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Transphyseal anterior cruciate ligament reconstruction using living parental donor hamstring graft: excellent clinical results at 2 years in a cohort of 100 patients

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Abstract

Purpose To determine outcomes of transphyseal ACL reconstruction using a living parental hamstring tendon allograft in a consecutive series of 100 children.

Methods One hundred consecutive juveniles undergoing ACL reconstruction with a living parental hamstring allograft were recruited prospectively and reviewed 2 years after ACL reconstruction with IKDC Knee Ligament Evaluation, and KT1000 instrumented laxity testing. Skeletally immature participants obtained annual radiographs until skeletal maturity, and long leg alignment radiographs at 2 years. Radiographic Posterior tibial slope was recorded.

Results Of 100 juveniles, the median age was 14 years (range 8–16) and 68% male. At surgery, 30 juveniles were graded Tanner 1 or 2, 21 were Tanner 3 and 49 were Tanner 4 or 5. There were no cases of iatrogenic physeal injury or leg length discrepancy on long leg radiographs at 2 years, despite a median increase in height of 8 cm. Twelve patients had an ACL graft rupture and 9 had a contralateral ACL injury. Of those without further ACL injury, 82% returned to competitive sports, IKDC ligament evaluation was normal in 52% and nearly normal in 48%. The median side to side difference on manual maximum testing with the KT1000 was 2 mm (range − 1 to 5). A radiographic PTS of 12° or more was observed in 49%.

Conclusions ACL reconstruction in the juvenile with living parental hamstring tendon allograft is a viable procedure associated with excellent clinical stability, patient-reported outcomes and return to sport over 2 years. Further ACL injury to the reconstructed and the contralateral knee remains a significant risk, with identical prevalence observed between the reconstructed and contralateral ACL between 12 and 24 months after surgery.

Level of evidence III (Cohort Study).

Keywords Juvenile · Anterior cruciate ligament · Paediatric · Reconstruction · Rupture · Reinjury

Introduction

Anterior cruciate ligament (ACL) injury is occurring with increasing frequency amongst juveniles [33, 34, 42, 44]. The natural sequelae of ACL deficiency in children are recurrent instability leading to chondral and meniscal damage [2, 16]. Reconstruction in juveniles is, therefore, the preference, however, this has been shown to be associated with a 2.5–5 times greater risk of ACL graft re-rupture compared to adults [32]. Furthermore, repeat ACL injury is reported to occur in 22–30% in the first 5 years after ACL reconstruction in adolescents and young adults [27, 40, 43].

Graft choice has long been a debate in ACL reconstruction. The ideal graft would recreate normal anatomical and biomechanical properties of the native ligament, providing biological integration, reduce recovery time and donor site morbidity [7]. Autograft has traditionally been the choice for ACL reconstruction, however, can be associated with donor site morbidity. Hamstring autograft harvest has been shown to be associated with persisting loss of knee flexion strength, and altered knee mechanics with walking and running [1, 20]. Harvesting of a patella tendon is associated with anterior knee pain, particularly when kneeling [28, 30, 36], and increased rates of degenerative change over the long term

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[29, 36]. Cadaveric allograft avoids donor site morbidity, though has been associated with a higher rate of ACL graft rupture in both adults and juveniles [11, 26].

The use of living donor hamstring tendon allograft has previously demonstrated excellent clinical and subjective outcomes in a small retrospective study of 32 juveniles [15]. More recently, Heath et al. reported the 5 year ACL graft survival of this technique in a retrospective phone interview study [17]. Living donor hamstring tendon allograft has the theoretical advantages of allowing for predictable graft diameters, eliminating donor site morbidity and maintaining normal biomechanical/neuromuscular properties around the knee joint [17]. There is a further benefit of fresh biological tissue and increased safety with regard to transmissible diseases. The latter advantages make living donor allograft particularly favorable to cadaveric ACL allograft, which itself has demonstrated a high failure rate in adults [37]. There are potential complications associated with transphyseal surgery in juveniles, most notably partial physeal growth arrest leading to secondary to mal-alignment and leg length discrepancy. However, it has been demonstrated that 7% of the physis has to be damaged in order for this to occur [23], and modern drilling techniques can result in excellent clinical outcomes without growth disturbance [9].

The purpose of this prospective longitudinal study was to examine the clinical results of endoscopic transphyseal ACL reconstruction using a living parental hamstring tendon graft in a consecutive series of 100 children less than 17 years of age at the time of surgery. The hypothesis was this technique would have acceptable clinical and subjective outcomes, without compromising the growth plates in juveniles.

Materials and methods

Between 2012 and 2015, 100 consecutive children underwent endoscopic transphyseal ACL reconstruction with living donor hamstring (HT) allograft. Inclusion criteria for the study were: age < 17 years; residing within 100 km of Sydney; a living parental donor; normal contralateral ACL and no other concomitant ligamentous injury in the knee. Ethical approval was sought and granted by St Vincent's Hospital Human Research Ethics Committee (SVH 12/073). The study was registered with ANZ New Zealand Clinical Trials Registry (reference ACTRN12612000631808).

Initial consultation was performed alongside the parental donor and involved taking a detailed history and examination. Complete ACL rupture was confirmed with clinical examination and magnetic resonance imaging (MRI).

Pre-operative donor screening

To eliminate the risk of transmissible infection, all donors were pre-operatively screened for Human Immunodeficient Virus (HIV), Hepatitis B and C, Human Papillomavirus (HPV) and Cytomegalovirus (CMV). The Rhesus status of all children was checked pre-operatively. When Rhesus negative females were identified, upon induction a measured dose of Rhesus immunoglobulin was administered to prevent sensitivity where Rhesus incompatibility was present.

Surgery

Both donors and recipients surgery were performed as day stay procedure. To decrease the exposure time of the donor graft, all cases were performed in fully manned, dual adjacent theatres. All cases were performed by the two senior authors (L.A.P. and J.P.R.). The Tanner grade [24, 25] of the child and radiographic classification of growth plates was documented on the day of surgery.

Donor harvesting

An oblique 2.5 cm incision was made just inferior and medial to the tibial tuberosity exposing the sartorius fascia. This was incised to expose the tendons of gracilis and semitendinosus. In most cases, both tendons were excised using a harvester (Linvatec, Largo, Florida). In the case of a small child or very narrow notch only 2 strands were used ($n = 15$). The tendon grafts were doubled over two pull-out lead sutures and all the strands were equally tensioned. Whilst holding the tension, proximally 25 mm were whip-stitched with a No. 1 Vicryl suture (Ethicon, Edinburgh, United Kingdom) and the distal 40 mm of graft were whip-stitched with a No. 2 Vicryl suture. The graft was wrapped in a vancomycin-soaked gauze and transferred into the adjacent theatre by the operating surgeon.

ACL reconstruction

Upon the surgeon's arrival in the adjacent theatre with the fully prepared donor graft, the child was already prepared and draped for surgery. Single-bundle ACL reconstruction via a transphyseal technique was performed in all cases. The femoral tunnel was drilled through a low anteromedial portal with the knee flexed to 110° to minimise oblique crossing of the distal femoral physis. This tunnel was positioned 5 mm anterior to the posterior capsular insertion. The tibial tunnel was drilled as vertically as possible, initially with a slow speed 4.5 mm pilot drill emerging through the tibial footprint of the native ACL. The tunnel was expanded with a single pass of a reamer equal to the diameter based off the donor graft. The donor graft was secured in the femur with either an Endobutton (Smith & Nephew, Andover, Massachusetts) proximal to the physis, or polyether ether ketone (PEEK), or titanium Round-bodied Cannulated Interference (RCI) screw (Smith & Nephew) distal to the physis. In the tibial tunnel, the ACL graft was fixed distal to the tibial physis with either a PEEK or RCI screw, or a staple. The choice of fixation on either side was dependent on the surgeons preference for that individual case e.g. if femoral tunnel was too short the Endobutton could be used to prevent any screw being left crossing the physis. Meniscal tears were sutured where appropriate.

Rehabilitation protocol

Patients were permitted to weight bear as tolerated with crutches post-operatively and, at individual surgeon's preference, placed in a range of motion brace for 2–6 weeks. For the first 10–14 days post-operatively, the swelling and pain was managed with Ice and analgesia, gradually progressing off crutches towards a normal gait. Progression through rehabilitation was goal based rather than time based. Those with meniscal repair were instructed to avoid loaded flexion for 12 weeks. Stage 2 of rehabilitation involved developing hamstring and quadriceps muscle control in addition to early proprioceptive skills. Stage 3 involved progression to more dynamic movements such as step lunges, half squats and lateral stepping once sufficient strength was achieved and no effusion was present. Progression to running drills, plyometric and agility drills followed. Once sufficiently competent sports specific skills and drills were commenced. Return to competitive sport was considered after 12 months from surgery if rehabilitation goals had been achieved.

Parental donors were all discharged on the day of surgery with analgesia and advice on hamstring stretching exercises. Donors were permitted to return to work after 1–2 days and were followed-up at 10–14 days, alongside their children to ensure their wounds had healed without any problems. When pain-free they were permitted to return to sport. They were advised to avoid heavy manual labour or running for 4–6 weeks.

Follow-up

Routine review was performed at 10–14 days, 6 weeks and 6 months after surgery. Subjects were further reviewed at 1 and 2 years with International Knee Documentation Committee (IKDC) Knee Evaluation by one of 2 experienced research physiotherapists (LJS or EH). Radiographs were performed annually for those patients with open growth plates including long leg alignment radiographs to assess look coronal alignment and leg length. Leg length was measured from the top of the femoral head to the centre of the tibial plafond. Coronal alignment was measured by the angle formed by the centre of the femoral head and the tibial plafond to the centre of the knee. Lateral radiographs were used to assess the medial PTS using the method described by Webb et al. [39].

Statistical analysis

Statistical analysis was performed using SPSS software version 24. Statistical significance was set at a priori at $p \leq 0.05$. Sub groups were compared with t-tests for linear variables and Chi-squared tests for categorical data. Sample size calculation?

Results

Of the 100 children, 68 patients were male and the right knee was involved in 51. The median age was 14 years at surgery (range 8–16). The hamstrings were donated by the father in 79 and mother in 21 of cases. The median hamstring graft diameter was 7.5 mm (range 6–10 mm). The median drill size was 7.5 mm (range 6–9) on the femur and 7.5 mm (range 6–10 mm) on the tibia. A 4 strand graft was used in 86 cases and a 2 strand graft in 14 children, which was determined by the size of the child. At the time of surgery, open growth plates were documented in 39 juveniles, closing in 22 juveniles and closed in 39. The distribution of Tanner stage of development is shown in Fig. 1. Partial meniscectomy was performed in 13 subjects, and meniscal suture in 8 subjects. Chondral lesions were observed in 4 cases. Femoral fixation was achieved with an interference screw in 61 cases and an endobutton in 39 subjects. Tibial fixation was achieved with an interference screw in 67 and a staple in 33 subjects. A positive family history was defined by a first degree relative with an ACL injury and was reported by 38/94 (40%) of the cohort.

The participant flow is shown in Fig. 2.

Radiographic assessment

Of the 61 subjects with open or closing growth plates at surgery, 53 underwent long leg alignment radiographs at 2 years (87%). There were no cases of physeal growth arrest or malalignment on long leg radiographs at 2 years. The median side to side leg length difference was 0.05 cm (range − 1.2 to 1.3 cm). No subjects had more than a 1.5 cm side-to-side difference in leg length. The median knee alignment at 2 years was 2.0° valgus (range 7° valgus to 2° varus) with the opposite knee median alignment being 1.0° (range 9° valgus to 5° varus). The median side-to-side difference at two years was − 1.0° (range −3° to 3.8°).

PTS was measured from a lateral radiograph on 92 of 100 subjects. The median PTS was 11° (range 0–17). There were 45 subjects with a PTS of > 12°.

Patient-reported outcome measures and clinical assessment

The results of the subjective and clinical assessment at 2 years is shown in Table 1. There was no difference between males and females for any of the subjective or clinical

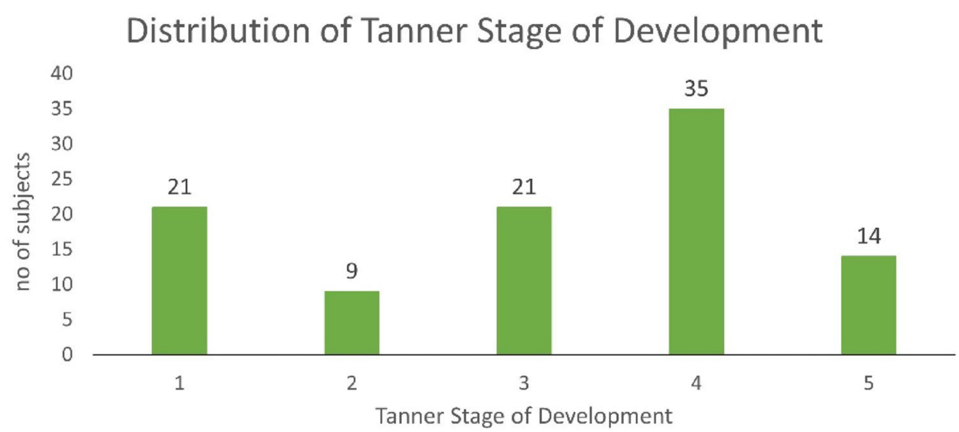

Fig. 1 Distribtion of Tanner stage of development

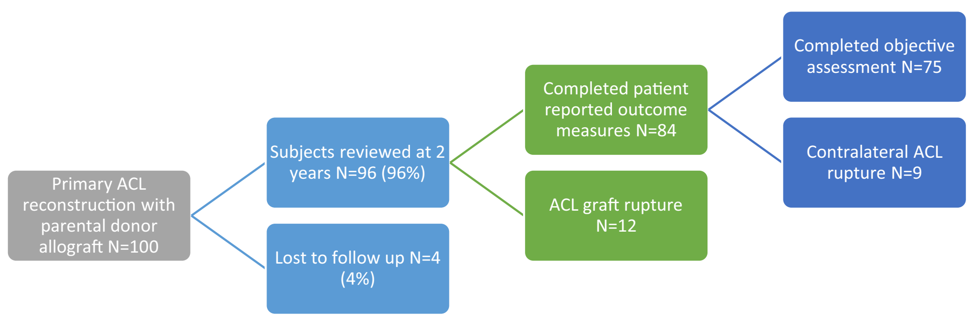

Fig. 2 Participant flow

Table 1 Two years subjective and objective clinical assessment

Patient-reported outcome measures (*n* = 84)	
Median IKDC score/100 (range)	96 (82–100)
Regular participation in strenuous or very strenuous sports, *N* (%)	72 (86%)
Return to same level of sport, *N* (%)	70 (83%)
No knee related decrease in activity, *N* (%)	77 (92%)
Clinical assessment (*N* = 75)	
Grade A IKDC overall grade, *N* (%)	38 (51%)
Grade A IKDC Effusion, *N* (%)	73 (97%)
Grade A IKDC Range of Motion, *N* (%)	72 (96%)
Ligament Evaluation (*N* = 75)	
Grade 0 Lachman, *N* (%)	50 (67%)
Grade 0 Pivot, *N* (%)	55 (73%)
< 3 mm side to side difference on KT1000 testing, *N* (%)	43 (57%)
Median mm side to side difference on KT1000 testing (range)	2.0 (− 1 to 5)
Overall IKDC Ligament Grade A, *N*(%)	42 (56%)

assessments. There was no significant difference between the Tanner Groups for any subjective or clinical assessments.

Objective assessment

Subjects with open or closing growth plates classification at surgery had a median increase in height of 9 cm (range 0–22 cm) as shown in Fig. 3.

Repeat ACL injury and complications

Out of the 100 subjects, 12 children sustained an ACL graft rupture and 9 sustained a contralateral ACL injury within 2 years. The median time from surgery to ACL graft rupture was 11 months (range 9–18). Six subjects sustained an ACL graft rupture within the 12 months of ACL reconstruction, all while playing team ball sports. ACL graft rupture occurred with a significantly higher frequency (6/38, 15.8%) in patients with a positive family history of ACL injury compared to subjects without a positive family history (3/56, 5.4%), ($p = 0.004$). The median graft diameter was 7.5 mm for both those that sustained an ACL graft rupture and those with intact ACL grafts (n.s.). Subjects with a PTS of > 12 did not have a significantly higher rate of ACL graft rupture (n.s.), or contralateral ACL injury (n.s.), than those with a PTS < 12°. ACL graft rupture occurred in 16/68 males (24%) and 5 of 32 females (16%) (n.s.). ACL graft rupture occurred in 3/51 (6%) Tanner 1–3 juveniles, and 9/49 (18%) Tanner 4–5 subjects ($p = 0.05$, fishers exact). Contralateral ACL injury occurred in 6 Tanner 1–3 juveniles (12%), and 3 Tanner 4–5 subjects (6%) (n.s.).

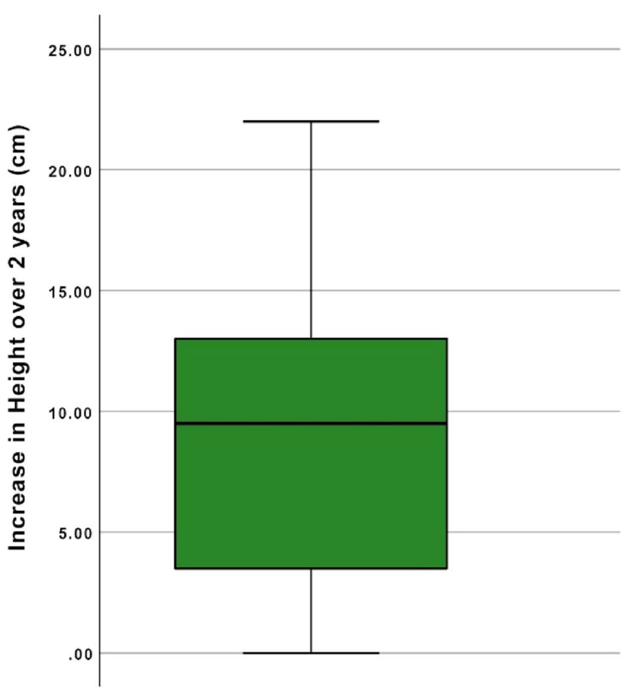

Fig. 3 Boxplot of increase in height of subjects with open or closing growth plates over 2 years

One patient required a subsequent medial meniscectomy for a tear that developed 7 months post-operatively. One patient required an excision of a cyclops lesion at 6 months post-operative. One 15 year old male with closing growth plates at surgery was noted to have a 3.8° side to side difference in mechanical alignment at 2 years post-operatively, however, this patient had no significant difference in leg length (3 mm). Pre-operative alignment films were not available. There were no patients or donors who had any evidence of wound or joint infections.

Discussion

The most important findings of the present study were ACL reconstruction using parental donor allograft was associated with excellent subjective outcomes, good objective ligament stability, a high rate of return to sports, as well as no significant difference in radiographic leg length over 2 years.

This study has demonstrated transphyseal ACL reconstruction with living donor allograft can be safely performed without growth disturbance. This adds further weight to the body of literature supporting a transphyseal drilling technique for ACL reconstruction in children [21]. The side-to-side difference in radiographic leg lengths was no more than 1.5 cm, which is consistent with the normal population [35]. It should be noted that one patient (1%) was found to have difference in valgus alignment of 3.8° in the coronal plane compared to the other side at review. Despite this, the patient demonstrated no difference in radiographic leg length and had an excellent clinical outcome, including a successful return to elite sports. In a recent study of ACL injured juveniles, 8 of 47 (17%) were reported to have > 3° side to side difference in alignment, inclusive of 3 who were treated without surgical reconstruction. The previously reported cut off of difference in leg length of 1 cm or more or an axis deviation of more than 3° [14] requires comparison to a preoperative film. A weakness of this study was that no preoperative alignment radiographs were performed, as this may have demonstrated a pre-existing difference in this subject. This present study agrees with other authors that, without preoperative baseline measures of leg length and alignment, it may be difficult to discern between pathological and normal variation in this population [10].

ACL reconstruction with a parental allograft was associated with good clinical ligament stability confirmed by physical examination. The median side to side difference on instrumented laxity testing was 2 mm, 57% of subjects had < 3 mm side to side difference, and 43% had 3–5 mm side to side difference. Goddard et al. [15] reported similar clinical outcomes at 2 years following living donor hamstring allograft in juveniles in a smaller cohort of 32 subjects.

One of the advantages of using a living donor allograft is a predictably larger graft size. This study demonstrated an average of 7.5 mm graft diameter which would be an acceptable graft size for young adults undergoing ACL reconstruction. In a recent consensus paper, it had been suggested that tunnel diameter should be no larger than 9 mm [4]. Our average graft size was notably less than this, though, the size of the implanted ACL graft was selected by the surgeons to match the anatomy of the child, with larger children receiving larger sized grafts as necessary.

The surgical technique aimed to avoid growth disturbance by having tunnels cross physeal planes as perpendicular as possible to minimise the volume of reamed physis reamed. Our technique also facilitated anatomical femoral tunnel positioning using the anteromedial portal to drill the femoral tunnel. Cruz et al. [8] suggested that a transtibial technique disrupted a lower area of physis in the distal femur and also created less eccentric tunnels compared to using an anteromedial portal as in our technique. Although this may be true, our technique had excellent clinical results and return to sports rates with no significant side-to-side leg length differences. This is supported by other smaller series [22] who use a similar anatomical transphyseal technique. There is a consensus stressing the importance of modifying the operative technique to relatively central and vertical tibial tunnels to avoid risk of damage to the tibial physis [4, 22].

A further proposed advantage of using living donor allograft is maintaining the integrity of the child's own hamstrings. This is for the twin purposes of preserving the neuromuscular control on the medial side of the knee, as well as keeping their own hamstrings available for the unfortunate case of repeat ACL injury. It is worth noting that although larger graft diameter and preservation of hamstrings are important factors, they did not positively affect the rate of ACL graft rupture over 2 years in this study compared to the literature [22, 38, 39].

There was a 12% incidence of ACL graft rupture at 2 years after ACL reconstruction with parental allograft in this series. Other series with a minimum 2 year review have reported rates of ACL graft rupture in juveniles with autografts to be between 8% at 2 years, and 12% [27] to 14% [41] at 5 years. Webster et al. observed a higher 13–28% incidence of ACL graft rupture in a juvenile subjects after autograft reconstruction over a mean of 5 years [41]. The combined contralateral ACL and graft re-rupture rate of 21% in this series were also similar to high rates observed in juvenile subjects in other series [27, 40], including a recent meta-analysis [43]. In a more recent study examining ACL graft survival after parental allograft reconstruction in juveniles, Heath et al. reported a 5 year rate of ACL graft rupture of 24% and contralateral ACL rupture of 14% [17]. Despite the use of a parental allograft ACL reconstruction in this cohort and the Heath et al. series, repeat ACL injury after reconstruction in juvenile's remains and common and challenging issue.

ACL graft rupture is a multi-factorial entity that is dependent on a multitude of intrinsic and extrinsic factors. Intrinsic risk factors for ACL injury include high PTS, narrow notch width, body mass index, decreased ACL size, familial history and limb alignment [6, 12, 27, 31, 39]. Almost half the subjects imaged in this study demonstrated a PTS > 12° (49%), which is higher than the 20% observed by Webb et al. in an adult population [39]. The relationship between increased PTS and ACL injuries has been documented in teenagers [38], and previous work has demonstrated the catastrophic effect an increase in tibial slope has on both the native ACL and well as the ACL graft, especially in juveniles [5, 13, 32]. In this cohort, there was a very high rate of return to sports (82%) such as soccer, rugby and netball [3, 18]. This is similar to a recent meta-analysis reported 81% of juvenile return to competitive play [19]. This exposure to high-risk activities places both the reconstructed ACL and the contralateral ACL at risk, and a similar incidence of ACL injury was observed between the reconstructed ACL (12%) and the contralateral ACL (9%) in this series. Between 12 and 24 months from ACL reconstruction, the prevalence of ACL injuries was exactly the same between the reconstructed ACL (7%) and the contralateral ACL (7%).

There was a higher rate of ACL graft rupture in the Tanner grades 4 and 5 subjects (18%), compared to Tanner grades 1–3 subjects (6%), which supports previous findings by Heath et al. [17]. Heath et al. attributed this higher rate of reinjury in adolescents compared to children to factors such as lower rates of parental supervision, more aggressive and competitive play, greater body mass in adolescents, and distinct differences in cellular healing of the graft, with younger children healing faster [17].

There are limitations to the present study to be acknowledged. As previously discussed this study would have been strengthened with pre-operative radiographic mechanical alignment to compare to the 2 years post-operative radiographs. Although 2 years is relatively a short length of follow-up, as the use of parental allografts for ACL reconstruction in children is an unusual technique it is important to report the outcomes in sufficient numbers to enable clinicians to assess its value, even over the shorter term.

Conclusion

This study reports a high rate of return to the sport in addition to excellent subjective and objective clinical outcomes at 2 years after ACL reconstruction with living donor hamstring allograft in a juvenile population. Parental donor allograft can be considered a viable alternative to traditional ACL graft choices in juveniles.

Compliance with ethical standards

Conflict of interest This study was funded by a research grant from the Friends of the Mater Foundation. JR receives institutional research support from Global Orthopaedics and Smith and Nephew, has given paid presentations for Depuy and Smith and Nephew, and is a shareholder in 360 Knee Systems. LP receives IP royalties from Signature Orthopaedics and Australian Biotechnology, research support from Australian Orthopaedic Association, Friends of the Mater Foundation and Smith and Nephew, stock or stock options from Australian Biotechnology, and is a paid presenter for Smith and Nephew.

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Ethical approval Ethical approval was obtained from St Vincents Human Research Ethics Committee, Sydney, Australia.

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