateral ACL. At 20 years after surgery there
257 were 57 living subjects with an intact ACL graft and contralateral ACL eligible for 20 year
258 review. Review was performed on 44 of 57 (77%) at 20 years. Of the 13 subjects without
259 clinical review 6 had moved interstate or overseas and were unable to attend for
260 geographical reasons, but did complete subjective review, 3 refused ongoing participation in
261 research, 2 did not attend and 2 were unable to located. The results are summarised in
262 Table 3.

263 Range of Motion

264 At 20 years after surgery, 39/44 had extension within 3 degrees of the contralateral limb. 4
265 patients had 3-5 degrees loss of extension and 1 patient had 10 degrees loss of extension.
266 The subject with 10 extension loss was a 43 year old male, with IKDC grade C grade on
267 radiographs and a subjective IKDC score of 89. 43 of 44 patients had flexion range within 5
268 degrees of the contralateral limb and 1 patients had 25 degree flexion loss. The patient with
269 25 degree flexion loss had a recent knee injury and MRI and clinical findings consistent with

270 a medial meniscal tear. The percentage of patients with extension loss increased
271 significantly between 2 and 5 years ($p=0.002$), but there was no change between 2 and 20
272 years ($p=0.46$)

273

274 Single-Legged hop Test

275 The single-legged hop test of knee function determines the percentage of the distance
276 achieved by hopping on the involved limb compared with the contralateral normal limb. 2
277 subjects did not perform the assessment due to recent ankle or hip injury. 35 subjects
278 ($n=83\%$) were able to hop $\geq 90\%$ of the contralateral limb, and 17% ($n=7$) were able to hop
279 between 76 and 89% of the contralateral limb.

280 Ligament Testing

281 Table 3 demonstrates the percentage of patients with normal (0-2mm laxity) or nearly
282 normal Lachman (3-5mm laxity), pivot-shift tests and instrumented testing at 20 years.

283 **Overall IKDC Grading**

284 Table 3 shows the 20-year IKDC grade for the 3 subgroups effusion, range of motion and
285 ligament evaluation, and the overall IKDC grade. Overall IKDC score is a very conservative
286 scale because the worst rating of any item in a given group determines the overall group
287 rating. Therefore, only patients with a normal knee will be rated class A.²⁶

288

289 **Radiographic Assessment**

290 Radiographs were reviewed in 61 patients. The compartment with the most degenerative
291 changes determines the overall IKDC radiographic grade. Results are shown in Figure 3 and

292 Table 5. Overall, 61% had evidence of OA at 20 years after surgery. However, only 20% of
293 subjects showed Grade C changes at 20 years, no Grade D findings.

294

295

296 ***Radiological tunnel placement (n = 85)***

297 85 of 90 patients had a suitable post-operative radiograph available for measurement of
298 radiological tunnel placement using the previously described method²²(Table 6).

299 ***Survival Analysis***

300 ACL graft survival was 96%, 94%, 94%, 90% at 5, 10, 15 and 20 years after ACL
301 reconstruction (Figure 6) Survival of the contralateral ACL was 86%, 75%, 71%, 67% at 5, 10,
302 15 and 20 years after ACL reconstruction (Figure 9).

303

304 If the coronal graft angle was < 17 degrees the odds for ACL graft rupture were increased by
305 a factor of 8.5, compared to those with a coronal graft angle of 17 or more (95% CI 2-47,
306 p=0.01) (Figure 7). 20 year survival of the ACL graft was 96% in those with an graft angle of
307 17 or more, and 77% in those with a graft angle of <17 degrees. On multiple regression
308 analysis ACL graft survival was not significantly effected by the factor of age <18 at the time
309 of reconstruction (OR 1.1, 95% CI 0.1-9.8, p=0.91), family history of ACL injury (OR 2.0, 95%
310 CI 0.5-8.2, p=0.35), or gender (OR 7.1, 95% CI 0.8-62, p=0.08).

311

312 Regression analysis of CACL survival showed that patients <18 years had a 3.2x greater odds
313 of CACL rupture than those over 18 years (95% CI 2.3-22.8, p=0.001) The survival of the

314 contralateral ACL was 44% in those <18 years, compared to 75% in those 18 or more (Figure
315 8). CACL survival was not influenced by gender (OR 1.1, 95% CI 0.3-3.0, p=0.92), or family
316 history of ACL injury (OR 1.1, 95%CI 0.5-2.8, p=0.79).

317

318 **DISCUSSION**

319 This study reports the 20-year outcomes of endoscopic ACL reconstruction using middle-
320 third patellar tendon autograft. It is known that other associated pathologies in the knee
321 (such as chondral damage) can result in a poor outcome despite ACL reconstruction. This
322 study reporting the findings of 'isolated' ACL injuries requiring reconstruction, based on the
323 adopted exclusion criteria. It is, however, noted that it is difficult to achieve this in reality
324 and that the truly 'isolated' ACL probably does not occur. The strict inclusion criteria
325 resulted in approximately 30% of patients with ACL rupture over the study period being
326 eligible for the study. Interpretation of the outcomes of this study cannot be generalised to
327 the wider population of ACL injured knees, but rather represent the best-case scenario after
328 ACL reconstruction.

329

330 **Osteoarthritis**

331 The long term role of ACL reconstruction preventing OA has not been well established in
332 the literature, but its role in menisco-protective functioning preventing further damage to
333 the menisci has been shown in several studies^{10, 38}. In this series 9 patients required further
334 meniscectomy, 6 of which were performed in the first 15 years following reconstruction and
335 3 meniscectomies were performed between the 15-20 year period. By comparison 4
336 patients underwent meniscectomy in the contralateral knee. In a prospective study of

337 conservatively treated ACL's the incidence of meniscal surgery was 54% over 5 years, and in
338 other studies reported as high as 95% at 20 years post injury^{17, 28}. Our findings support the
339 hypothesis that ACL reconstruction is effective in reducing further meniscal damage,
340 compared to conservative treatment.

341

342 Our results suggest that BPTB ACL reconstruction is not as arthogenic as previously
343 suggested in the literature^{15, 29}. In this series radiological degenerative change was present
344 in 27% subjects at 5 years, 51% at 15 years, and 61% at 20 years. However the proportion of
345 patients with moderate to severe changes was low, only 20% of subjects had Grade C (up to
346 50% joint space narrowing) changes at 20 years, and no Grade D. This in contrast with other
347 studies looking at the progression of OA in ACL reconstructed knees, where higher levels of
348 more severe degenerative changes are seen, some as high as 20% at 10 years with
349 moderate to severe radiographic changes^{1, 15, 29}. The presence of other pathologies in the
350 knee such as chondral injuries or meniscal tears may increase the rate and degree of OA^{11, 20,}
351 ^{21, 28, 31, 32, 39}, and this may account for the lower incidence reported in our series compared
352 to others. It should be remembered that the cohort of subjects in this study would now be
353 an average age of 45 years. Others have shown that in the painful knee population the
354 incidence of radiographically detectable OA in the 35-54 year age group is 5%³². BPTB ACL
355 reconstruction does not appear to be associated with high rates of moderate to severe
356 radiological degenerative change over 20 years, but it may be higher than the incidence
357 seen in the general population, suggesting that this procedure does not prevent
358 osteoarthritis, but may reduce the severity of premature degeneration when the meniscus
359 is preserved.

360

361 **Clinical Outcomes**

362 Clinical outcomes reveal that 95% of subjects with intact ACL grafts had a normal or nearly
363 normal knee at 20 years according to IKDC criteria. High subjective scores are maintained
364 over 20 years, and normal ligament examination was seen in 84%. With regards to ROM
365 only 1 patient had a loss of extension $>5^{\circ}$ and there was no statistically significant
366 progression of loss of extension between 2 and 20 years, which is consistent with previous
367 studies^{23, 24}. At 20 years 50% of patients were back to strenuous activity, which suggests that
368 ACL reconstruction with BPTB is an effective procedure for getting subjects back to sporting
369 activity. Kneeling pain is a persistent issue post surgery despite a two incision approach. It is
370 important to document that this common post-operative finding persists in up to 67% at 20
371 year follow up, so must be addressed as part of the patients education on this procedure.
372 ACL reconstruction with a BPTB is a well tolerated procedure with good clinical and
373 subjective outcomes maintained over 20 years.

374

375 **Gender differences**

376 Females in this study demonstrated unfavourable outcomes compared to males with
377 respect to lower IKDC subjective score, were more likely to report pain on strenuous
378 exercise and were less likely to participate in strenuous activity. Females also had a lower
379 incidence of ACL graft rupture (2%) compared to males (16%) ($p=0.03$), although gender did
380 not achieve statistical significance on multiple regression analysis of ACL graft survival
381 ($p=0.08$). Poorer subjective outcomes seen in females compared to males may preclude
382 activity at a strenuous level, thereby limiting the reconstructed ACL exposure to activities

383 which could place the graft at risk of failure, and result in lower incidence of graft rupture.
384 ACL reconstruction with BPTB has a favourable outcome for females compared to males
385 with regards to ACL graft rupture but may be poorly tolerated with respect to subjective
386 outcomes.

387

388 **Further ACL Injury**

389 Contralateral knee ACL rupture occurred more frequently than ACL graft rupture. The
390 survival of the contralateral ACL was 69% at 20 years, compared to 90% in the reconstructed
391 ACL. Previous studies have that reported ACL rupture rates of BPTB of 6-13% between 10-15
392 years^{23, 40}. The higher incidence of contralateral ACL injury, compared to ACL graft rupture
393 could be due to a number of factors, including the potential genetic and biomechanical
394 considerations putting the native ACL at risk, the possibility of the subject favouring the
395 reconstructed knee or the fact that the BPTB reconstruction is stronger than the native
396 ligament.

397

398 **Outcome after ACL graft rupture and revision surgery**

399 Subjects who had a BPTB graft rupture had a higher incidence of radiological degenerative
400 change (71%) compared to those with intact ACL grafts (60%), however their mean
401 subjective scores were still high at 20 years (mean 84). The outcomes of failed BPTB
402 reconstructions may be associated with slightly higher incidence of degenerative change but
403 not necessarily poorer subjective outcomes

404

405 **Tunnel placement**

406 It is documented that a common cause for failure of ACL reconstruction is suboptimal
407 positioning of the bone tunnels in both femur and tibia³⁵. At 20 years the ACL graft survival
408 was significantly lower in those with a coronal graft angle of less than 17 degrees, with an
409 8.5 times greater odds ratio, compared to those with a graft angle of >17 degrees. More
410 vertical graft placement is associated with increased failure, due to persistent anterolateral
411 rotational instability^{2, 19}. Over recent years there has been a trend towards placing the
412 femoral tunnel lower on the lateral wall of the intercondylar notch^{5, 18}. The mean coronal
413 graft angle was 19 degrees in this series, which may be higher than current trends. Whether
414 the current trend for lower placement of the femoral tunnel on the intercondylar notch
415 results in lower rates of ACL graft rupture is yet to be shown.

416

417 **Age**

418 When compared to those over 18 years, subjects under 18 years at the time of ACL
419 reconstruction did not have higher rates of ACL graft rupture, but did have higher rates of
420 contralateral ACL rupture. More than half of those <18 years (56%) had a contralateral ACL
421 rupture over the 15 years. Other studies have shown that adolescents may well have a
422 higher risk of ACL graft rupture, that they may have a higher preoperative activity level,
423 issues with compliance with rehabilitation and be more likely to place the graft at risk^{3, 26}.
424 Our study has not shown the ACL graft survival to be significantly lower in adolescents than
425 adults. However, the strongest predictor of contralateral ACL rupture was age less than 18,
426 compared to over the age of 18 (25% v 56%). This could be due to multifactorial aspects of
427 this age group, including pre-existing genetic or biomechanical factors placing the native ACL

428 at risk, that the BPTB graft is stronger than the native ACL. Patients may also favour the
429 reconstructed knee, placing the contralateral knee at increased risk of injury.

430

431 There are some limitations to this study. The strict inclusion criteria was designed to
432 examine and report the natural history of ACL reconstruction without the confounding
433 effects of other injuries. It must be noted that this represents approximately 1 in 3 of the
434 ACL reconstructed population and the results of this study are not generalisable to those
435 with confounding injuries, such as meniscal or cartilage damage, which is likely to worsen
436 outcome. The strengths of this study include the very high follow up over 20 years, the
437 prospective longitudinal design, and the homogenous group of patients, treated by a single
438 highly experienced knee surgeon ensuring consistency in surgical technique. The
439 arthroscopic surgical technique reported in this study is consistent with modern techniques,
440 with femoral tunnel drilling via the anteromedial portal.

441

442 **CONCLUSIONS**

443 This study reports the long term outcome of patients having undergone middle-third BPTB
444 reconstruction at 20 years. In the reconstructed knee good long term outcomes with
445 regards to subjective scores, return to strenuous activity governed by a stable knee with
446 good ROM are demonstrated. We have shown that females may have unfavourable
447 outcomes with regards to subjective scores and pain, which may protect the ACL graft from
448 further injury. Radiological assessment of graft inclination angle is an important predictor of
449 ACL graft rupture, contralateral ACL injury is common, especially in the young, and OA
450 progression may not be as common as previously suspected.

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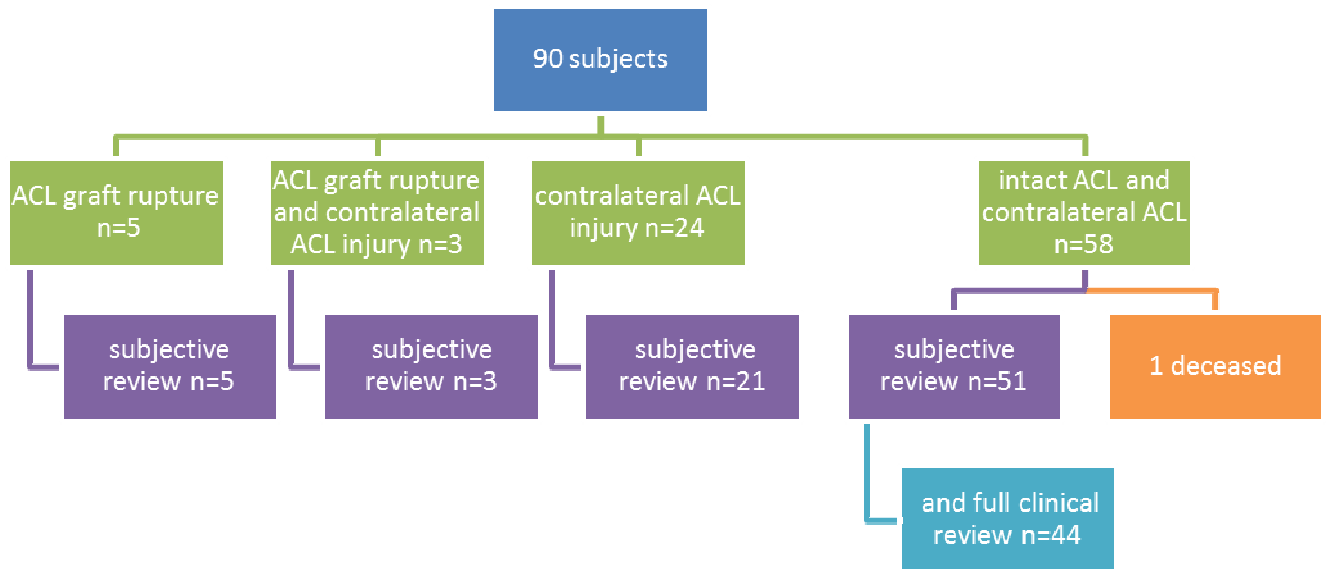
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559 **FIGURES**

560 **Figure 1:** Participant Flow

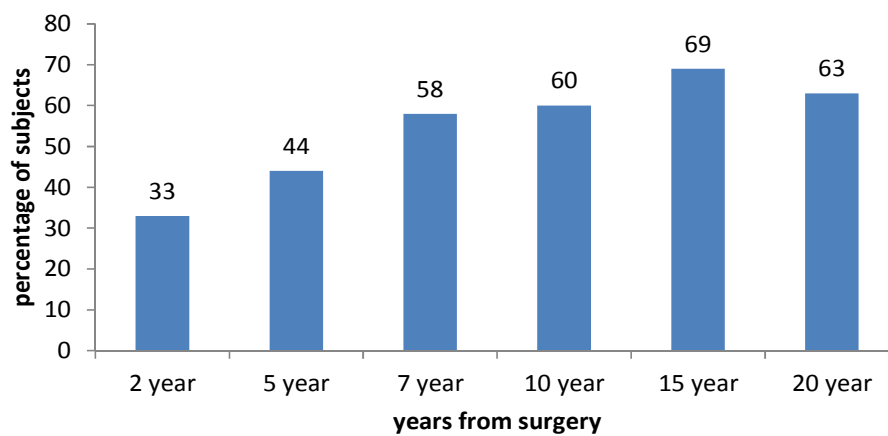


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564 **Figure 2:** Percentage of patients with kneeling pain or difficulty at each review

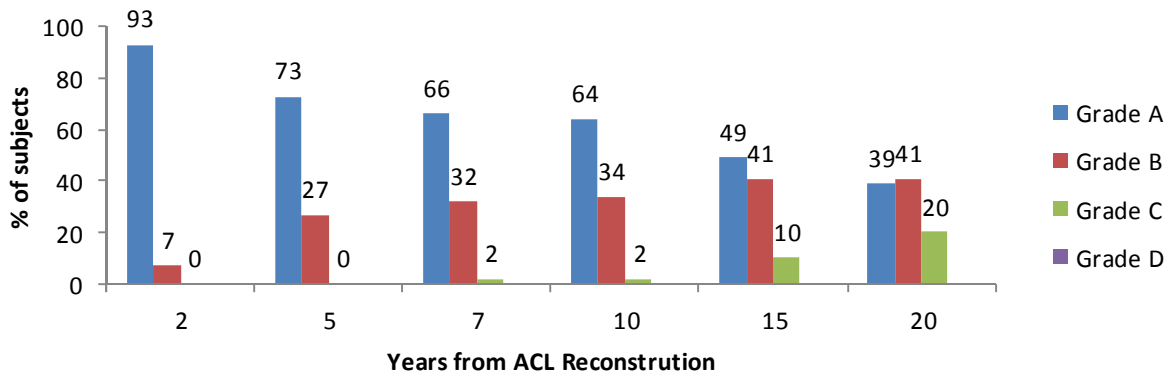


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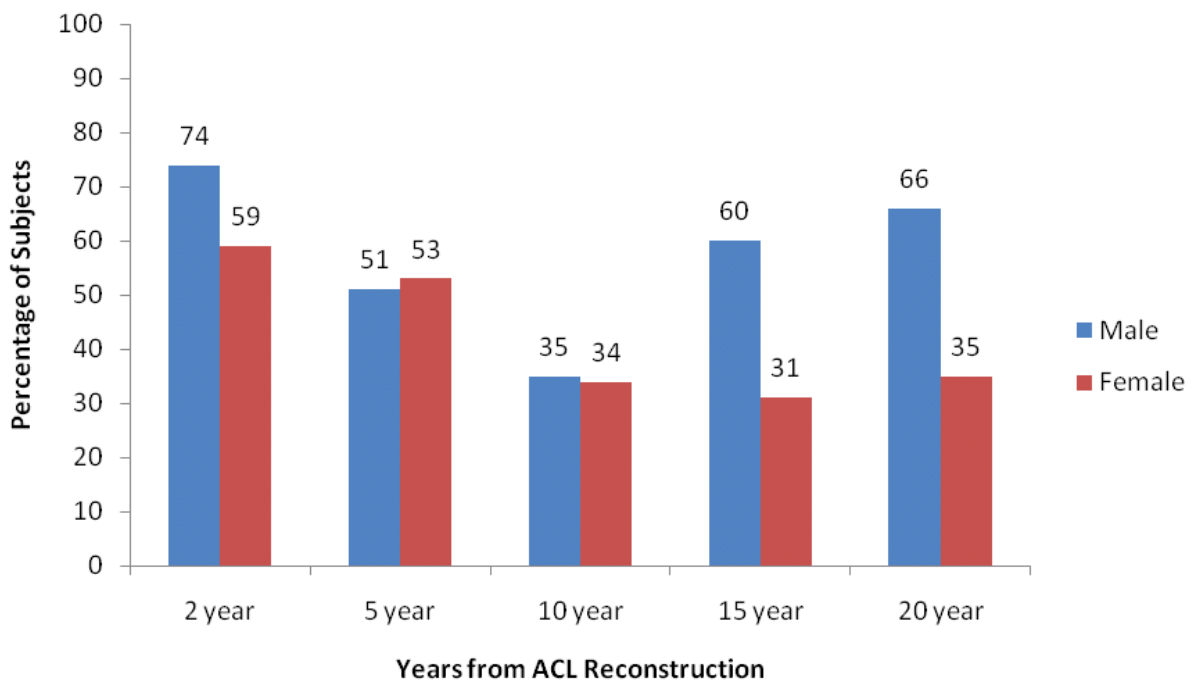
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568 **Figure 3:** Overall IKDC Radiological Grading



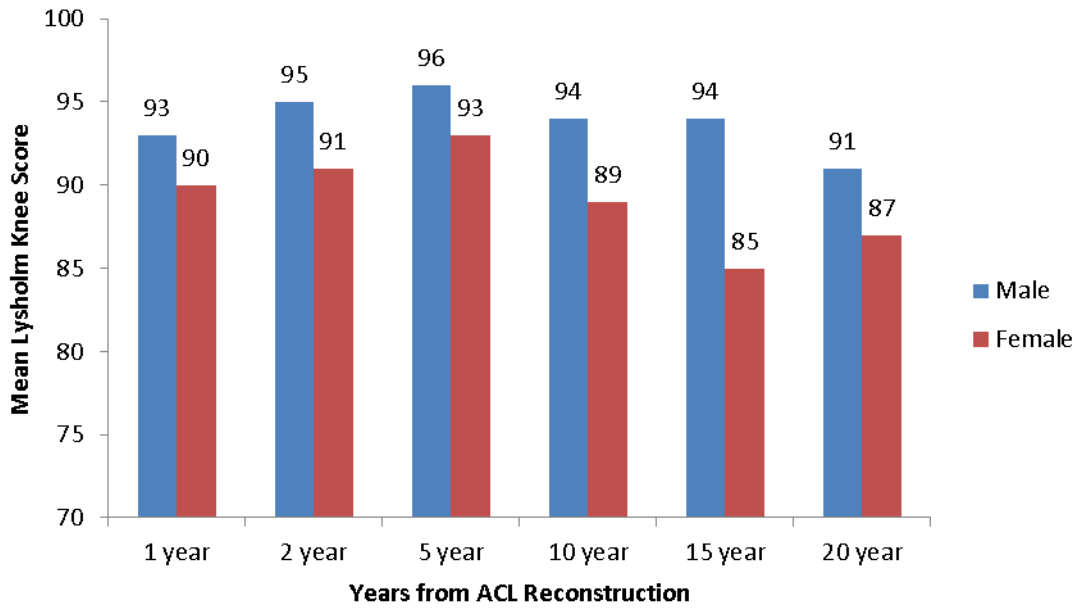
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571 **Figure 4:** Percentage of males and females participating in strenuous sports at 2-20
572 years after reconstruction



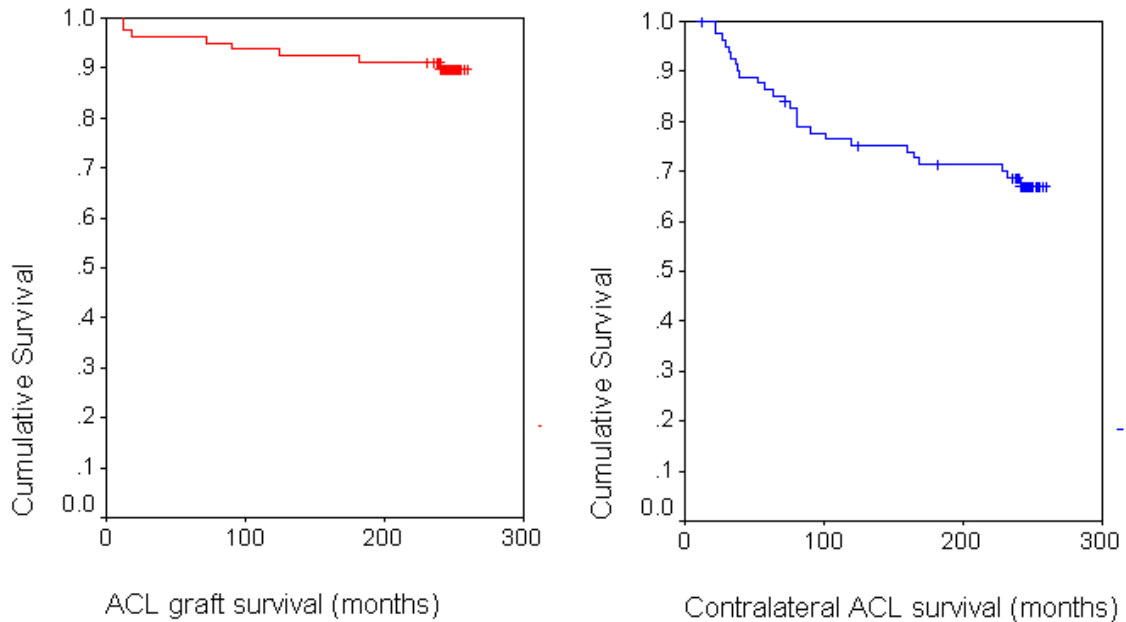
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583 **Figure 5:** Mean Lysholm Knee Score of males and females at 2-20 years after
 584 reconstruction



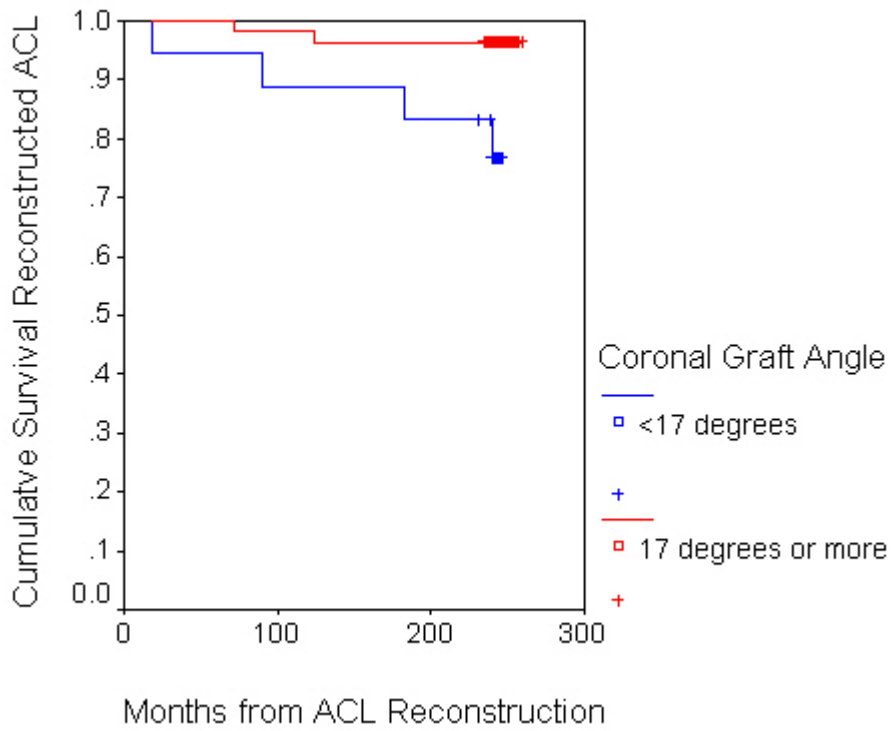
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586 **Figure 6:** Kaplan Meier ACL graft (left) And Contralateral ACL (right) survival over 20 years



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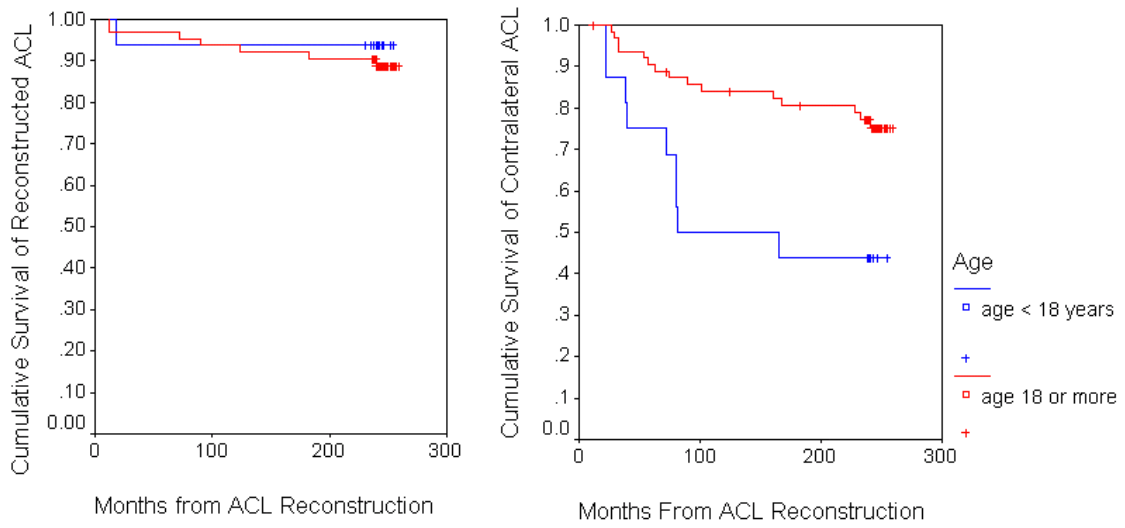
588 **Figure 7:** Kaplan Meier survival of the reconstructed ACL according to coronal graft angle.



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591 **Figure 8:** Cumulative survival of the ACL Graft (left) and contralateral ACL (right)
592 according to age



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594 **TABLES**

595 **Table 1: Further Surgery over 15 years**

# of Patients	Surgery to Index Knee	Months Post-op	# of Patients	Surgery to Contralateral Knee	Months Post-op
6	Revision ACL reconstruction *	12, 18, 76, 91, 126, 182	25	Contralateral ACL reconstruction *	Mean 82 (range 22-165)
9	Partial meniscectomy	14, 18, 62, 69, 99, 99, 204, 220, 228	4	Contralateral partial meniscectomy	44, 72, 96, 99
2	Arthroscopic debridement of Cyclops lesion	6, 242			
1	Arthroscopic arthrolysis	3			
1	Excision of patellar tendon cyst	24			
1	Arthroscopic chondroplasty	21			
1	Removal of tibial screw	87			

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599 **Table 2:** Results of the 8 patients who had an ACL graft rupture. All 8 patients
 600 completed subjective review, 6 attended for clinical review.

	No of patients (%)
Proceeded to revision ACL reconstruction	6/8 (75%)
Effusion	1/6 (17%)
IKDC Score Mean (Range) N=8	84 (66-93)
IKDC Ligament Grade A	4/6 (67%)
IKDC ROM Grade A	4/6 (67%)
IKDC Overall Grade A	2/6 (33%)
Grade B	2/6 (33%)
Grade C	2/6 (33%)
Strenuous or Very Strenuous Activity at 20 years	2/8 (25%)
IKDC Radiological	
Grade A	2/7 (29%)
Grade B	2/7 (29%)
Grade C	3/7 (42%)
Grade D	0

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605 **Table 3:** Comparison of female and male outcomes at 20 years

	Female	Male	Sig
No of subjects	42	38	
ACL graft rupture (%)	2%	16%	0.03
Contralateral ACL (%)	26%	35%	0.34
Subjective review no of subjects	37	35	
Mean IKDC Subjective Score (standard deviation)	83 (16)	90 (13)	0.03
Participating in strenuous or very strenuous activity at 20 yrs (%)	35%	66%	0.009
Pain with very strenuous activity at 20 years (%)	57%	20%	0.02
Objective review no of subjects	22	22	
IKDC Ligament Grade Normal (%)	96%	68%	0.03
Overall IKDC Grade Normal (%)	86%	55%	0.05
Radiological Grade Normal (%)	39%	40%	0.31

606

607 **Table 4: Summary of IKDC Clinical Examination at 20 years**

Summary of Clinical Examination at 20 years (n=44)	Grade A Normal	Grade B Nearly Normal	Grade C Abnormal	Grade D Severely Abnormal
Effusion	40 (90%)	4 (10%)		
Lachman	37 (84%)	7 (16%)		
Pivot Shift	42 (95%)	2 (5%)		
KT1000	38 (86%)	6 (14%)		
IKDC Ligament	37 (84%)	7 (16%)		
IKDC ROM	38 (86%)	4 (9%)	2 (5%)	
IKDC Overall	31 (70%)	11 (25%)	2 (5%)	
Single Legged Hop *not performed by 2 patients	35 (83%)	7 (17%)		

608

609 **Table 5: Summary of IKDC Radiographic Examination at 20 years**

Summary of Radiographic Examination at 20 years (n=61)	Grade A Normal	Grade B Nearly Normal	Grade C Abnormal	Grade D Severely Abnormal
Medial Tibiofemoral	29 (48%)	23 (38%)	9 (15%)	
Lateral Tibiofemoral	51 (83%)	9 (15%)	1 (2%)	
Patellofemoral	42 (69%)	11 (18%)	8 (13%)	
Overall	24 (39%)	25 (41%)	12 (20%)	

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612 Table 6: Comparison of the parameters of tunnel placement between patients with
 613 ruptured and those with intact grafts at 20 years

614

	Intact ACL graft	Ruptured ACL graft	p-value
Number of patients (n)	78	7	
Mean (sd) tunnel placement			
Sagittal femoral (%)	85 (8)	78 (10)	0.05
Sagittal tibial (%)	41 (9)	36 (5)	0.20
Mean (sd) coronal graft inclination (°)	19.7 (4)	16.2 (4)	0.05