Abstract

Purpose: Accurate prediction of autograft size for anterior cruciate ligament reconstruction can assist in preoperative planning and decision-making regarding graft choices. This study seeks to determine the accuracy of MRI measurements by comparing intraoperative measurements of the patella, semitendinosis, and gracilis tendons while correlating these measurements with patient anthropometric data such as gender, height, and weight.

Methods: A series of 20 consecutive patients were enrolled who underwent a magnetic resonance imaging study of the knee and proceeded with surgical reconstruction of the anterior cruciate ligament. Intraoperative measurements of the diameter of semitendinosis and gracilis tendons or width of patella tendon were compared to radiographic measurements obtained on the MRI. These measurements were analyzed using a paired t-test as well as regression analysis to evaluate strength of correlation between measurements and also to determine correlation with height, weight, and gender.

Results: There was no statistical difference between intraoperative and radiographic measurements (p > 0.05). There was strong correlation (Pearson r = 0.98, p = 0.00) found between intraoperative and radiographic measurements of the autograft tendons. Weaker correlation was seen with gender, height, and weight with intraoperative measurements.

Conclusions: Measuring the diameter of the semitendinosis and gracilis tendons and patellar width on MRI can give an accurate prediction of actual intraoperative sizes of these anatomic structures. Height, weight, and gender were also correlated with tendon sizes implying that a patient of female gender or of smaller stature in height or weight may have smaller tendon sizes. Routine use of preoperative MRI measurements can guide surgeons with specific graft preferences to other surgical options if the graft is measured to be insufficient in size.

Appropriate graft selection for anterior cruciate ligament (ACL) reconstruction is a critical and important decision for surgeons and patients. There remains no consensus on which autograft provides the optimal balance between graft strength, ease and durability of reconstruction, and patient safety while minimizing donor site morbidity.1–5 However, problems and issues clearly arise with graft strength when harvested hamstring autograft are of insufficient diameter.6,7 Similarly, donor site complications of the patella tendon harvest may increase when more than one-third of the total width of the patella tendon is harvested for autograft use.8–10

Many surgeons have attempted to predict autograft size in order to assist in preoperative decision-making regarding graft choice. One study has proposed using patient anthropometric data, such as height, weight, and gender, as a method to predict hamstring diameter.11 In reviewing the literature, we only came across two studies that examined MRI to determine the cross-sectional area of hamstring allograft for preoperative planning.12,13 There is otherwise a lack of published literature on methods to preoperatively determine autograft size.
Magnetic resonance imaging (MRI) is routinely performed for the diagnosis and treatment of ACL injuries. MRI is an excellent imaging modality allowing for qualitative characterization of intraarticular soft tissue anatomy, which allows confirmation of ACL complete and partial ruptures. As MRI technology has steadily advanced, the image quality has also improved allowing for higher resolution images, which are allowing for quantitative measurements of anatomical structures. In fact, the use of MRI to measure the lengths of ACL and patella tendon allowed Brown and associates to propose a formula to avoid graft length mismatch.

If MRI can be used to accurately measure the size of the patella, semitendinosus, and gracilis tendons, this data may be of utility for surgeons for preoperative surgical planning. It would be beneficial for surgeons to be able to reliably determine whether hamstring tendons would be of suboptimal autograft diameter or whether the patella tendon would be too narrow for harvesting. This information could help the surgeon and patient determine appropriate graft choice preoperatively, which would reduce unnecessary graft harvest and an abrupt intraoperative change in plan due to insufficient autograft size.

The purpose of this study was to compare the accuracy of MRI measurements with intraoperative measurements of the patella, semitendinosus, and gracilis tendons while correlating these measurements with patient anthropometric data such as gender, height, and weight.

Materials and Methods
Over the course of July 2006 through November 2007, we identified 20 patients with ACL ruptures through history and clinical exam and confirmed by diagnostic MR scans of the knee. A high resolution MR imaging protocol was used. Multiple sequences were performed at 1.5 T, utilizing send-receive knee coils. For the purposes of this study, only two sets of axial images were systematically evaluated using the following MRI settings (FLASH, with a flip angle of 75 and TE of 12; proton density fat suppressed with a TE of 33, ETL of 8, TR of 3500, FOV of 14, and matrix of 320 by 256). At three distinct locations, measurements were made with electronic calipers (Figs. 1 and 2).

These patients desired surgical ACL reconstruction and agreed to participate in our study. Consent was obtained with approval from our institutional review board. The decision of autograft, bone-patella-bone versus hamstring, was made from a combination of surgeon and patient preference. Preoperative patient anthropometric data, including age, gender, height, and weight, were recorded (Table 1).

These patients then underwent a standard arthroscopic-assisted ACL reconstruction with harvesting of either bone-patella-bone or hamstring autografts. All patients underwent a consistent operative technique performed by a single surgeon. Bone-patella-bone autografts were obtained utilizing a midline skin incision from the inferior pole of the patella to the tibial tubercle. A combination of sharp and blunt dissection was carried out to expose the medial and lateral edges of the patella tendon. The entire transverse width of the tendon was measured and recorded at 1 cm below the inferior pole of the patella using surgical calipers (Fig. 3).

Harvesting of the semitendinosus and gracilis tendons was obtained by utilizing an oblique skin incision over the pes anserinus insertion. After fully identifying exposing both
the gracilis and semitendinosis tendons, a tendon stripper was used to free the tendons proximally. The tendons were then sharply dissected off the distal insertion from the pes anserinus and placed onto an ACL graft board (Fig. 4). The width of the semitendinosis and gracilis tendons were measured and recorded at three locations: 1, 2, and 3 cm, proximally from the insertion on the pes anserinus using surgical calipers.

One experienced musculoskeletal radiologist retrospectively reviewed the MR scans of each patient that underwent surgery and independently measured either the patella tendon or the hamstring tendons depending upon the autograft that was used in surgery. The radiologist was blinded to the surgical measurements and performed the measurements at the same anatomic locations in accordance to the intraoperative measurement protocol.

Standard statistical analysis was performed using the paired t-test to directly compare the intraoperative and radiographic measurements. We also used a correlation coefficient (Pearson r) and multiple linear regression to determine the relationship between the MRI and intraoperative measurements with gender, height, and weight. A test was considered statistically significant if the obtained P value was less than 5 percent (p < 0.05).

**Results**

There was no statistical difference found between intraoperative and radiographic measurements via the paired t-test (p > 0.05). Using regression analysis, the intraoperative and radiographic measurements were found to be closely related (r = 0.98, p = 0.00). Thus, measurements obtained in the intraoperative and radiographic setting were found to be similar and highly correlated (Table 2).

Multiple stepwise regression analysis revealed further correlations between anthropometric data and the collected measurements. Gender was found to be moderately correlated to both intraoperative (r = 0.3, p = 0.01) and radiographic measurements (r = 0.21, p = 0.08); however, only intraoperative data and gender correlation was statistically significant. Both intraoperative and radiographic data showed statistically significant correlation with height and weight. Stronger correlation was seen with intraoperative measurements for both height (r = 0.39, p = 0.001) and weight (r = 0.47, p = 0.00) as compared to radiographic correlation with height (r = 0.31, p = 0.008) and weight (r = 0.36, p = 0.002).

**Discussion**

We studied 20 consecutive patients between July 2006 and November 2007 who underwent ACL reconstruction and received a high resolution MRI. These patients had the diameters of their semitendinosis and gracilis tendons and widths of their patella tendon compared intraoperatively to measurements obtained on MRI. Our hypothesis was that MRI measurements should be correlated with the actual intraoperative measurements. We also hoped to correlate the measurements with anthropometric data, such as height, weight, and gender, to ascertain the predictive value of this data.

Our results suggest that radiographic and intraoperative data are statistically related. Thus, measuring the diameter

### Table 1 Anthropometric Data

<table>
<thead>
<tr>
<th></th>
<th>N Hamstring</th>
<th>Patella</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>12</td>
<td>4</td>
<td>8</td>
<td>30.5 ± 10.4</td>
<td>69.9 ± 2.4</td>
<td>184.2 ± 21.8</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>24.6 ± 6.0</td>
<td>64.8 ± 3.6</td>
<td>136.9 ± 17.9</td>
</tr>
</tbody>
</table>

### Table 2 Graft Measurement Correlation

<table>
<thead>
<tr>
<th>Gender</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P-value</td>
<td>P-value</td>
</tr>
<tr>
<td>Intraoperative</td>
<td>0.3</td>
<td>0.01</td>
</tr>
<tr>
<td>Radiographic</td>
<td>0.21</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**Figure 3** Intraoperative photograph during harvest of the bone-patella tendon-bone autograft. The width of the patella tendon is measured at 1 cm distal to the inferior pole of the patella.
of the semitendinosis and gracilis tendons and patellar width on MRI should give an accurate prediction of actual intraoperative sizes of these anatomic structures. As well, we found that height, weight, and gender were also correlated with tendon sizes. This correlation was stronger with actual intraoperative measurements as compared to radiographic measurements. However, the trend is clear that patients of female gender or of smaller stature in height or weight may have smaller tendon sizes. The ability to accurately predict autograft sizes preoperatively via MRI could prove useful in these patients who may not be suitable candidates for autograft.

Tuman and coworkers correlated patient anthropometric data with hamstring graft size and found that height, mass, and gender were associated with hamstring diameter with height being the strongest factor. In our study, we also found a relationship between both intraoperative and radiographic sizes of patella and hamstring tendons with patient height, weight, and gender. However, the relationships between these anthropometric factors were more strongly correlated with intraoperative measurements than with radiographic measurements. This suggests that using anthropometric data can also be used to estimate graft and tendon size.

The ability to accurately determine preoperative sizes of hamstring autografts prior to surgery can be of great benefit to surgeons and patients. Cross-sectional area of hamstring autografts has been found to be inversely related to graft laxity and anterior-posterior translation after ACL reconstruction. Furthermore, greater clinical laxity has been found in female athletes as compared to male athletes and smaller hamstring graft size in female athletes has been proposed as the reason. Hamstring autograft that is found to be too small in cross-sectional diameter intraoperatively might require allograft supplementation or even abandonment of the hamstring autograft in order to secure adequate fixation and stability. Thus, if the hamstring tendon diameter could be determined prior to surgery to be insufficient to provide a stout enough graft, preoperative clinical decision making could focus on other autograft options such as patella or quadriceps tendon.

Hamada and Bickel have studied the use of MRI to determine the cross-sectional area of hamstring allograft for preoperative planning and have found that it is a useful tool to determine appropriate autograft tissue. Furthermore, MRI has been utilized for assessing anatomic measurements in other studies on ACL reconstruction. Brown and colleagues examined the lengths of various structures in the knee on MRI in order to derive a formula to prevent allograft mismatch. Avoiding graft length mismatch is not only important for bone-patella-bone allograft but is also an issue for autograft. Although we only measured patella tendon width in our study and did not assess radiographic or intraoperative length, patella tendon length should be readily discernible and accurately measured on MRI.

Donor site morbidity is a concern for both patella tendon and hamstring autografts. Despite excellent clinical results otherwise, anterior knee pain has been reported after harvesting of bone-patella tendon-bone autograft. Patella fractures and patella tendon ruptures are infrequent but devastating complications that have arisen after patella tendon autograft harvesting. Harvesting no more than 10 mm of patella tendon width while leaving two-thirds of remaining tendon has been recommended in order to prevent these disastrous complications. Thus, a surgeon and patient may be better served by alternate graft choices if preoperative radiographic measurement of the patella tendon ascertains that there may be insufficient amount of remaining tendon post-harvesting.

Patients generally tolerate harvest of the semitendinosis and gracilis tendons with little long-term detriment to hamstring strength and functioning. However, Yasuda and associates showed that hamstring muscle strength did decrease for 9 months after harvest before recovering. Thus, harvesting of insufficiently-sized semitendinosis and gracilis tendons that are abandoned or require allograft supplementation is counterproductive as it could negatively impact rehabilitation after ACL reconstruction. Our study shows that preoperative planning with the use of MRI could potentially deter the harvest of insufficient hamstring tendon and therefore avoid donor site morbidity.

One limitation of our study is the small sample size of patients. Although the power and magnitude of the study is obviously improved with larger numbers, we feel that the
data clearly shows a strong correlation between intraoperative and radiographic measurement. There was an inherent difficulty in intraoperative measurement of the semitendinosis and gracilis tendons, which was improved when the graft was placed under slight tension to replicate the tendon anatomy in vivo. As well, without the use of a high resolution MRI protocol, it would be difficult to accurately measure tendons on MRI. This prevents the applicability of the use of MRI to measure tendons universally. However, as MRI technology advances and becomes widely available, this restraint will likely become less of an issue.

We believe that MRI can be used to assess the size of patella and hamstring tendons when evaluating a patient for potential autograft harvesting prior to anterior cruciate ligament reconstruction. Clinical experience has shown us that for most patients either hamstring or patella tendon autograft are feasible surgical options as both provide adequately sized grafts and strong substitutes for ACL. However, if autograft harvest is desired in patients of smaller stature or female gender who may have questionably sized autograft tendons, preoperative MRI measurements of tendon sizes could provide useful information prior to an educated discussion regarding the use of autograft or allograft for ACL reconstruction. Additionally, routine use of preoperative MRI measurements can also direct surgeons with specific graft preferences to other surgical options if the graft is measured to be insufficient in size.

Disclosure Statement
None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

References