Original Article

No Deficits in Functional Outcomes of the Contralateral Limb Are Seen When the Hamstring Is Harvested for Augmentation of Small Diameter Ipsilateral Hamstring Autograft

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Purpose: To evaluate clinical outcomes of the contralateral, nonoperative limb in patients undergoing contralateral hamstring (HS) autograft harvest compared with patients undergoing ipsilateral HS autograft harvest alone. **Methods:** This study included 96 patients who underwent isolated anterior cruciate ligament reconstruction (ACLR) using 4-stranded HS autograft (n = 85) or 4-stranded HS autograft augmented with contralateral HS (n = 13) due to inclusion of ipsilateral graft diameter <8 mm. Isokinetic flexion and extension strength and dynamic performance of the ipsilateral and contralateral limbs and limb symmetry index (LSI) were evaluated at 6 months' postoperatively. Rates of contralateral native ACL tear at minimum 2 years also were compared. For all comparisons, $P < .05$ was considered statistically significant. **Results:** Normalized isokinetic knee flexion and extension strength of the contralateral limb did not differ between cohorts ($P = .34$; $P = .21$, respectively). LSI for knee extension peak torque and knee flexion peak torque did not differ between cohorts ($P = .44$; $P = .67$, respectively). No difference in LSI was seen for any dynamic performance testing (single leg hop, $P = .97$; triple leg hop, $P = .14$; 6-m timed hop, $P = .99$). No difference was observed in International Knee Documentation Committee ($P = .99$) or Knee Injury and Osteoarthritis Outcome Score subscale measures ($P = .39$-.86). No difference in rates of contralateral knee native ACL tears were seen between cohorts (HS autograft + contralateral HS augmentation, n = 2, 15.4%; HS autograft, n = 7, 8.4%; $P = .26$). **Conclusions:** In this study, at the time of return to sport, we found no differences in contralateral limb functional performance or limb symmetry measurements between patients undergoing contralateral HS autograft harvest for augmentation of smaller (<8 mm) diameter HS autografts harvested from the injured extremity. **Level of Evidence:** Level III, retrospective cohort study.

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Anterior cruciate ligament reconstruction (ACLR) is a common surgery, with approximately 400,000 procedures performed in the United States annually.[1] Although graft selection is dependent on surgeon preference and individualized patient needs, there exist several advantages and disadvantages to each autograft choice.[2] Advantages to the use of hamstring (HS) autograft in comparison with other autograft choices include decreased levels postoperative knee pain, absence of violation to the extensor mechanism, and greater graft tensile strength.[2-5] However, one notable limitation to the use of HS autografts for ACLR is unpredictable graft sizes, which can range from 6 to 9 mm.[4,6,7] Although certain patient-specific demographics and cross-sectional measurements on magnetic resonance imaging may be used to help predict legs that will yield a HS autograft diameter less than 8 mm, grafts not exceeding this threshold have been demonstrated to be associated with an increased risk of failure of ACLR.[4,6,7] HS autografts harvested from the surgical leg that do not exceed this threshold in size may therefore undergo additional folding of the semitendinosus tendon to create a 5-stranded graft or be augmented with allograft or the patient's contralateral HS in order to achieve a diameter greater than 8 mm.[8] Although multiple studies report good outcomes in a patient's injured knee after ACLR when the ipsilateral HS autograft is augmented with contralateral HS autograft, there is a relative paucity of literature examining clinical and functional outcomes of the patient's contralateral, uninjured knee.[9-11] With the primary objective of many ACLR procedures being to return patients to sport or previous baseline level of activity, it is critical to determine the impact that contralateral HS autograft harvest has on a patient's postoperative function and determine whether deficits to this extremity result that may place patients at greater risk of subsequent injury. The purpose of this study was to evaluate clinical outcomes of the contralateral, nonoperative limb in patients undergoing contralateral HS autograft harvest compared with patients undergoing ipsilateral HS autograft harvest alone. We hypothesized that no difference in objective clinical or functional outcomes would exist between the 2 cohorts at the time of return to sport.

Methods

This retrospective cohort study was approved by the academic center's institutional review board (University of Virginia, Institutional Review Board for Health Sciences Research, IRB-HSR #173999). All patients undergoing primary ACLR at our institution between March 2013 and August 2018 who participated in Lower Extremity Assessment Protocol (LEAP) testing were evaluated for inclusion in this study. Participants were included in LEAP testing regardless of meniscal pathology but were excluded in the presence of chondral injury requiring intervention other than a microfracture or collateral ligament injuries, but were not excluded from the study if clearance to return to sport occurred at a later time point. All ACLR procedures were performed at a single academic institution by 1 of 6 fellowship-trained orthopaedic sports medicine surgeons. All cases were performed using arthroscopic assistance and with independent femoral tunnel creation. No included patients underwent lateral extra-articular tenodesis as this procedure was not being performed routinely at our institution during the time this study was conducted.

Through retrospective chart review, patients were included for analysis in this study if they underwent isolated ACLR using a 4-stranded HS autograft augmented with contralateral HS tissue due to the ipsilateral graft diameter being less than 8 mm in diameter (cohort 1) or a 4-stranded HS autograft harvested from the injured leg (cohort 2). Decision to perform contralateral HS autograft harvest in the setting of the ipsilateral graft being less than 8 mm in diameter was made at the discretion of the attending surgeon and was performed in all patients with graft size of less than 8 mm.

Patients undergoing revision ACLR or additional ligamentous reconstruction were excluded. In addition, patients with less than 2 years of postoperative follow-up or who had not participated in LEAP testing were excluded. LEAP testing is a standard part of the treatment and rehabilitation protocol for all patients undergoing ACLR at our institution, and therefore a very small number of overall ACLR cases performed at our institution would be excluded for this reason. All identified patients provided informed consent to participate in the LEAP testing.

For all identified patients, retrospective chart review was performed to obtain patient demographic information, including age, sex, and body mass index. Operative notes were used to identify patients who had undergone contralateral HS autograft harvest. Incidence of ipsilateral ACL graft rupture and contralateral, native ACL tear also was evaluated through retrospective chart review. When minimum of 2 years of follow-up could not be obtained through chart review alone, patients were contacted and queried with regard to having undergone ipsilateral knee revision ACLR or contralateral knee ACLR. Only patients with follow-up information were included in this study.

LEAP testing was conducted according to institutional standards, further described below, by 3 trained doctoral students including X.T. who were overseen by a doctor of philosophy (Ph.D.) in kinesiology and health sciences. In all patients, LEAP testing was performed at approximately 6 months' postoperatively, due to this being the time that patients are being evaluated for return to sport. Patient-reported outcomes, including the International Knee Documentation Committee (IKDC) and Knee Injury and Osteoarthritis Outcome Score (KOOS), were reviewed for each patient at the 6-month postoperative follow-up visit, as well.[12,13]

The primary outcome of interest in this study was a comparison of normalized isokinetic knee flexion and extension strength of the contralateral limb between the 2 cohorts of patients. Secondary outcomes of interest included a comparison of dynamic performance testing, patient-reported outcome scores (IKDC and KOOS), and rates of ipsilateral ACL graft rupture and contralateral native ACL tear between cohorts.

LEAP Procedures

Knee Strength During Flexion and Extension

Knee flexion and extension strength was measured on bilateral lower extremities postoperatively using a Biodex Systems 4 multimode dynamometer (Biodex Medical Systems, Shirley, NY) at a speed of 90°/s. The testing was performed with isokinetic and concentric movements. Testing was performed on the contralateral limb, followed by the ipsilateral limb. Practice trials on each limb were conducted to help with familiarization of the task. As the patients completed their efforts the peak torque was measured in both knee flexion and extension. Peak torque was normalized to the participant's body mass (Nm/kg). Final limb symmetry index (LSI) was calculated as the ipsilateral limb measurement divided by the contralateral limb measurement. A value of 100% indicates perfect symmetry.

Dynamic Hop Testing

Patients underwent 4 single-leg hopping trials for each limb. These included a (1) single leg hop for maximal distance where participants hopped straight forward on one limb, (2) 3 consecutive hops in a straight line for maximal distance, and (3) timed hop where subjects hopped as quickly as possible for 6 meters. Distances were measured in centimeters, time in seconds. Limb symmetry was determined as a percentage of the contralateral limb.

Statistical Analyses

Analyses were performed using Stata 17 (StataCorp LLC, College Station, TX). Descriptive statistics such as mean and standard deviation were calculated for all quantitative variables. Flexion and extension strength as well as LSI and hop tests of the limbs were compared between the cohorts using an analysis of covariance model analysis controlling for age, sex, and body mass index. Using an alpha of 0.05 and power of 0.80, a sample size of 128, with 64 participants per cohort would be required to detect a difference of 9% in our primary outcome isokinetic flexion and extension strength limb symmetry, whereas a sample of 17 participants per cohort would be required to detect a difference of 17%. For all comparisons, $P < .05$ was considered statistically significant.

Results

A total of 316 consecutive patients were evaluated for inclusion in this study; 96 were identified who underwent isolated, uncomplicated ACLR with HS autograft (Fig 1). Of these 96 patients, 83 underwent ACLR using 4-stranded HS autograft, whereas in 13 patients the ipsilateral HS autograft was augmented with contralateral HS autograft tissue due to the ipsilateral graft being less than 8 mm in diameter. Demographics of each cohort of patients are described in Table 1. There were significant differences in age, mass, and height, which were accounted for in the statistical model (Table 1). All patients had minimum follow-up of 2 years' postoperatively, with no significant difference existing in mean time of follow-up postoperatively between cohorts (Table 1). All patients were generally allowed to return to sports at 6 months' postoperatively.

With regard to the primary outcome of interest, normalized isokinetic knee flexion ($P = .34$) and extension strength ($P = .21$) did not significantly differ between cohorts at 6 months' postoperatively (Table 2). Similarly, LSI for knee extension peak torque and knee flexion peak torque did not significantly differ between cohorts ($p = 0.44$; $P = .67$, respectively). There were also no significant differences seen in LSI for any dynamic performance testing (single leg hop, $P = .97$; triple leg hop, $P = .14$; 6-m timed hop, $P = .99$) (Table 2).

There were also no significant differences observed in patient-reported outcome scores between the 2 cohorts (Table 3). In the augmented cohort 76.9% (10/13) of patients and 66.3% (55/83) of patients in the 4-stranded HS graft cohort achieved patient acceptable symptom state (PASS) thresholds for the IKDC. For the KOOS subscales in the augmented cohort 100% (13/13), 92.3% (12/13), 61.5% (8/13), 100% (13/13), and 84.6% (11/13) of patients exceeded PASS thresholds for the symptom, pain, activities of daily living, sport, and quality of life scores, respectively. The corresponding PASS rates for the 4-stranded HS graft cohort were 92.8% (77/83), 71.1% (59/83), 41.0% (34/83), 74.7% (62/83), and 66.3% (55/83).[14]

There were 13 (13.5%) overall graft re-ruptures in the included patient population. Two of 13 patients (15.4%) in whom the ipsilateral HS graft was augmented with contralateral HS tissue experienced graft rupture, in comparison with 11 of 83 patients (13.3%) who underwent ACLR with an ipsilateral, 4-stranded HS autograft. This difference in rates of ACL graft rupture between cohorts was not statistically

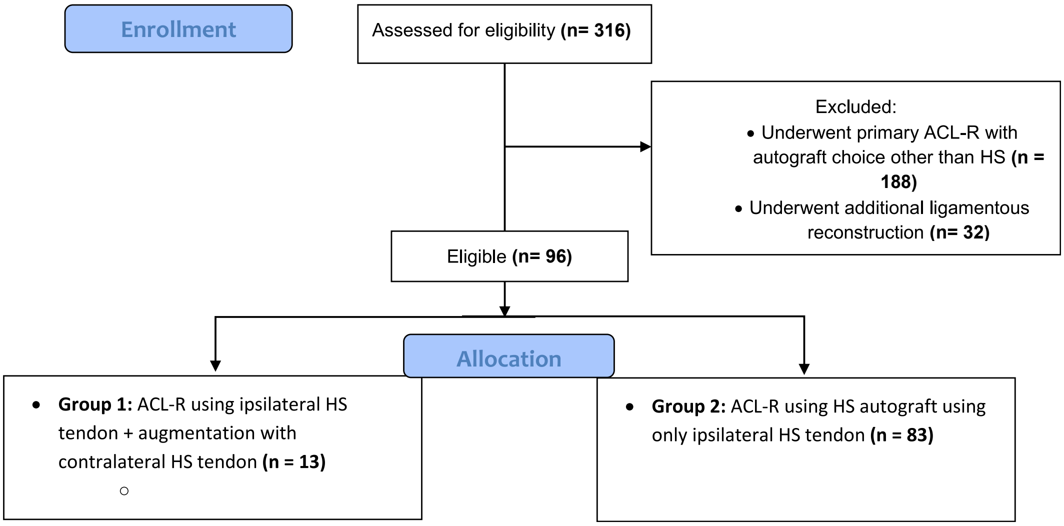

Fig 1. A flow chart demonstrating the selection of eligible patients for inclusion or exclusion in the current study, as well as the respective allocation to the study cohorts. (ACLR, anterior cruciate ligament reconstruction; HS, hamstring.)

significant ($P = .84$) (Table 1). There were 9 patients (9.4%) who experienced rupture of the contralateral, native ACL. Two of 13 (15.4%) of patients in whom the ipsilateral HS graft was augmented with contralateral HS tissue experienced contralateral knee ACL rupture, in comparison with 7 of 83 patients (8.4%) who underwent ACLR with an ipsilateral, 4-stranded HS autograft. This difference in rates of contralateral ACL rupture between cohorts was not statistically significant ($P = .26$) (Table 1). No patients experienced complications related to ipsilateral or contralateral HS harvest.

Discussion

The most important finding from this study was that there does not appear to be a difference in contralateral limb objective functional performance at the time of return to sport assessment when patients undergo contralateral HS autograft harvest for augmentation of small diameter HS autografts. Specifically, in this study, patients who underwent contralateral HS autograft augmentation had no statistically significant deficits in isokinetic knee flexion or extension strength or dynamic functional performance testing of the contralateral limb at 6 months' postoperatively. Although this study may be underpowered in order to draw definitive conclusion from this comparison between cohorts, given the rarity of contralateral HS autograft harvest for graft augmentation in the literature, these findings remain a worthwhile contribution to the existing knowledge of clinical information surrounding this topic. These findings also suggest that patients are not at greater risk of contralateral knee injury due to deficits that could result from donor-site morbidity. Further validating this is that this present study also did not identify a difference in rates of contralateral knee ACL injury between patients who had and had not undergone contralateral HS autograft harvest for augmentation of the ipsilateral HS autograft, although the study was underpowered for this endpoint. These findings suggest that augmentation of smaller diameter ipsilateral HS autografts with contralateral HS autograft tissue is an adequate option when HS autograft size from the patient's ipsilateral, injured extremity is insufficient.

The use of soft-tissue grafts less than 8 mm in diameter has been shown to be an independent risk factor for ACL graft rupture and need for revision

Table 1. Demographic Information

	Cohort 1	Cohort 2	*P* Value
Sex, n	13	83	.19
Female	8	25	
Male	5	48	
Age, y	19.6 ± 10.6	29.5 ± 13.3	**.01**
Mass, kg	61.1 ± 13.9	76.3 ± 18.1	**.004**
Height, cm	165.7 ± 8.2	172.7 ± 9.7	**.01**
BMI	22.04 ± 3.3	25.5 ± 5.5	**.03**
Mean follow-up, y	2.99	2.69	–
LEAP testing (time, months postsurgery)	6.5 ± 1.3	6.8 ± 2.3	.65
Graft ruptures	2 (15.4%)	11 (13.3%)	.84
Contralateral ACL injuries	2 (15.4%)	7 (8.4%)	.26

NOTE. Demographic information and rates of ipsilateral ACL graft rerupture and contralateral knee ACL rupture between study cohorts of patients. Bolded values were found to be statistically significant ($P < .05$).

Cohort 1: ACLR using ipsilateral HS autograft + contralateral HS autograft augmentation

Cohort 2: ACLR using only ipsilateral HS autograft

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; BPTB, bone–patella tendon–bone; HS, hamstring; LEAP, Lower Extremity Assessment Protocol.

Table 2. LEAP Outcome Scores by Cohort

	Cohort 1	Cohort 2	*P* Values
Limb symmetry index knee flexion 90°/s, %	87.6 ± 16.0	85.1 ± 17.4	.67
Limb symmetry index knee extension 90°/s, %	83.0 ± 13.3	73.7 ± 19.8	.44
Limb symmetry index single leg hop, %	97.9 ± 7.9	87.6 ± 16.5	.97
Limb symmetry index triple hop, %	97.7 ± 4.3	92.0 ± 12.8	.14
Limb symmetry index 6m timed hop, %	101.7 ± 6.3	109.8 ± 17.1	.99
Involved knee flexion, Nm/kg	0.8 ± 0.2	0.8 ± 0.2	.44
Uninvolved knee flexion, Nm/kg	0.9 ± 0.3	0.9 ± 0.2	.34
Involved knee extension, Nm/kg	1.8 ± 0.5	1.6 ± 0.5	.67
Uninvolved knee extension, Nm/kg	2.1 ± 0.4	2.1 ± 0.4	.21

NOTE. Shown is a comparison of objective functional performance metrics between study cohorts, as assessed per the institution's LEAP testing. *P* values indicated are representative of ANCOVA model covarying for age, sex, and BMI.

Cohort 1: ACLR using ipsilateral HS autograft + contralateral HS autograft augmentation.

Cohort 2: ACLR using only ipsilateral HS autograft.

ACLR, anterior cruciate ligament reconstruction; ANCOVA, analysis of covariance; BMI, body mass index; HS, hamstring; LEAP, Lower Extremity Assessment Protocol.

Table 3. Patient-Reported Outcome Scores by Cohort

	Cohort 1	Cohort 2	*P* Value
IKDC	84.8 ± 11.2	79.4 ± 14.3	.99
KOOS Symptom	89.6 ± 6.6	81.4 ± 14.9	.64
KOOS Pain	96.7 ± 4.3	90.2 ± 9.9	.60
KOOS Activities of Daily Living	98.5 ± 2.9	95.8 ± 6.8	.39
KOOS Sport	91.9 ± 7.5	80.7 ± 19.0	.86
KOOS Quality of Life	77.4 ± 16.4	65.8 ± 21.7	.65

NOTE. Shown is a comparison of patient reported outcome scores between study cohorts. *P* values indicated are representative of ANCOVA model covarying for age, sex, and BMI.

Cohort 1: ACLR using ipsilateral HS autograft + contralateral HS autograft augmentation.

Cohort 2: ACLR using only ipsilateral HS autograft.

ACLR, anterior cruciate ligament reconstruction; ANCOVA, analysis of covariance; BMI, body mass index; HS, hamstring; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score.

surgery.[6,15-19] In a systematic review and meta-analyses of clinical studies comparing HS autograft size and failure rate, Conte et al.[7] reported a 6.8 times greater relative risk of failure if the graft diameter was less than or equal to 8 mm. Therefore, several strategies exist to increase the diameter of the ACL graft when ipsilateral HS autograft harvest yields a graft diameter below this threshold.[8,17,20-24] HS autografts harvested from the injured leg may undergo additional folding of the semitendinosus tendon to create a 5-stranded graft or be augmented with allograft or the patient's contralateral HS in order to achieve a diameter greater than 8 mm.[8] Augmentation of grafts with allograft tissue has been associated with increased rates of graft rupture, however.[22,23] In addition, folding the semitendinosus tendon again to create a 5-stranded graft may still yield a graft less than 8 mm in diameter in up to 25% of cases.[25] Therefore, the use of contralateral HS autograft tissue for augmentation of ipsilateral HS autografts is clinically relevant.

The primary concern with using HS tissue from the patient's contralateral, uninjured knee is donor-site morbidity. With the primary goal of many ACLR procedures being to return to previous levels of activity or sport, it is important to determine whether contralateral HS harvest for graft augmentation would yield relevant functional strength deficits and place patients at greater risk of subsequent injury. Our current study suggests that augmentation with a contralateral HS autograft is a viable option to increase graft diameter without causing significant functional detriment to the contralateral limb at the time of return to sport around six months postoperatively. Although the literature surrounding this topic is limited, previous investigations are heterogenous with regard to this outcome. Yasuda et al.[26] randomized 65 patients to undergo either ipsilateral or contralateral HS autograft harvest during ACLR in order to distinguish between the morbidity caused from HS autograft harvest and that of the ACLR surgery. In knees in which only HS autograft harvest was performed, peak HS muscle torque was significantly lower than knees that did not undergo any surgical intervention at nine months postoperatively. However, peak HS torque in knees that underwent both ACLR and HS graft harvest versus those that only underwent ACLR did not significantly differ beyond three months postoperatively.[26] McRae et al.[11] also randomized 100 patients to receive an ipsilateral or contralateral HS autograft and reported only a significant difference in concentric knee flexion strength in knees that underwent ACLR with ipsilateral HS autograft compared with nonoperative knees (no ACLR or HS harvest) at 3 months' postoperatively. No significant difference was found when comparing knees that underwent isolated HS autograft harvest with nonoperative knees at 3, 6, 12, or 24 months' postoperatively.[11] In contrast, Lautamies et al.,[27] Von Essen et al.,[10] and Seto et al.[28] have all reported persistent knee flexion strength deficits in patients who have undergone ACLR with HS autograft. The mixed results in the literature regarding the presence of clinically relevant strength deficits suggest further study is needed to clarify this effect and to determine whether, if present, any deficits represent actualized risk to patients with regard to a greater potential for injury when the HS autograft is harvested from the contralateral, uninjured knee during ACLR for augmentation of ipsilateral HS autografts.

Although limited by lack of sufficient power, the results from this study suggest that contralateral HS autograft harvest does not result in a significantly different rate of ACL rupture in the contralateral limb. Wright et al.[29] found an overall rate of contralateral ACL injury of 11.8% at 5 years or more postoperatively in their systematic review of 2,682 patients who underwent ACLR. In the present study, the risk of contralateral ACL rupture was 15.4% in those undergoing a contralateral HS graft harvest, which falls within the reported range of 0.6% to 22.7% in the literature.[6] Other studies, including those of McRae et al.[11] and von Essen et al.,[10] also have found no significant difference in the rates of rupture of the contralateral ACL after harvest of HS autograft from the contralateral, uninjured knee. Although studies with a larger sample size are likely needed to more definitively demonstrate this finding, these results are collectively consistent to this effect.

Finally, it is worth noting that within this consecutive series, 13.5% of patients yielded HS autografts less than 8 mm in diameter. Hamstring autograft diameter has been found to correlate with numerous demographic factors, such as sex, height, body mass index, and thigh circumference, as well as HS cross-sectional measurement on magnetic resonance imaging.[7,18] The recognition of certain risk factors for yielding a HS autograft less than 8 mm in diameter and demonstration in this study that this is not an uncommon occurrence suggests that surgeons should either consider alternative autograft choices or be aware of augmentation strategies in these scenarios to avoid placing patients at greater risk for re-rupture with the use of smaller grafts. Such knowledge can also aid surgeons in counseling patients preoperatively with regard to graft selection and surgical planning.

Limitations

This study is not without limitations, primarily in its sample size and retrospective nature. The small number of participants in the augmented cohort creates the possibility of type II error, given the large amount of difference in outcomes required to achieve power. The present study population was a sample of convenience and reflective of clinical practice. The retrospective nature of this study also, by definition, subjects it to the possibility that other confounding variables, such as the timing between injury and surgery and degree of preoperative activity and function may influence the outcomes observed. There also exists the possibility of selection bias influenced the results of the study, in that demographic differences existed between cohorts with patients in the cohort that required contralateral HS augmentation for graft diameter less than 8 mm being significantly younger and having decreased height, weight, and body mass index. In order to account for such selection biases, a more ideal comparison group may have been including patients whose HS graft measures less than 8 mm, and comparing patients who received, or didn't receive, contralateral augmentation. However, given the known increased failure rate of grafts not exceeding the 8 mm threshold and the available patients present with initial graft diameters less than 8 mm, this would not be a practical comparison. In addition, we were also unable to adjust for baseline differences between the cohorts in LEAP data, as preoperative measures were not performed. Finally, we were not able to control for adherence to postoperative protocol and physical therapy, which may contribute to contralateral limb strength.

Conclusions

In this study, at the time of return to sport, we found no differences in contralateral limb functional performance or limb symmetry measurements between patients undergoing contralateral HS autograft harvest for augmentation of smaller (<8 mm) diameter HS autografts harvested from the injured extremity.

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