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1 **Twenty-Year Outcome of a Longitudinal Prospective Evaluation of Isolated Endoscopic Anterior**

2 **Cruciate Ligament Reconstruction with Either Patellar Tendon or Hamstring Autograft**

3

4 **ABSTRACT**

5 **Background:** Long-term prospective studies of isolated endoscopic anterior cruciate ligament
6 (ACL) reconstruction are limited and may include confounding factors.

7 **Purpose:** This study compares the outcomes of isolated ACL reconstruction using patellar tendon
8 autograft (PT) and hamstring autograft (HT) in 180 patients over 20 years.

9 **Study Design:** Case series; Level of evidence, 4.

10 **Methods:** 180 participants undergoing isolated ACL reconstruction between 1993 and 1994 were
11 prospectively recruited. Evaluation was performed at 1, 2, 5, 7, 10, 15, and 20 years after surgery
12 and included the International Knee Documentation Committee (IKDC) Knee ligament evaluation
13 with radiographic evaluation, KT1000, and subjective scores.

14 **Results:** Over 20 years, 16 (18%) had an ACL graft rupture in the HT group, and 9 (10%) in the PT
15 group (p=0.13). ACL graft rupture was associated with male gender (OR 3.9, p=0.007), non-ideal
16 tunnel position (OR 3.6, p=0.019) and those aged <18 at time of surgery (OR 4.6, p=0.003). The
17 odds of contralateral ACL rupture, were increased in those with the PT graft compared to the HT
18 graft (OR 2.2, p=0.02) , and those age <18 at the time of surgery (OR 3.4, p=0.001). The mean IKDC
19 score was 86 for the PT and 89 for HT at 20 years (p=0.18). At 20 years 53% of the PT group and
20 57% of the HT group participated in strenuous or very strenuous activities (p=0.55). Kneeling pain
21 was present in 20% of the HT group and 63% of PT group (p=0.018). Radiographic osteoarthritic
22 change was found in 61% of the PT group, and 41% of the HT group (p=0.008) at 20 years.

23 **Conclusion:** Participants receiving the PT graft had significantly worse outcomes compared to
24 those receiving HT graft regarding radiologically detectable osteoarthritis, kneeling pain and
25 contralateral ACL injury. At 20 years both HT and PT autografts continue to provide good
26 subjective outcomes and objective stability. However, further ACL injury is common, particularly in
27 males, the young, and those with tunnel malposition.

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

29 **Clinical Relevance:** There is limited literature reporting the long-term outcome of ACL

30 reconstructive surgery, specifically regarding reinjury, arthritis and functional outcome. This study

31 reports the outcomes of ACL reconstruction over 20 years, providing better understanding of the

32 long term effects of ACL reconstruction and the incidence of further ACL injury.

33 **What is known about the subject:** There is a paucity of long-term outcomes of single incision,

34 endoscopic reconstruction of the ACL. This prospective study excludes confounding factors and

35 reports the 20 year results of isolated ACL rupture treated with either autologous quadruple

36 strand hamstring or patellar tendon autograft.

37 **What this study adds to existing knowledge:** We report the long term outcome of both the

38 reconstructed knee and the natural history of further injury to the contralateral ACL. This is the

39 longest prospective follow up study of endoscopic ACL reconstruction in the literature.

40 **INTRODUCTION**

41 Anterior cruciate ligament (ACL) injury commonly occurs in the young active population, and may
42 lead to recurrent episodic instability, pain, meniscal injuries, osteoarthritis (OA), affect long-term
43 function of the knee and subsequent degenerative change.^{5, 6, 10, 11, 20, 29, 31, 42} Endoscopic
44 reconstruction is considered the gold standard for the treatment of ACL ruptures, aiming to
45 produce a stable knee by recreating the ACL anatomy.^{9, 14, 20, 22, 28} There is a paucity of studies
46 confirming the long term results of ACL reconstruction, and it may well be that timely
47 reconstruction may prevent osteoarthritis (OA).^{13, 16, 20, 30, 47}

48 Few studies have reported the long-term outcomes of single-incision endoscopic reconstruction of
49 the ACL without associated other injuries including meniscal, collateral ligament, and chondral
50 surface damage.^{6, 21, 28, 38, 41} This prospective study excludes these confounding factors and has
51 been previously reported in the literature at 2, 5, 7, 10 and 15 years after surgery.^{12, 24, 34, 35, 37} The
52 purpose of this study was to report the 20-year outcomes of isolated ACL ruptures treated with
53 endoscopic reconstruction using middle-third patellar tendon or quadrupled hamstring autografts.

54 Our hypothesis was that the long term outcome of ACL reconstruction is affected by graft
55 selection.

56

57 **MATERIALS AND METHODS**

58 Ethical approval was obtained from an independent hospital Human Ethics Committee [REDACTED]
59 [REDACTED] This study is an ongoing prospective cohort study with the
60 twenty year results being reported.

61 Patient Selection

62 ACL reconstruction was offered to patients who demonstrated clinical ACL instability with at least
63 grade II Lachman and Pivot Shift tests. The acute injury was managed with physical therapy to
64 facilitate a full or near full range of movement with minimal pain and swelling prior to surgery. At
65 the time of surgery those requiring removal of more than one third of one meniscus were
66 excluded from the study. There were 17 cases included in the study that had meniscal suturing.
67 The process of patient selection for this study has been previously documented and the inclusion
68 and exclusion criteria are presented in Table 1. The large number of exclusions is due to the strict
69 criteria, which were designed to minimize the confounding variables and allow a true comparison
70 of results between graft types.

71 **Table 1. Inclusion and Exclusion Criteria**

Inclusion Criteria	Exclusion Criteria
Endoscopic ACL Reconstruction with either <u>patellar</u> tendon or hamstring tendon autograft between January 1993 and November 1994	Any associated ligament injury requiring surgery Evidence of chondral damage or degeneration Previous meniscectomy Excision of >1/3 of one meniscus at time of reconstruction Abnormal radiograph Abnormal contralateral knee joint Patients seeking compensation for their injury Patients unwilling to participate in a research programme

73 From January 1993 to April 1994, 333 patients were prospectively examined and underwent
74 surgical reconstruction of the ACL using PT autograft. Of this group, 90 patients fulfilled the study
75 inclusion criteria and were included in this study. In October 1993, the senior author [REDACTED]
76 started using the HT autograft, and after April 1994 used the HT graft exclusively. There were 39
77 patients who underwent surgery during the 6 month overlap period, 15 received the HT autograft
78 and 24 received the PT autograft. The decision of which graft to use during this period was based
79 on the initial consultation where patients who were seen from mid October 1993 were offered the
80 HT autograft. From October 1993 to November 1994, 372 patients underwent ACL reconstruction
81 using 4 strand HT autograft. Out of this group, 90 met the selection criteria and were included in
82 this study.

83 Surgical Technique

84 All procedures were performed by the senior author [REDACTED]. The technique was standardized for all
85 patients and has previously been described in detail.^{12, 49} In the PT group, the ipsilateral middle
86 third bone - patellar tendon - bone graft was used, and the tunnel diameter was 1mm greater than
87 the measured bone block diameter (range 8 to 11mm). In the HT group, a 4 strand Gracilis and
88 Semitendinosus tendon graft was used, and the tunnel diameter equaled the measured diameter
89 of the graft (range 6 to 9mm).

90 The femoral tunnel was drilled before the tibial tunnel via the anteromedial arthroscopic portal
91 with the knee in maximal flexion, and positioned 5mm anterior to the posterior capsular insertion.

92 The tibial tunnel was centered on a line between the anterior tibial spine and the posterior margin
93 of the anterior horn of the lateral meniscus, half a graft diameter lateral along that line.

94 In all cases the fixation consisted of a 7 x 25mm titanium cannulated interference screw (RCI,
95 Smith and Nephew Endoscopy, Andover, Mass) for both femoral and tibial fixation.

96 Rehabilitation

97 Both groups were treated with the same rehabilitation program. Patients began weight bearing
98 and co-contractions of the hamstrings and quadriceps immediately after surgery. No brace was
99 used and crutches were discarded as soon as possible. An accelerated rehabilitation program was
100 instituted by physiotherapists, focusing on achieving full extension ideally by 14 days after surgery,
101 and full flexion and extension by 6 weeks. Jogging was commenced at 6 weeks, and return to
102 competitive sport was restricted until 6 months and only after reconfirming knee stability on
103 clinical examination.

104 Assessment

105 All patients were assessed by an experienced independent examiner prior to surgery and 6 and 12
106 months after surgery, then annually for 5 years and again at 7, 10, 15, and 20 years after surgery.
107 The International Knee Documentation Committee (IKDC) evaluation form was used and
108 symptoms and signs of knee function were assessed to determine the IKDC grade. From 2003
109 onwards the updated IKDC (2000) evaluation form was used.^{3, 7} The Lysholm knee score was
110 obtained by a self-administered questionnaire^{18, 26, 46}. Clinical assessment of knee stability was
111 performed and recorded as a side-to-side difference compared to the normal contralateral knee,
112 using the Lachman, Anterior Drawer and the Pivot Shift tests. Lachman test was graded as follows:
113 Grade 0 is no difference, grade 1 is 1 to 5mm laxity, grade 2 is 5 to 10mm laxity, and grade 3 is
114 greater than 10mm laxity. The Pivot Shift test was assessed as grade 0 being negative, grade 1
115 being a glide, grade 2 a clunk, and grade 3 being gross. Instrumented laxity testing was determined
116 using the KT-1000 arthrometer (MEDmetric Corp, San Diego, Calif) measuring side-to-side
117 differences in displacement on manual maximum testing²⁵. Range of motion was determined using
118 a goniometer. Single leg hop test was also performed as a further assessment of function.

119 Radiographs were taken at 2, 5, 7, 10, 15 and 20 years after surgery including weight bearing
120 anteroposterior (AP), 30 degree flexion posteroanterior (PA), lateral and 45 degree Merchant

views. These were assessed by an independent experienced musculoskeletal radiologist for evidence of degenerative change in the medial, lateral and patellofemoral compartments and classified according to the IKDC guidelines as being: A, normal; B, minimal change and barely detectable joint space narrowing; C, moderate changes and joint space narrowing of up to 50%; and D, severe changes and more than 50% joint space narrowing. The worst grade of the three compartments was used to assign the overall radiographic grade.

The radiographs were also reviewed to assess tunnel position, using methods previously reported.³⁶ Ideal tunnel position was defined as being sagittal tibial tunnel 40-50% anterior, sagittal femoral tunnel 80-90% posterior, and coronal graft inclination greater than 17 degrees as supported by previous study³⁶.

Statistical Method

The outcomes were compared between groups were assessed using the Mann-Whitney U test for continuous measurements (mean KT-1000 arthrometer, Lysholm score) and the chi-squared test (χ^2) test for ordered categorical variables (IKDC categories, Lachman, Pivot Shift test). The Wilcoxon signed ranked test was used to assess change over time. Logistic regression analysis was used to assess the relative contribution of selected variables on dichotomous outcomes. SPSS 11.0 for Windows (SPSS Science Inc., Chicago, IL) was used for all the above statistical analysis. Logistic regression was used for the relationship between radiologic outcomes and the variables of further surgery and tunnel placement. Survivorship of the ACL graft and contralateral ACL was calculated using the Kaplan-Meier survival method. Comparisons of survival curves were made with log-rank tests and univariate Cox Regression. Factors that were significant ($p < 0.05$) on univariate survival analysis were entered into multivariate Cox regression and then eliminated in a step-wise fashion, until only the independent significant factors remained. Statistical significance was set at a 5% level.

145 **RESULTS**

146 Follow Up

147 The original study group contained 180 patients, with 90 patients in each group. The participant
148 flow at 20 years is shown in Figure 1.

149
150 **Figure 1: Participant flow at 20 years**

151 The rate of follow up for the 2 to 20 years reviews is shown in Table 2.

152 **Table 2: Patients reviewed with subjective results (Graft Ruptures and Deaths Excluded)**

Follow-up years	Hamstring Tendon Group	Patellar Tendon Group
2	78 of 85 (92%)	79 of 87 (91%)
5	76 of 83 (92%)	79 of 87 (91%)
7	73 of 82 (89%)	77 of 85 (91%)
10	74 of 78 (95%)	75 of 82 (91%)
15	70 of 75 (93%)	72 of 82 (88%)
20	66 of 74 (89%)	71 of 80 (89%)

153

154 The objective components of the IKDC require comparison of the reconstructed knee to the
155 contralateral normal knee, however 40 patients sustained a contralateral ACL rupture within the
156 follow up period of this study. The objective results for these patients have therefore been
157 removed, while the subjective results have been included.

158 **Demographics**

159 At surgery, the mean age of the PT group was 25 years (range 15-42) and the mean age of the HT
160 group was 24 years (range 13-52). 14 patients from the PT group and 15 patients from the HT
161 group were aged 18 or less at the time of surgery. There were 48 males in the PT group and 47
162 males in the HT group.

163

164 **Operative Findings**

165 Reconstruction was performed less than 12 weeks after injury for 70 out of 90 in the HT group,
166 and 66 out of 90 in the PT group (p=0.42). Medial meniscal injuries were noted in 20 out of 90 in
167 the HT group, and 18 out of 90 in the PT group. Lateral meniscal injuries were seen in 43 out of 90
168 in the HT group, and 34 out of 90 in the PT group (p=0.35). Meniscal suturing was performed in 10

169 HT, and 7 PT patients, and minimal resection of less than one third of the meniscus in 9 HT and 6
 170 PT patients (p=0.52).

171 Further Surgery

172 The details of any subsequent surgery on the index knee are listed in Table 3.

173 **Table 3: Further Surgery over 20 years.**

	Patellar Tendon Group	Hamstring Tendon Group
No further surgery to index knee*	71	63
Meniscectomy*	9	12
Revision ACL reconstruction	6	14
Excision of tibial screw	1	2
Excision patellar tendon cyst	1	
Excision Cyclops	2	1
Arthroscopy	2	
Open reduction and internal fixation of tibial fracture		1
Femoral Varising osteotomy		1

174 *No significant difference between PT and HT group for incidence of further surgery (p=0.15), or
 175 meniscectomy (p=0.19)

176 ACL Graft Rupture

177 ACL graft rupture occurred in 16 patients (18%) from the HT group and 9 patients (10%) in the PT
 178 group (p=0.13).

179 Regression analysis was performed to assess the association between ACL graft survival and the
 180 selected variables of gender, family history of ACL injury, graft type, age 18 or less at time of
 181 surgery and radiographic tunnel position. The significant variables are shown in Table 4 and

182 Figures 2-4. ACL graft rupture was not significantly associated with graft type (p=0.11), or family
183 history of ACL injury (p=0.276) over 20 years.

184 **Table 4: Survival of the ACL Graft with Hazard Ratios for Significant Variables**

Factor and Category		2 Year Survival	5 Year Survival	7 Year Survival	10 Year Survival	15 Year Survival	20 Year Survival	Hazard Ratio	95% CI	p-value
All		95	94	92	90	88	85			
Gender	Males	94	93	90	87	83	78	3.9	1.5- 10.6	0.007
	Females	96	95	94	92	91	89			
Age	18 or less	85	81	76	76	71	67	4.6	1.7-12.7	0.003
	>18 years	96	96	94	91	89	88			
Tunnel placement	Ideal	100	100	100	96	95	93	3.6	1.2-10.3	0.02
	Non-ideal	93	92	89	86	85	82

185
186 **Figures 2: Cumulative survival of ACL Graft according to Gender.** Males were more likely to
187 rupture ACL graft than females with an odds ratio of 3.9 (95% CI 1.5 – 10.6, p=0.007).

188

189 **Figures 3: Cumulative survival of ACL Graft according to Tunnel placement.** Non-ideal tunnel
 190 position was associated with ACL graft rupture compared to ideal tunnel position with an odds
 191 ratio of 3.6 (95% CI 1.2 – 10.3, p=0.019).

192

193 **Figures 4: Cumulative survival of ACL Graft according to Age.** Those 18 or less had 4.6 times
 194 greater odds of an ACL graft rupture (95%CI 1.7-12.7, p=0.003), compared to those over 18 years
 195 at the time of ACL reconstruction.

196

197 Contralateral ACL Rupture

198 Over 20 years 40 participants sustained a rupture of the contralateral ACL, 27 subjects (30%) who
199 received the PT graft and 13 subjects (14%) who received the HT graft (p=0.035).

200 Regression analysis was performed to assess the association between CACL survival and the
201 selected variables of gender, family history of ACL injury, graft type, and age 18 or less at time of
202 surgery. The significant variables are shown in Table 5 and Figures 5-6. CACL survival was not
203 significantly associated with gender (p=0.24), or family history of ACL injury (p=0.47) over 20 years.

204

205 **Table 5: Survival of the Contralateral ACL with Hazard Ratios for Significant Variables**

Factor and Category		2 Year Survival	5 Year Survival	7 Year Survival	10 Year Survival	15 Year Survival	20 Year Survival	Hazard Ratio	95% CI	p-value
All		96	88	85	82	79	75			
Age	18 or less	91	77	64	59	55	50	3.4	1.7-6.8	0.001
	>18 years	96	70	88	86	83	81			
Graft	Patellar	98	87	80	76	72	70	2.2	1.2-4.3	0.022
	Hamstring	94	90	89	89	85	84

206

207 **Figures 5: Cumulative survival of Contralateral ACL according to age.** Those aged 18 or less had
 208 3.4 time greater odds of a CACL rupture (95% CI 1.7-6.8, $p=0.001$), compared to those over 18
 209 years at the time of ACL reconstruction

210

211

Figures 6: Cumulative survival of Contralateral ACL according to Graft Type. Those who received the PT graft had 2.2 times greater odds of CACL rupture (95%CI 1.1-4.3, $p=0.02$), compared to those that received the HT graft.

Incidence of further ACL injury

Further ACL injury to either the reconstructed or contralateral knee occurred in 30% ($n=27$) of the HT group, and 37% ($n=33$) in the PT group ($p=0.343$).

SUBJECTIVE RESULTS

IKDC Subjective Score

The mean IKDC score for the HT group was 89 (SD=12), compared to the PT group with a mean of 86 (SD=16) ($p=0.18$).

226 Lysholm Knee Score

227 At the 20 years the mean Lysholm Knee Score was 92 (SD 16)in the HT group and 92 (SD 11) in the
228 PT group (p=0.88). The results of the Lysholm Knee Score over the 20 year period is shown in
229 Figure 7.

230 **Figure 7: Mean and 95% Confidence Interval for Lysholm Knee Score of Hamstring and Patellar**
231 **Grafts and 2 to 20 year review periods**

233 Activity Level

234 Participants rated their current regular activity level as being very strenuous (such as jumping and
235 pivoting sports like basketball or soccer), strenuous (such as heavy physical work, skiing, or tennis),
236 moderate (such as moderate physical work or running), light (such as walking and house or yard
237 work), or unable to perform any of the above activities. There was no significant difference in
238 activity level between the HT group and the PT group (Table 6, p=0.55).

240 **Table 6: Comparison of Activity Levels at 20 years between hamstring and patellar tendon**
241 **groups.** There was no significant difference between the groups at 20 years (p=0.55)

	Patellar Tendon Group	Hamstring Tendon Group
Very Strenuous	34%	42%
Strenuous	23%	21%
Moderate	31%	21%
Light	1%	15%
Unable	0%	0%

242

243 Kneeling Pain

244 Kneeling pain was reported as not difficult, minimally difficult, moderately difficult, extremely
245 difficult or unable. No or mild difficulty with kneeling was reported by 80% (n=53) of the HT group
246 and 62% (n=44) of the PT group (p=0.018).

247

248 **OBJECTIVE RESULTS**

249 Objective results assessed include clinical ligament evaluation, range of movement, single leg hop
250 test, and the overall IKDC grade. Given that these clinical assessments require comparison to the
251 normal contralateral knee, those patients who had sustained a contralateral ACL rupture are not
252 included in these results after their contralateral injury. As a result there were 49 of a possible 63
253 patients tested clinically in the HT group (78%), and 43 of a possible 58 (74%) in the PT group at 20
254 years.

255

256 Clinical Ligament Evaluation

257 Laxity was assessed with Lachman test and Pivot Shift, and instrumented testing with the KT1000
258 arthrometer. Figure 8 summarises the overall IKDC clinical ligament evaluation at 20 years.

Figure 8: Patients with “Normal” Ligament Examination at 20 years

260

261 *Lachman test.* In the HT group 76% of patients (n=37) had grade 0 Lachman, and 25% (n=12) had
262 grade 1. In the PT group 84% (n=36) had grade 0 and 16% (n=7) had grade 1 Lachman test
263 (p=0.33). There were no cases in either group with grade 2 or 3 Lachman.

264 *Pivot shift test.* In the HT group 90% (n=44) had a grade 0 Pivot and 10% (n=5) had a grade 1 Pivot.
265 In the PT group 98% (n=42) had a grade 0 Pivot and 2% (n=1) had a grade 1 Pivot (p=0.13). No
266 patients had a grade 2 Pivot.

267 *Instrumented testing.* At 20 years, <3mm side to side difference on KT1000 manual maximum
268 testing was found in 76% (n=37) of the HT group and 86% (n=37) of the PT group (p=0.26). The
269 mean manual maximum displacement between 2-20 years is shown in Figure 9, at 20 years this
270 was 1.0 (SD 1.5) in the PT group and 1.6mm (SD 1.8) in the HT group (p=0.08)

271

272 **Figure 9: Mean and 95% Confidence Interval for Side to Side Difference in Instrumented Laxity**
273 **Testing with KT1000 Arthrometer of Hamstring and Patellar Grafts and 2 to 20 year review**
274 **periods**

275

276

277 Range of Movement

278 The HT group had 94% (n=46) with less than 3 degrees and 6% (n=3) with 3 to 5 degrees extension
279 loss. The PT group had 86% (n=37) with less than 3 degrees and 9% (n=4) with 3 to 5 degrees
280 extension loss, and 5% (n=2) with more than 5 degrees extension loss (p=0.254). One patient from
281 each the HT and PT group had a flexion deficit of more than 5 degrees (p=0.365)

282

283 Single Leg Hop Test

284 The single leg hop test measures the distance achieved by a single leg hop on the reconstructed
285 leg compared to a hop on the contralateral normal leg, expressed as a percentage. A grade A hop
286 equates to a distance 90% or greater than the contralateral limb. Grade B is 75 to 89%, and grade

287 C is less than 75%. In the HT group 77% (n=33) achieved a grade A and 23% (n=10) achieved grade
288 B. In the PT group 85% (n=35) percent achieved grade A and 15% (n=6) achieved grade B.

289

290 Overall IKDC

291 The overall IKDC gives a grade after assessing the 4 subgroups, including function, symptoms,
292 range of movement, and laxity. The results give a grade of A, B, C or D for each of the subgroups,
293 and the worst rating is used to determine the overall IKDC grade. This is a very conservative
294 measurement, as only a completely normal knee achieves grade A. Figure 10 demonstrates the
295 percentage in each group, and shows no significant difference between the HT and PT groups
296 (p=0.23).

297 **Figure 10: Percentage with a Normal (Grade A) IKDC at 20 years**

298

299 If patients with ACL graft rupture are assumed to have an abnormal overall IKDC evaluation then in
300 the proportion of subjects with normal or nearly normal (Grade A or B) overall IKDC ligament

301 evaluation at 20 years was 74% (48 of 65) in the HT group and 76% (40 of 52) in the HT group
302 (p=0.752).

303

304 **RADIOGRAPHIC RESULTS**

305 At the 20 years, there were a total of 122 patients that had radiographs performed, 61 in the HT
306 group and 61 in the PT group. A normal or nearly normal overall IKDC Radiographic grade was
307 found in 87% (n=53) of the HT group and 80% (n=49) of the PT group (p=0.328). The percentage of
308 subjects with a Grade A Radiological IKDC grade in each compartment is shown in Figure 11.

309 **Figure 11: Percentage of Patients with IKDC Grade A Radiological Grade at 20 years by**
310 **compartment**

311

312 The proportion of subjects with an abnormal IKDC radiographic grade was significantly higher in
313 the PT group than the HT group at 5 years (p=0.02), 7 years (p=0.005), 10 years (p=0.04), 15 years
314 (p=0.04) and 20 years (p=0.008) (Figure 12).

315

Figure 12: IKDC Radiological Grade in the Patellar and Hamstring Tendon Groups at years 2 to 20

years

The influence of the factors of graft type, further surgery and tunnel placement were assessed with regression analysis on the outcome of overall radiographic grade. Ideal tunnel position was not associated with radiographic outcome ($p=0.838$). Further surgery increased the odds of abnormal radiographic grade by a factor of 2.6 (95% CI 1.1-6.1, $p=0.03$). Use of the PT graft increased the odds of having an abnormal radiographic grade by a factor of 2.4 (95% CI 1.2-5.2, $p=0.019$), compared to those who received the HT graft.

Tunnel Position

Tunnel position was measured and classified overall as ideal or non-ideal, according to the criteria outlined in the methods. There were 174 out of 180 x-rays reviewed for tunnel position measurement with 89 from the HT group and 85 from the PT group. The mean values for tunnel placement are shown in Table 7.

333 **Table 7: Comparison of Tunnel Placement Parameters between Hamstring and Patellar Tendon**
 334 **Groups**

Mean Tunnel Position (Standard Dev)	Hamstring Tendon Group	Patellar Tendon Group	P Value
No of patients	89	85	
Posterior Femoral (Sagittal View)	84 (5)	82 (5)	0.032
Anterior Tibial (Sagittal View)	49 (4)	44 (5)	0.003
Graft Inclination (Coronal view)	19 (4)	21 (5)	0.076

335

336 Ideal sagittal femoral placement has been described as greater than 80% posterior along
 337 Blumensaats line. In the HT group 85% (n=76) were ideally placed and in the PT group and 67%
 338 (n=57) were ideally placed (p=0.004).

339 Ideal graft inclination angle has been described as greater than 17 degrees from the vertical. Graft
 340 inclination of greater than 17 degrees was found in 69% (n=60) of the HT group 69% and 78%
 341 (n=65) of the PT group (p=0.114).

342 Ideal sagittal tibial tunnel placement has been described as 40 to 50% anterior along the tibial
 343 plateau line. In the HT group 60.7% (n=54) were ideally placed. In the PT group the 71.8% (n=61)
 344 were ideally placed. There was no significant difference in ideally placed sagittal tibial tunnel
 345 position (p=0.083)

346 Overall ideal position requires all three measurements to be ideal. In the HT group 37.1% (n=33)
 347 had an overall ideal tunnel position. In the PT group 38.8% (n=33) had an overall ideal tunnel
 348 position. There was no difference in the number of ideal tunnel positions between the two groups
 349 (p=0.468).

351 **GENDER DIFFERENCES**

352 Table 8 shows the outcomes sub grouped according to graft and gender.

353 **Table 8: Differences between subgroups of male and female for both graft choices.**

	Female Patellar	Male Patellar	Female Hamstring	Male Hamstring	P value
ACL Graft Rupture (%)	2%	17%	16%	19%	0.081
Contralateral ACL Injury	23%	35%	9%	19%	0.033
Mean IKDC Subjective Score	83	90	88	91	0.017
Strenuous or Very Strenuous Activity without Pain	67%	88%	85%	84%	0.047
Regular Participation in Strenuous or Very Strenuous Activity	49%	65%	65%	63%	0.44
Kneeling Difficulty	43%	32%	26%	12%	0.043
Overall Ligament Grade A	96%	71%	68%	76%	0.258
Normal Overall IKDC Grade	86%	52%	61%	62%	0.072
Normal Overall IKDC Radiographic Grade	39%	40%	66%	52%	0.003

354

355

356

357 DISCUSSION

358 There is a paucity of studies comparing the long-term outcome of endoscopic ACL reconstruction
359 using modern techniques. This study reports the outcomes at 20 years of ACL reconstruction
360 comparing the use of HT against PT, the longest reported follow up in the literature. Our results
361 support the hypothesis that long term outcome of ACL reconstruction is effected by graft
362 selection.

363

364 Osteoarthritis

365 Associated injuries in the knee can result in sub-optimal outcomes following ACL reconstruction.
366 Chondral damage or meniscal pathology increase the rate of osteoarthritis in the knee. This
367 research studies an isolated ACL injury, removing the effect of known confounders of significant
368 chondral and meniscal pathology, allowing meaningful comparisons of hamstring and patellar
369 graft with regarding OA.^{11, 17, 20, 32, 42} At 20 years there was a higher incidence of detectable
370 radiological OA in the PT group (61%) compared to the HT group (41%). Other studies have
371 shown progression of OA in the reconstructed knee being as high as 20% at 10 years.^{1, 15, 30}
372 However the proportion of subjects with moderate to severe radiographic degenerative changes
373 was small in this series, 20% of the PT group and 13% of the HT group at 20 years. As the mean age
374 of the participants in this study at the 20 year review was 50 years of age, the incidence of OA
375 after ACL reconstruction with regarding moderate to severe degenerative change, may be
376 considered comparable to the normal population⁴⁸. Our study may reveal lower rates of
377 degenerative change compared to other series due to the selection of subjects without significant
378 concurrent injuries to the menisci and articular cartilage. In randomized controlled trials of graft
379 type, Sajovic et al. reported higher rates of OA with the PT graft compared to the HT graft at 5 and
380 11 years^{39, 40}, but Holm et al. no significant difference in the development of radiological OA

381 between HT and PT grafts at 10 years¹⁹. Our series represents the longest currently available
382 review of endoscopic ACL reconstruction comparing graft types. The mechanism responsible for
383 the higher rate of osteoarthritis seen with the patellar tendon graft compared to the HT graft is
384 not clear, but others have demonstrated measurable and sustained differences in gait patterns
385 and biomechanics after ACL reconstruction are graft specific⁵⁰.

386 **ACL Graft and Contralateral ACL Injury**

387 Further ACL injury after reconstruction is common, whether to the reconstructed knee or the
388 contralateral knee. In this series further ACL injury to either the reconstructed or contralateral
389 knee occurred in 30% of the HT group, and 37% in the PT group ($p=0.343$). While the incidence of
390 further injury was equivalent between graft types, the side on which further ACL injury occurs was
391 graft specific. ACL graft rupture occurred more commonly in the HT group, although this did not
392 reach significance (18% in HT group, compared to 10% in the PT group, $p=0.13$). Conversely,
393 contralateral ACL rupture occurred more commonly with the PT graft (30%) compared to the HT
394 graft (14%) ($p=0.035$) and others have reported similar findings^{44, 51-53} The reason for this is
395 unknown. Possible reasons include the BPTB reconstruction is larger and stronger than the native
396 knee ligament, or the contralateral knee is neglected during rehabilitation⁵³. Alternatively, patients
397 may favour the reconstructed knee, placing the native ACL at greater risk. Regardless of the side
398 on which further ACL injury occurs, this is a devastating outcome for the patient. Although the
399 surgical technique used in this series has remained relatively unchanged, we have significantly
400 altered the rehabilitation protocols since the early 1990s. The implementation of modern
401 rehabilitation protocols with a greater focus on plyometrics, agility and sports specific drills, as
402 well as delaying a return to competitive sports for 12 months after reconstruction may positively
403 influence the rate of further injury after ACL reconstruction and should be encouraged.

405 **Clinical outcomes**

406 Long term clinical outcomes were equivalent between graft types for the variables of self reported
407 outcomes, IKDC grades, range of motion and activity levels at 20 years, which is consistent with
408 previous studies.^{22, 23}

409 **Age**

410 Those < 18 years at the time of ACL reconstruction had a 4.6 times greater odds of an ACL graft
411 rupture and 3.4 times greater odds of a CACL rupture compared to those >18 years. Of the 29
412 patients aged 18 or less at the time of reconstruction, 18 (62%) sustained either an ipsilateral
413 (n=7) or contralateral ACL injury (n=14) over the 20 year review (3 of the 29 sustained both an ACL
414 graft rupture and a contralateral ACL injury). Other studies have also identified higher rates of
415 further ACL injury in the young compared to their adult counterparts^{33, 8, 27, 43, 52} Further ACL injury
416 in the young was most common in the first 5 years after surgery where more than 50% of the
417 injuries occurred. After 5 years from surgery the slope of the survival curves in the young more
418 closely resembles that of the adult counterparts (Figure 4-5). Studies have shown that this
419 adolescent group may be less compliant with rehabilitation, and more likely to take part in
420 activities placing the ACL at risk (such as team contact sport participation)^{2, 27}, which would
421 contribute to this increased risk of injury. The increased risk of native or reconstructed ACL
422 rupture in the young could also be due to genetic predisposition, anatomical or biomechanical
423 considerations of the juvenile knee.

424 **Gender**

425 The outcome of ACL reconstruction in this study was examined as factor of graft type and gender
426 (Table 8). Others have reported poorer outcomes after ACL reconstruction in females compared to
427 males.⁴⁵ Females who received a PT graft displayed a trend towards the lowest rate of graft
428 rupture (p=0.08) and highest incidence of a normal IKDC examination (p=0.07), but also had the

lowest mean IKDC subjective scores, highest incidence of pain with activity and greatest difficulty with kneeling and lowest level of sports participation. This may mean that the females with PT graft do not wish to indulge in activities causing discomfort and thereby precluding strenuous activity. Activity modification in this manner will place the graft at lower risk of graft rupture, compared to patient groups with higher subjective scores wishing to participate in contact and team sports (automatically engaging in activities associated with rupture risk). Males who received the PT graft had a significantly higher incidence of further ACL injury ($p=0.05$) and range of motion deficit ($p=0.05$), compared to the other groups.

Tunnel Placement

Currently there is still debate on the correct placement of both the femoral and tibial tunnels for ACL reconstruction. This study has shown that ideal sagittal femoral placement as being 80% along Blumensaats line, a graft inclination angle of greater than 17 degrees from the vertical, and sagittal tibial tunnel placement 40-50% along the tibial plateau. Femoral tunnel placement has recently been lower on the lateral wall of the intercondylar notch, but lower placement trends have not as yet revealed lower graft re-rupture rates.⁴

The limitations of this study are well documented^{12, 24, 35}, and the strict inclusion criteria attempts to produce a knee as close to an isolated ACL injury as possible. The lack of confounding factors or other injuries does not represent the entire population sustaining an injury of this nature, probably reflecting 30% of patients sustaining this injury pattern. It is therefore not generalizable to all ACL ruptures but rather represents the 'best case scenario'. The lack of randomization of graft type introduces the potential for bias. The strengths 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 method for both autologous graft types.

453 **CONCLUSIONS**

454 Over 20 years endoscopic ACL reconstruction using either autologous HT or PT graft results with
455 femoral drilling via the anteromedial portal is associated with excellent subjective outcomes and
456 clinical ligamentous stability that are maintained, with high rates of continued participation in
457 active sports. Regardless of graft type, ACL reconstructed patients have a high incidence of further
458 ACL injury of over 30%. Graft rupture is strongly associated with a young age, non-ideal graft
459 position and males. Injury to the contralateral ACL injury associated with young age and the use of
460 the patellar tendon graft choice. HT graft patients have significantly lower incidence of kneeling
461 difficulty and radiological osteoarthritis than their PT reconstructed counterparts. In so far that the
462 operative procedure, radiological tunnel placement and short term clinical outcomes of the two
463 graft choices are similar any significant differences in outcome are most likely attributable to graft
464 choice. While both the hamstring and patellar tendon grafts can be considered viable choices, the
465 prospective long term results in this series favour the hamstring tendon graft, over the patellar
466 tendon graft, for the lower incidence of radiological osteoarthritis.

467

- 469 1. Ajuied A, Wong F, Smith C, et al. Anterior Cruciate Ligament Injury and Radiologic
470 Progression of Knee Osteoarthritis: A Systematic Review and Meta-analysis. *Am J Sports*
471 *Med.* 2014;42(9):2242-2252.
- 472 2. Andernord D, Desai N, Björnsson H, Ylander M, Karlsson J, Samuelsson K. Patient Predictors
473 of Early Revision Surgery After Anterior Cruciate Ligament Reconstruction: A Cohort Study
474 of 16,930 Patients With 2-Year Follow-up. *Am J Sports Med.* 2014;43(1):121-127.
- 475 3. Anderson AF. Rating Scales. In: Fu F, Harner C, Vince K, eds. *Knee Surgery*. Baltimore:
476 Williams and Wilkins; 1994:275-296.
- 477 4. Azzam M, Lenarz C, Farrow L, Israel H, Kieffer D, Kaar S. Inter- and intraobserver reliability
478 of the clock face representation as used to describe the femoral intercondylar notch. *Knee*
479 *Surg Sports Traumatol Arthrosc.* 2011;19(8):1265-1270.
- 480 5. Beynnon B, Johnson R, Abate J, Fleming B, Nichols C. Treatment of Anterior Cruciate
481 Ligament Injuries, Part 2. *Am J Sports Med.* 2005;33(11):1751-1767.
- 482 6. Beynnon B, Johnson R, Abate J, Fleming B, Nichols C. Treatment of Anterior Cruciate
483 Ligament Injuries, Part I. *Am J Sports Med.* 2005;33(10):1579-1602.
- 484 7. Biau D, Tournoux C, Katsahian S, Schranz P, Nizard R. ACL reconstruction:a meta-analysis of
485 functional scores. *Clin Orthop Rel Res.* 2007;458:180-187.
- 486 8. Bourke H, Salmon LJ, Waller A, Patterson V, Pinczewski LA. The survival of the anterior
487 cruciate ligament graft and the contralateral ACL at a minimum of 15 years. *Am J Sports*
488 *Med.* 2012;40(9):1985-1992.
- 489 9. Cain EJ, Clancy WJ. Anatomic endoscopic anterior cruciate ligament reconstruction with
490 patella tendon autograft. *Orthop Clin North Am.* 2002;33(4):717-725.
- 491 10. Church S, Keating JF. Reconstruction of the anterior cruciate ligament: timing of surgery
492 and the incidence of meniscal tears and degenerative change. *J Bone Joint Surg Br.*
493 2005;87(12):1639-1642.
- 494 11. Cohen M, Amaro J, Ejnisman B, al. e. Anterior cruciate ligament reconstruction after 10 to
495 15 years: association between meniscectomy and osteoarthritis. *Arthroscopy.*
496 2007;23(6):629-634.
- 497 12. Corry I, Webb J, Clingeleffer A, Pinczewski L. Arthroscopic reconstruction of the anterior
498 cruciate ligament. A comparison of patellar tendon autograft and four-strand hamstring
499 tendon autograft. *Am J Sports Med.* 1999;27:444-454.
- 500 13. Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-
501 injured patient. *Am J Sports Med.* 1994;22(5):632-644.
- 502 14. Drogset JO, Grøntvedt T, Robak OR, Mølster A, Viset AT, Engebretsen L. A Sixteen-Year
503 Follow-up of Three Operative Techniques for the Treatment of Acute Ruptures of the
504 Anterior Cruciate Ligament. *J Bone Joint Surg Am.* 2006;88(5):944-952.
- 505 15. Eckstein F, Wirth W, Lohmander L, Hudelmaier M, Frobell R. Five-year follow-up of knee
506 joint cartilage thickness changes after acute anterior cruciate ligament rupture. *Arthritis*
507 *Rheumatol.* 2014;67(1):152-161.
- 508 16. Fithian D, Paxton L, Goltz D. Fate of the anterior cruciate ligament-injured knee. *Orthop Clin*
509 *North Am.* 2002;33(4):621-636.
- 510 17. Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long-term
511 incidence of gonarthrosis. *Sports Med.* 1999;27(3):143-156.
- 512 18. Hoher J, Bach T, Munster A, Bouillon B, Tiling T. Does the mode of data collection change
513 results in a subjective knee score? Self administration versus interview. *Am J Sports Med.*
514 1997;25(5):642-647.

- 515 19. Holm I, Oiestad B, Risberg M, Aune A. No difference in knee function or prevalence of
516 osteoarthritis after reconstruction of the anterior cruciate ligament with 4-strand
517 hamstring autograft versus patellar tendon-bone autograft: a randomized study with 10-
518 year follow-up. *Am J Sports Med.* 2010;38(3):448-454.
- 519 20. Kessler MA, Behrend H, Henz S, Stutz G, Rukavina A, Kuster MS. Function, osteoarthritis
520 and activity after ACL-rupture: 11 years follow-up results of conservative versus
521 reconstructive treatment. *Knee Surg Sports Traumatol Arthrosc.* 2008;16:442-448.
- 522 21. Laxdal G, Kartus J, Ejerhed L, et al. Outcome and Risk Factors After Anterior Cruciate
523 Ligament Reconstruction: A Follow-up Study of 948 Patients. *Arthroscopy.* 2005;21(8):958-
524 964.
- 525 22. Lebel B, Hulet C, Galaud B, Burdin G, Locker B, Vielpeau C. Arthroscopic Reconstruction of
526 the Anterior Cruciate Ligament Using Bone Patellar Tendon Bone Autograft. *Am J Sports*
527 *Med.* 2008;36(7):1275-1282.
- 528 23. Lewis PB, Parameswaran AD, Rue J-PH, Bach BR. Systematic Review of Single-Bundle
529 Anterior Cruciate Ligament Reconstruction Outcomes: A Baseline Assessment for
530 Consideration of Double-Bundle Techniques. *Am J Sports Med.* 2008;36(10):2028-2036.
- 531 24. Leys T, Salmon L, Waller A, Linklater J, Pinczewski L. Clinical Results and Risk Factors for
532 Reinjury 15 Years After Anterior Cruciate Ligament Reconstruction. *Am J Sports Med.*
533 2012;40(3):595-605.
- 534 25. Lubowitz JH, Bernardini BJ, Reid JB, III. Current Concepts Review: Comprehensive Physical
535 Examination for Instability of the Knee. *Am J Sports Med.* 2008;36(3):577-594.
- 536 26. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on
537 use of a scoring scale. *Am J Sports Med.* 1982;10(3):150-588.
- 538 27. Magnussen R, Lawrence J, West R, Toth A, Taylor D, WE. G. Graft Size and Patient Age Are
539 Predictors of Early Revision After Anterior Cruciate Ligament Reconstruction With
540 Hamstring Autograft. *Arthroscopy.* 2012;28:526-531.
- 541 28. Maletius W, Messner K. Eighteen- to twenty-four-year follow-up after complete rupture of
542 the anterior cruciate ligament. *Am J Sports Med.* 1999;27(6):711-717.
- 543 29. Nebelung W, Wuschech H. Thirty-five years of follow-up of anterior cruciate ligament-
544 deficient knees in high-level athletes. *Arthroscopy.* 2005;21(6):696-702.
- 545 30. Oiestad BE, Engebretsen L, Storheim K, Risberg MA. Knee Osteoarthritis After Anterior
546 Cruciate Ligament Injury. *Am J Sports Med.* 2009;37(7):1434-1443.
- 547 31. Otto D, Pinczewski L, Clingeleffer A, al e. Five-year results of single-incision arthroscopic
548 anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sport Med.*
549 1998;26(2):181-188.
- 550 32. Pernin J, Verdonk P, Si Selmi T, Massin P, Neyret P. Long-term follow-up of 24.5 years after
551 intra-articular anterior cruciate ligament reconstruction with lateral extra-articular
552 augmentation. *Am J Sports Med.* 2010;38(6):1094-1102.
- 553 33. Persson A, Fjeldsgaard K, Gjertsen J-E, et al. Increased Risk of Revision With Hamstring
554 Tendon Grafts Compared With Patellar Tendon Grafts After Anterior Cruciate Ligament
555 Reconstruction: A Study of 12,643 Patients From the Norwegian Cruciate Ligament
556 Registry, 2004-2012. *The American Journal of Sports Medicine.* 2014;42(2):285-291.
- 557 34. Pinczewski L, Deehan D, Salmon L, Russell V, Clingeleffer A. A five-year comparison of
558 patellar tendon versus four-strand hamstring tendon autograft for arthroscopic
559 reconstruction of the anterior cruciate ligament. *Am J Sports Med.* 2002;30(4):523-536.
- 560 35. Pinczewski LA, Lyman J, Salmon LJ, Russell VJ, Roe J, Linklater J. A 10-Year Comparison of
561 Anterior Cruciate Ligament Reconstructions With Hamstring Tendon and Patellar Tendon
562 Autograft: A Controlled, Prospective Trial. *Am J Sports Med.* 2007;35(4):564-574.

- 563 **36.** Pinczewski LA, Salmon LJ, Jackson WFM, von Bormann RBP, Haslam PG, Tashiro S.
564 Radiological landmarks for placement of the tunnels in single-bundle reconstruction of the
565 anterior cruciate ligament. *J Bone Joint Surg Br.* 2008;90(2):172-179.
- 566 **37.** Roe J, Pinczewski L, Russell V, Salmon L, Kawamata T, Chew M. A 7-year follow-up of
567 patellar tendon and hamstring tendon grafts for arthroscopic anterior cruciate ligament
568 reconstruction: differences and similarities. *Am J Sports Med.* 2005;33(9):1337-1345.
- 569 **38.** Ruiz A, Kelly M, Nutton R. Arthroscopic ACL reconstruction: a 5-9 year follow-up. *Knee.*
570 2002;9(3):197-200.
- 571 **39.** Sajovic M, Strahovnik A, Dernovsek MZ, Skaza K. Quality of Life and Clinical Outcome
572 Comparison of Semitendinosus and Gracilis Tendon Versus Patellar Tendon Autografts for
573 Anterior Cruciate Ligament Reconstruction: An 11-Year Follow-up of a Randomized
574 Controlled Trial. *The American Journal of Sports Medicine.* 2011;39(10):2161-2169.
- 575 **40.** Sajovic M, Vengust V, Komadina R, Tavcar R, Skaza K. A Prospective, Randomized
576 Comparison of Semitendinosus and Gracilis Tendon Versus Patellar Tendon Autografts for
577 Anterior Cruciate Ligament Reconstruction: Five-Year Follow-Up. *Am J Sports Med.*
578 2006;34(12):1933-1940.
- 579 **41.** Salmon L, Russell V, Refshauge K, et al. Long term outcome of endoscopic ACL
580 reconstruction with patellar tendon autograft. Minimum 13 year review. *Am J Sports Med.*
581 2006;34(5):721-732.
- 582 **42.** Seon J, Song E, Park S. Osteoarthritis after anterior cruciate ligament reconstruction using a
583 patellar tendon autograft. *Int Orthop.* 2006;30(2):94-98.
- 584 **43.** Shelbourne KD, Gray T, Haro M. Incidence of Subsequent Injury to Either Knee Within 5
585 Years After Anterior Cruciate Ligament Reconstruction With Patellar Tendon Autograft. *Am*
586 *J Sports Med.* 2009;37(2):246-251.
- 587 **44.** Sward P, Kostogiannis I, Roos H. Risk factors for a contralateral anterior cruciate ligament
588 injury. *Knee Surg Sports Traumatol Arthrosc.* 2010;18(3):277-291.
- 589 **45.** Tan SHS, Lau BPH, Khin LW, Lingaraj K. The Importance of Patient Sex in the Outcomes of
590 Anterior Cruciate Ligament Reconstructions: A Systematic Review and Meta-analysis. *Am J*
591 *Sports Med.* 2015;44(1):242-254.
- 592 **46.** Tegner Y, J L. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop.*
593 1985;198:43-49.
- 594 **47.** Thompson S, Salmon L, Waller A, Linklater J, Roe J, Pinczewski L. Twenty-Year Outcomes of
595 a Longitudinal Prospective Evaluation of Isolated Endoscopic Anterior Cruciate Ligament
596 Reconstruction With Patellar Tendon Autografts. *The American Journal of Sports Medicine.*
597 2015;43(9):2164-2174.
- 598 **48.** Thorstensson CA, Andersson MLE, Jönsson H, Saxne T, Petersson IF. Natural course of knee
599 osteoarthritis in middle-aged subjects with knee pain: 12-year follow-up using clinical and
600 radiographic criteria. *Annals of the Rheumatic Diseases.* 2009;68(12):1890-1893.
- 601 **49.** Webb J, Corry I, Clingeffer A, Pinczewski L. Endoscopic reconstruction for isolated
602 anterior cruciate ligament rupture. *J Bone Joint Surg Br.* 1998;80(2):228-294.
- 603 **50.** Webster K, Wittwer J, O'Brien J, Feller J. Gait patterns after anterior cruciate ligament
604 reconstruction are related to graft type. *Am J Sports Med.* 2005;33(2):247-254.
- 605 **51.** Webster KE, Feller JA, Hartnett N, Leigh WB, Richmond AK. Comparison of Patellar Tendon
606 and Hamstring Tendon Anterior Cruciate Ligament Reconstruction: A 15-Year Follow-up of
607 a Randomized Controlled Trial. *The American Journal of Sports Medicine.* 2016;44(1):83-90.
- 608 **52.** Webster KE, Feller JA, Leigh WB, Richmond AK. Younger Patients Are at Increased Risk for
609 Graft Rupture and Contralateral Injury After Anterior Cruciate Ligament Reconstruction.
610 *Am J Sports Med.* 2014;42(3):641-647.

611 **53.** Wright R, Magnussen R, Dunn W, Spindler K. Ipsilateral Graft and Contralateral ACL
612 Rupture at Five Years or More Following ACL Reconstruction: A Systematic Review. . *J Bone*
613 *Joint Surg Am.* 2011;93(12):1159-1165.
614
615