Endoscopic Anterior Cruciate Ligament Reconstruction in Children Using Living Donor Hamstring Tendon Allografts

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Endoscopic Anterior Cruciate Ligament Reconstruction in Children Using Living Donor Hamstring Tendon Allografts

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Background: The incidence of anterior cruciate ligament (ACL) injuries in children is increasing, but ACL reconstruction with traditional autograft sources is associated with high rates of further ACL injury when compared with adult populations. The outcome of ACL reconstruction using an alternative graft source, the living donor hamstring tendon (HT) allograft, has not been reported.

Purpose: To determine the outcome of endoscopic transphyseal single-tunnel ACL reconstruction using living donor HT allografts.

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

Methods: Between 2007 and 2008, 32 children underwent endoscopic transphyseal single-tunnel ACL reconstruction using living donor HT allografts. The HT allograft was harvested from a parent. At a minimum 2 years' follow-up, full International Knee Documentation Committee (IKDC) knee ligament examination was performed on the children including instrumented testing using the KT-1000 arthrometer. Donors underwent subjective review at a minimum 2 years' follow-up.

Results: Thirty-one children (97%) were able to be contacted for review. Of these, 2 (6%) sustained an ACL graft rupture within 2 years after surgery. Twenty-nine children completed clinical and subjective review. The mean age at ACL reconstruction was 13 years (range, 8-16 years). The mean HT graft size was 7.2 mm (range, 6-8 mm). The mean IKDC subjective score was 97 (range, 84-100). Twenty-eight patients (97%) had a normal or nearly normal IKDC ligament grade. At 2 years after surgery, 27 patients (93%) reported regularly participating in very strenuous or strenuous activities. There were no cases of limb malalignment. Twenty eight (97%) of the donors reported that they would undergo the same procedure again under the same circumstances.

Conclusion: Excellent clinical and subjective outcomes were achieved with high levels of return to desired activities. This technique allows a more predictable size of the HTs compared with an autograft from the child and maintains an intact neuromuscular hamstring structure in the child. Finally, the child's own HTs are reserved for future use. Anterior cruciate ligament reconstruction using living donor allografts should be considered a viable choice in children.

Keywords: ACL reconstruction; allograft; juvenile; technique; clinical

Anterior cruciate ligament (ACL) injuries are becoming increasingly common in skeletally immature patients as more children participate in high-risk sports. It has been reported that up to 3.4% of all ACL injuries occur in this group.[24,38] Medicare Australia statistics show that the number of ACL reconstructions in patients under 16 years of age has more than tripled over the past decade.[39] In addition, Moksnes et al[40] recently reported in their systematic review that studies on the treatment of skeletally immature children with ACL injuries have major deficiencies with regard to methodological quality and that further well-designed prospective studies are required.

There are several treatment considerations that are unique to this group that led us to seek alternative graft options. First, there is a high incidence of repeat ACL injuries seen in children. Shelbourne et al,[46] in a series examining over 1400 patients at 5-year follow-up, reported that the rate of further ACL injuries after reconstruction is as high as 17% for those younger than 18 years compared with 4% for those older than 25 years. This is supported by Bourke et al,[10] who reported that patients under 18 years old were 3 times more likely to rupture their graft than those over 18 years in a series of 200 patients. Most

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recently, Lind et al[31] identified that patients below 20 years of age had 2.6 times the risk of revision compared with those over 20 years in the Danish ACL registry population-based study of over 12,000 patients. The exact cause for the higher incidence of further ACL injuries remains unclear.

Second, graft diameter as well as patient age is associated with early graft failure.[34] The diameter of soft tissue grafts is known to be directly related to height and weight.[7,8,45,50,51] In children, this means that sourcing an autograft with a suitable diameter for ACL reconstruction can be a challenge.

Third, cadaveric ACL allografts have been associated with high failure rates of 13% to 44% in adults, which renders them an inappropriate graft option in the young child.[41,52] The ideal graft choice in children should be biologically active, allow accelerated rehabilitation, be appropriately sized for graft survival, not cause donor site morbidity, and retain the neuromuscular structures of the knee. Related living donor allografts for ACL reconstruction have the potential to fulfill these criteria.

The purpose of this study was to determine the outcome of endoscopic ACL reconstruction in a series of children using living donor hamstring tendon (HT) allografts. Presently, this is the only series reporting outcomes of ACL reconstruction in children exclusively using living donor HT allografts.

MATERIALS AND METHODS

Between 2007 and 2008, 32 children underwent endoscopic transphyseal single-tunnel ACL reconstruction using living donor HT allografts. All procedures were performed by 2 experienced knee surgeons (L.A.P., J.P.R.). Inclusion criteria for patients were (1) primary ACL reconstruction between 2007 and 2008, (2) age <17 years at the time of ACL reconstruction, (3) ACL reconstruction with a related living HT allograft, (4) reside within 100 km of the Sydney metropolitan area, (5) normal contralateral ACL, and (6) less than grade 2 medial collateral ligament (MCL) or posterior cruciate ligament (PCL) injury. Those suffering a further ACL graft injury sustained during the study period were excluded from further analysis, but their results are described. A subset of those patients (n = 14) with Tanner 1 and 2 grading included in this study has been previously reported.[22]

A detailed history and clinical examination including the Lachman and pivot-shift tests confirmed the diagnosis of an ACL rupture[33] as well as examination under anesthesia and findings at surgery. Plain radiographs were obtained in all children and the degree of physeal closure assessed and graded as open, closing, or closed. Magnetic resonance imaging (MRI) scans confirming complete ACL ruptures were performed preoperatively in 31 of the 32 patients. Endoscopic ACL reconstruction was offered to all children. A detailed history including details of any medical problems including cancer, previous or current infectious diseases, medications, and previous knee surgery was obtained on all allograft donors. The left limb was selected for HT donation in all cases to allow the donors to drive a car with automatic transmission using their unoperated right limb as soon as possible after surgery and recovery from general anesthesia. The hamstring donor was the recipient's father in 26 cases and the mother in 6 cases.

In addition, the total cost of surgery for both the child and living HT donor was calculated including hospital, surgeon, and anesthesiologist charges from our institution. Ethical approval was sought and granted by a local independent human ethics committee.

Preoperative Screening

All children and donors underwent preoperative screening for blood-borne viruses including human immunodeficiency virus (HIV), hepatitis B and C, human papillomavirus (HPV), and cytomegalovirus (CMV). All children underwent histocompatibility testing including Rh status. Any Rh-negative female patients were given the appropriate dose of Rh immunoglobulin on induction of anesthesia to prevent Rh sensitization if Rh incompatibility was present.

Surgical Technique

All procedures were performed by the 2 senior authors (L.A.P. and J.P.R.). Two fully staffed adjacent operating theaters were utilized. All surgery was performed as day cases.

Parent Allograft Donors

The gracilis and semitendinosus tendons were harvested from the parent donor through a 2.5-cm oblique incision medial and distal to the tibial tubercle.[14,43] A tendon harvester (Linvatec, Largo, Florida) was used to obtain a 22-cm tendon graft. Assessment was made as to the number of strands required in the graft based on the size of the child to ensure a graft of adequate diameter but not one that would cause impingement in the knee. There were fifteen 4-stranded grafts, six 3-stranded grafts, and eight 2-stranded grafts. The tendon grafts were doubled over 2 pull-out lead sutures. The proximal 25 mm of the graft was whip-stitched with a No. 1 Vicryl suture (Ethicon, Edinburgh, United Kingdom) into a plug. The distal 40 mm of the graft was equally tensioned and stitched with a No. 2 Vicryl suture (Ethicon). Local anesthetic was infiltrated around the wound and thigh. The wound was closed with a subcuticular Monocryl suture (Ethicon). The tendons were wrapped securely in dry gauze and taken by the surgeon to the second operating theater.

Children's Endoscopic ACL Reconstruction

In the second operating theater, the child was already under anesthesia and prepared and draped for surgery. Endoscopic transphyseal anatomic single-tunnel ACL reconstruction was performed, and the operative technique has been previously described.[22] Suturing of appropriate meniscal tears was performed using an all-inside technique. The femoral tunnel was positioned 5 mm anterior to the posterior capsular insertion at the 10:30-11:30 clock position and was drilled through the low anteromedial portal with the knee in 110° to 120° of flexion to ensure more perpendicular crossing of the femoral physis. The tibial tunnel was drilled to emerge through the posteromedial ACL footprint, centered on a line from the anterior horn of the lateral meniscus to the medial tibial spine so that the tunnel was adjacent to but not removing the apex of the medial tibial spine. The tibial tunnel was made as long as possible so that the tibial tunnel crossed the tibial physis as perpendicular as possible. Femoral fixation included the standard roundhead 7 × 25–mm titanium cannulated interference screw (Round Cannulated Interference [RCI], Smith & Nephew, Andover, Massachusetts), Endobutton (Smith & Nephew), or staple. Tibial fixation included the RCI screw and/or staple. Staple fixation was performed using the belt-buckle technique. Suspensory fixation was selected according to surgeon preference when the tunnel length was deemed insufficient to allow for screw fixation without the risk of crossing the growth plates. Full hyperextension and stable Lachman and anterior draw test results were achieved in all children. Routine postoperative radiographs were obtained. The Tanner stage[36,37] was documented in all children.

Rehabilitation

Postoperative braces were used in children if an Endobutton and/or staple was used for graft fixation. All children followed an accelerated rehabilitation program that has been previously described.[14] Patients were allowed full weightbearing immediately, straight-line jogging at 6 weeks, side-stepping activities at 3 months, and training for ball sports at 5 months, with a full return to competitive ball sports delayed until 12 months. All children were strongly encouraged to participate in appropriate plyometric training programs to minimize further injury.

The parent allograft donors were allowed full weightbearing and hamstring stretching exercises immediately, with a return to work usually the day after surgery. Donors were advised that when hamstring stretching exercises were performed pain free, it was acceptable to return to sport.

Follow-up

All children were assessed preoperatively and at 6 weeks, 1 year, and 2 years postoperatively. Clinical assessment included range of motion, ligament stability, and instrumented testing using the KT-1000 arthrometer (MEDmetric Corp, San Diego, California) including the manual maximum test. Symptoms of knee function were assessed with the International Knee Documentation Committee (IKDC) subjective assessment.[3] Activity levels were classified according to the IKDC grades: 5 = very strenuous (eg, basketball, soccer), 4 = strenuous (eg, skiing, tennis, heavy physical work), 3 = moderate (eg, running, jogging), 2 = light (eg, housework, yard work), and 1 = unable to perform any of the above activities. Knee ligament stability was evaluated by the Lachman and pivot-shift tests[33] and side-to-side differences reported. The Lachman grades were 0 (<3-mm laxity), 1 (3- to 5-mm laxity), or 2 (>5-mm laxity). The pivot-shift test was graded as 0 (negative), 1 (glide), 2 (clunk), or 3 (gross). Functional assessment was done with the single-legged hop test. From our prospective, knee surgery registry patient demographics including age, sex, details of previous surgery, as well as operative details including Tanner stage, graft choice, and associated meniscal and articular surface injuries were collated.

The parent allograft donors were assessed at a 2-week wound check clinic. At 2-year follow-up, they were asked to note tenderness, irritation, or numbness at the HT allograft harvest site. They were also questioned as to whether they would undergo the same procedure again under the same circumstances.

RESULTS

Between 2007 and 2008, 32 children under 17 years of age who underwent a primary ACL reconstruction with live donor allografts met the inclusion criteria and were considered eligible for the study. No patients were excluded for significant injury to the PCL or MCL or contralateral ACL. The mean age at surgery was 13 years (range, 8-16 years). There were 21 male and 11 female patients. The procedure was performed on the left knee in 17 patients and on the right knee in 15 patients. Fifteen children were graded as a Tanner 1 or 2. Growth plates were closed in 5 patients. The mean time to surgery was 7 months (range, 1 month to 6 years). Further details on surgical variables are shown in Table 1.

In the first 2 years after the surgery, 2 boys sustained an ACL graft rupture. The first was a 13-year-old boy, who received a 3-stranded 7.5-mm hamstring allograft and slipped awkwardly at 4 weeks after surgery. He underwent revision ACL reconstruction with an HT autograft. The second was a 12-year-old boy, who received a 7.5-mm 4-stranded hamstring allograft and fell twisting his knee while preparing for a high jump at 10 months after surgery; he underwent revision ACL reconstruction with a live donor allograft. Both boys underwent revision ACL reconstruction. Of the 30 children with intact ACL grafts, 29 (97%) were reviewed at 2 years after surgery with subjective and clinical assessment. At the 2-year review, 14 patients had open physes, 4 patients had closing physes, and 11 patients had closed physes on radiographs.

Operative Data

At the index surgery, 19 children had intact menisci. Two children had undergone previous meniscectomy, and 3 children underwent partial medial meniscectomy at the time of ACL reconstruction. Five (17%) required lateral meniscal repair at the time of surgery. Femoral fixation was achieved with an RCI screw in 20, Endobutton in 8, and a staple in 1

TABLE 1
Detail of Surgical Variables[a]

Donor's Relationship	Sex	Age at Surgery, y	No. of Graft Strands	Graft Diameter, mm	Femoral Fixation	Tibial Fixation	ACL Graft Rupture	Sport of Injury	Return to Sport of Injury at 2 Years
Father	Female	12	2	6.5	RCI	RCI	No	Basketball	Yes
Mother	Male	16	4	7.5	RCI	RCI	No	Soccer	Yes
Father	Female	9	2	6.5	EB	ST	No	Trampoline	Yes
Father	Female	15	4	8	RCI	RCI	No	Netball	Yes
Father	Male	13	4	8.5	RCI	RCI	No	Rugby	Yes
Father	Female	11	3	7	RCI	ST	No	Skiing	No
Father	Male	16	4	8	RCI	RCI	No	Rugby	Yes
Mother	Female	14	4	7.5	RCI	RCI	No	Netball	Yes
Father	Male	10	2	7	EB	ST	No	Playground	Yes
Father	Female	15	4	7.5	RCI	RCI	No	Soccer	Yes
Father	Male	12	2	8	EB	ST	No	Motorbike	Yes
Mother	Male	12	4	7	RCI	ST	No	Soccer	Yes
Father	Male	12	2	6.5	EB	ST	No	Motorbike	Yes
Father	Male	12	4	7.5	RCI	RCI	No	Soccer	Yes
Father	Male	12	4	7.5	RCI	RCI	No	Rugby	Yes
Mother	Male	12	4	7	RCI	ST	Yes	Rugby	Yes
Mother	Female	12	4	7.5	EB	ST	No	Soccer	No
Father	Male	13	3	7.5	RCI	RCI	Yes	Touch football	Yes
Father	Male	12	2	6.5	EB	ST	No	AFL	Yes
Father	Male	12	4	6	ST	ST	No	Rugby	Yes
Father	Female	11	4	7	EB	ST	No	Athletics	Yes
Father	Female	14	3	7.5	RCI	RCI	No	Soccer	Yes
Father	Male	12	4	7	EB	ST	No	Rugby	Yes
Mother	Male	11	3	7	RCI	ST	No	Cycling	Yes
Father	Male	16	4	7.5	RCI	RCI	No	Soccer	Yes
Father	Female	13	4	7	RCI	RCI	No	Basketball	Yes
Father	Male	13	3	6.5	RCI	ST	No	Basketball	Yes
Father	Male	14	3	7.5	RCI	RCI	No	Rugby	Yes
Father	Female	16	4	8	RCI	RCI	No	Gymnastics	Yes
Father	Male	8	2	6	RCI	ST	No	Soccer	Yes
Father	Male	11	2	7	RCI	ST	No	Rugby	Yes
Father	Female	15	3	7.5	RCI	RCI	No	Soccer	Yes

[a]RCI, Round Cannulated Interference screw; EB, Endobutton; ST, staple; AFL, Australian Football League.

child. Tibial fixation was achieved with an RCI screw in 14 children and a staple in 15 children. The mean graft size was 7.2 mm (range, 6-8 mm), and the distribution of graft size relative to the child's age is shown in Figure 1.

Subjective Assessment. At 2 years after surgery, the mean IKDC subjective score was 97 (range, 84-100), and the mean Lysholm knee score was 97 (range, 79-100). Regular participation in very strenuous activities (eg, competitive team ball sports) was reported by 25 children (86%), strenuous activities (eg, tennis, skiing) in 2 children, and moderate activities (eg, jogging) in 2 children. All children denied any knee-related restriction in activity.

Clinical and Functional Assessment. At 2 years after surgery, the overall IKDC score was documented as normal in 12 patients (41%), nearly normal in 15 patients (52%), and abnormal in 2 patients (7%). The percentage of children with normal or nearly normal examination findings for each of the IKDC subgrades is shown in Figure 2.

Mean flexion was 138° (range, 130°-150°). Twenty-eight children (97%) had full extension, and 1 child had <5° extension loss compared with the contralateral limb.

At 2-year follow-up, all patients had a stable knee. Fifteen children (52%) had a negative Lachman test finding, and the remainder (48%) had a grade 1 Lachman test result with a firm end point. Twenty-five patients (86%) had a negative pivot shift, and 4 patients (14%) had a pivot glide. On instrumented testing, 12 children (43%) had ≤3-mm side-to-side difference, 14 children (50%) had 3- to 5-mm side-to-side difference on KT-1000 arthrometer instrumented testing, and 1 child (4%) had >5 mm. The mean side-to-side difference on KT-1000 arthrometer manual maximum testing was 2.3 mm.

A knee effusion was present in 1 child, who had undergone a lateral meniscectomy, had a grade 1 pivot shift, and had a 2-mm side-to-side difference on instrumented ligament examination.

Postoperatively, all patients had normal alignment compared with the contralateral noninjured leg on clinical assessment. There was no clinically detectable leg length discrepancy. On single-legged hop testing, 26 children (90%) were able to hop >90% of the distance of the opposite knee.

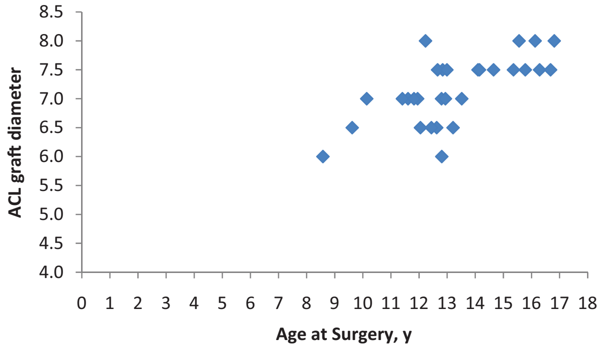

Figure 1. The distribution of graft size relative to the child's age.

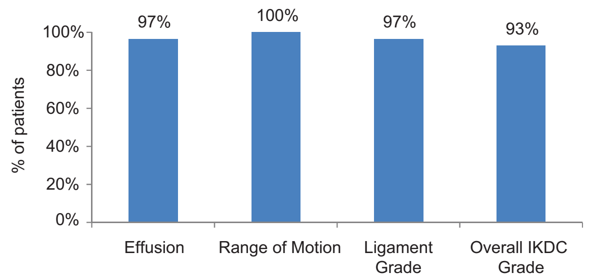

Figure 2. The percentage of children with normal or nearly normal examination findings for each of the International Knee Documentation Committee subgrades.

Complications. There were no superficial or deep wound infections in either the children or allograft donors. There was no clinical evidence of saphenous nerve injury in the allograft donors. At the 2-year follow-up, none of the children who had a lateral meniscal repair required further surgery for ongoing symptoms. No children had new symptoms suggestive of subsequent meniscal injuries at 2-year review.

HT Allograft Donor Follow-up. At 2-year follow-up, 24 donors (83%) reported no donor site morbidity. Five donors (17%) reported mild symptoms. Three donors (10%) complained of hamstring tightness, 1 (3.5%) of scar sensitivity, and 1 (3.5%) had both. Twenty-eight (97%) of the donors reported that they would undergo the same procedure again under the same circumstances. One donor (3%) felt that his postoperative recovery was too disruptive to his occupation as a heavy manual worker to consider donating again under the same circumstances.

Costs. The total cost of ACL reconstruction for both the child and living HT donor was calculated to be AUS$8205.65. The cost calculation was based on standard Medicare rates and included specialists' fees (surgeon, anesthesiologist, surgical assistant), hospital fees, and pathology laboratory fees for preoperative screening blood tests. Specialists' additional gap costs were excluded. Comparison is made in Table 2 with the total cost of primary ACL reconstruction using an autogenous HT graft and fresh-frozen allograft.

TABLE 2
Relative Cost (in AUS$) of the Live Donor Allograft, Fresh-Frozen Allograft, and Autograft

	Live Donor Allograft	Fresh-Frozen Allograft	Autograft
Specialists' fees (surgeon, anesthesiologist, assistant)	$1646	$1341	$1341
Hospital fees	$6337	$4729	$4729
Graft supply	$0	$2190	$0
Pathology screening	$222	$0	$0
Total cost	$8205	$8261	$6071

DISCUSSION

As the number of children participating in high-demand sports rises, the demand for ACL reconstruction in the skeletally immature patient will increase as well. Surgery to restore knee stability is essential in these young patients to prevent future meniscal[19,23,48] and articular surface damage.[2] This is the only study describing clinical and subjective outcomes with the exclusive use of living donor HT allografts in ACL reconstruction in children. Anterior cruciate ligament reconstruction using living donor allografts obtains good outcomes and should be considered a viable choice in children.

Options for graft selection in children are limited to soft tissue grafts to avoid the risk of physeal growth disturbance due to bony block placement across the open physis.[48]

In children, there is the potential for injury to the physis secondary to tunnel drilling or graft fixation. This can lead to limb malalignment and leg length discrepancy including growth arrest and overgrowth.[13,26,28,32] However, recent studies have reported excellent clinical and subjective outcomes with endoscopic transphyseal anatomic single-tunnel ACL reconstruction without growth disturbance.[2,5,22,29,30] This study further supports the evidence for the transphyseal technique in children.

Subjective Assessment and Activity

Return to sports is one of the major patient objectives after ACL reconstruction and is perhaps even more important in children competing in high-demand sports such as football, soccer, hockey, and skiing involving pivoting, side stepping, and jumping. At 2-year follow-up, the mean IKDC subjective score was high (mean, 97), and regular participation in very strenuous activities (eg, competitive team ball sports) was reported in 25 children (86%). No children were restricted in activity because of their knees. An ACL injury in active athletic children is emotionally devastating, and surgical treatment and lengthy rehabilitation away from full sports participation can be difficult for them to cope with. However, these subjective assessments suggest excellent outcomes can be achieved, and families can be reassured and counseled as such.

Clinical and Functional Assessment

Twenty-eight children (97%) had a normal or nearly normal IKDC ligament grade, and 27 children (93%) had a normal or nearly normal overall IKDC score (Figure 2). Knee stability was restored in all patients, and this is confirmed by the high number of children returning to very strenuous activities (86%). This compares favorably with other series reporting ACL reconstruction in children.[17,27,30,47]

Benefits of Living Donor HT Allograft Over Autograft

Sourcing an appropriately sized graft is one of the challenges in ACL reconstruction in children. Graft diameter can be predicted by height, sex, and weight,[8,34,45,50,51] so it is predictable that children will have significantly smaller HTs available for harvest. The MRI studies of ACL grafts in children have shown that the grafts increase in length but not in diameter as the child grows.[9] If a small-diameter graft is harvested at ACL reconstruction, a child will be unable to compensate for this with remodeling. This confirms our belief that graft diameter is of significant importance in ACL reconstruction in children and may explain why smaller HT autograft size and younger patient age are associated with early graft revision.[35] A living donor HT allograft from an adult is likely to provide an HT graft with a bigger diameter compared with an autograft from a child of smaller height and weight. It is important that the graft is appropriately sized for the knee so that graft impingement is avoided, and accordingly, the size of the graft is selected on a case-by-case basis with smaller children, usually younger than 13 years, receiving only 2-stranded grafts (Figure 1).

It has also been shown that sex influences graft size. One study showed that HT grafts smaller than 8 mm in diameter are obtained in 42% of female patients but in only 18% of male patients.[34] It is for this reason as well that we recommend using the child's father for the living HT allograft donor as the preferred parent donor.

The hamstring muscles are known to have a protective effect on the ACL as they counteract anterior shear forces by co-contracting during knee extension. Although the HT does regenerate in the majority of cases, hamstring harvest for ACL reconstruction has been shown to adversely affect strength in some patients.[4,12] Hamstring retention may be especially important in children as it has been shown that massive increases in hamstring strength occur with maturity, especially in male children.[1] Maintaining the neuromuscular hamstring structure in children preserves the secondary stabilizers to anterior tibial translation, which may help recovery and proprioceptive function.

The use of living donor HT allografts avoids donor site morbidity in the child. In the early postoperative period, the discomfort associated with HT harvest is eradicated. Donor site morbidity such as kneeling pain and injury to the infrapatellar branch(es) of the saphenous nerve[6] has been well reported after ACL reconstruction in adults, with lower rates for HT grafts than bone–patellar tendon–bone grafts.[15,25,44] Additionally, a smaller tibial skin incision can be made in the children, necessary only for placement of the tibial tunnel and distal graft fixation.

Benefits of Living Donor HT Allograft Over Cadaveric Allograft

An alternative to autografts for ACL reconstruction is a cadaveric allograft. While cadaveric allograft tissue appears to be an appealing graft choice, there are concerns specific to it. Disease transmission, delayed graft incorporation, potential immune reactions, increased postoperative traumatic rupture rate, sterilization, and graft preparation problems including weakened irradiated allografts, bone tunnel enlargement, and graft cost have all been reported.[16,20,21,42,52] Studies have reported a higher incidence of graft ruptures with both cadaveric nonirradiated and irradiated allografts compared with autologous grafts.[11,49] A living donor HT allograft from a parent of the recipient child rather than a graft from an unknown cadaveric donor helps minimize some of the concerns associated with cadaveric allograft tissue.

HT Allograft Donor Morbidity

We recognize that our technique has the potential to introduce morbidity into the living parent donors. In this series, 28 of 29 donors (97%) would undergo the same procedure again, and while appreciating the ethical importance of potential morbidity in the donors, we were reassured by our results. There is no doubt that ACL reconstruction in children is a complex and difficult issue, and it should be remembered that there is not presently one perfect solution. Future studies with larger numbers will further evaluate morbidity in the living donors.

Cost Effectiveness

The current unstable economic and political environment suggests the need for an increasingly cost-conscious awareness among health consumers and providers. Cost-effectiveness analysis has been used to analyze the different graft choices in primary ACL reconstruction to determine the most cost-effective graft choice.[18] A cadaveric allograft was the most costly and the least effective strategy reported. However, this study was based on the "average" patient undergoing ACL reconstruction. In our series, the overall cost of surgery for both the child and donor was 35% more than for ACL reconstruction using autogenous HT grafts and 0.7% less than using fresh-frozen allografts. This additional cost over autogenous HT grafts may be justified if the incidence of further ACL injuries is reduced with this technique and it is achieved at a lower risk to the patient.

Further ACL Injury

Previous studies have reported the high incidence of further ACL injuries in children both to the graft and to the contralateral ACL.[10,46] In patients less than 18 years old, this has been reported to be as high as 18%[46] to 29%[10] over a 5-year period. The exact cause of the higher incidence of further ACL injuries remains unclear, but it may be related to the high rate of return to high-level sports seen in children. Certainly, in this series, there was a very high rate of return to very strenuous activities such as competitive team ball sports (86%), and this increases the exposure to potential graft-rupturing activities such as pivoting, side-stepping, and jumping sports. One of the 2 graft ruptures in this series was a 12-year-old boy who fell twisting his knee preparing for a high jump at 10 months after surgery. The other graft rupture was more unusual in that the 13-year-old boy slipped awkwardly at 4 weeks after surgery. Overall, the incidence of ACL graft ruptures in this series was 6% at 2 years. This compares favorably with other series of children in which 2-year ACL graft ruptures have been reported in 18% when an HT autograft is used.[10] We acknowledge that only longer term evaluation of this technique will determine if further ACL injury rates are successfully reduced, and these studies are in progress. However, even if further ACL injuries occur, use of this technique affords the advantage that the children's own hamstrings are preserved as a graft option for the future.

Study Limitations

We recognize that there are limitations to this study. Despite the increasing incidence of ACL ruptures in children, this injury remains a rare event for the purposes of reporting case series describing a new technique. The pediatric population is heterogeneous by nature, and while not ideal, this has to be accepted as part of studying this group. Our study population was heterogeneous with regard to meniscal status. Yet, identifying a suitably sized population with intact menisci in the context of ACL ruptures in children would be extremely difficult and would preclude the reporting of techniques such as this that seek to advance the treatment and care of rare and complex injuries. We also appreciate that some surgeons will have ethical concerns of the potential morbidity that this technique introduces into the living parent donor. With a new, previously unthought-of technique, this is understandable, and only further well-designed studies will reassure that group. Despite these limitations, this is the only study reporting a new graft source, the living donor allograft, that we believe is a viable and acceptable option to both the donor and child.

CONCLUSION

We present the outcome of ACL reconstruction in a series of children with a novel graft option: the related living donor HT allograft. Excellent clinical and subjective outcomes were achieved with a high return to desired activities. This technique allows a more predictable size of the HTs compared with an autograft from the child and maintains an intact neuromuscular hamstring structure in the child. Finally, the child's own HTs are reserved for future use. Anterior cruciate ligament reconstruction using living donor allografts should be considered as a viable choice in children.

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