Avoiding Mismatch in Allograft Anterior Cruciate Ligament Reconstruction: Correlation Between Patient Height and Patellar Tendon Length

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Purpose: The purpose of this study was to evaluate whether a correlation exists between patient height and soft-tissue patellar tendon length. **Methods:** Magnetic resonance imaging (1.5 T) was performed for knee pathology on 403 patients. The patellar tendon length was measured in the midsagittal plane by a board-certified musculoskeletal radiologist. Patient height was recorded to the nearest inch. Patients were grouped into 6 subgroups with 4-inch range intervals based on height. The entire study group was analyzed. Subgroup analysis and gender analysis were performed to determine statistical significance. **Results:** The mean patellar tendon length was 45 ± 7 mm (range, 30 to 66 mm). Wide ranges were noted among each height subgroup irrespective of gender. Significant differences were noted between most height subgroups independent of gender. **Conclusions:** This study showed that a correlation exists between patient height, gender, and patellar tendon length. Although variation occurs among patients of the same height, significant differences in mean patellar tendon lengths do exist between patients in different height subgroups. **Clinical Relevance:** Parameters are provided using patient gender and height to reduce the potential for graft-construct mismatch when ordering bone–patellar tendon–bone allografts for anterior cruciate ligament reconstruction.

Anterior cruciate ligament (ACL) reconstruction is one of the most common surgical procedures in orthopaedics. Although multiple graft options are available, the use of allograft tissue is increasing in popularity to reduce postoperative pain and perioperative morbidity associated with autograft harvest.[1-6] One potential problem specific to patellar tendon grafts during endoscopic ACL reconstructions is the possibility of graft-tunnel mismatch.[5,7-10] This occurs when the relative length of the bone-tendon-bone (BTB) construct exceeds the combined length of the femoral tunnel, intra-articular ACL distance, and tibial tunnel length, resulting in extrusion of the tibial plug. It is specific to endoscopic ACL reconstruction with BTB autograft and allograft and not encountered with the 2-incision ACL reconstruction technique. Renewed interest in anatomic ACL reconstruction has led to an increase in femoral tunnel drilling through an accessory medial portal. Some recent research indicates that this may result in shorter femoral tunnel lengths and intra-articular distances, thereby increasing the chances of graft-tunnel mismatch.[11] If inadequate bone from the tibial plug lies within the tibial tunnel, fixation of the graft may be compromised.

When graft-tunnel mismatch occurs, options to rectify the problem include femoral recession, graft rotation, and alternative tibial fixation techniques including stapling and tying the graft over a post.[5,10,12,13]

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The incidence of graft-tunnel mismatch has been reported to be between 10% and 26%,[5,14,15] with 1 study by a group at our institution, Verma et al.,[15] indicating an increased risk when using BTB allografts as compared with autografts.

To date, most methods of addressing mismatch have focused on how to estimate the tibial tunnel length based on the graft length, rather than focusing on obtaining an appropriate-sized graft. Only 1 study has attempted to make recommendations for ordering allografts of specific lengths based on patient factors such as height.[16] Furthermore, to our knowledge, there are only 2 previous studies that attempted to examine whether a correlation between patellar tendon length and height exists. Brown et al.[16] used a magnetic resonance imaging (MRI) method similar to that used in our study and noted a strong positive correlation between intra-articular graft length of the ACL and patient height but no significant association between patient height and patellar tendon length. Denti et al.[8] studied 50 knees that underwent endoscopic ACL reconstruction and 9 cadaveric knees to look for associations between the length of the intra-articular ACL graft or that of the patellar tendon length and compared them with patient weight or height and then with each other. They reported a weak correlation between patellar tendon length and patient height.

With increasing numbers of ACL allograft reconstructions being performed, there is an increased potential for graft-construct mismatch when "short" patients receive tendon grafts from "taller" patients. The purpose of this study was to (1) evaluate whether a correlation exists between patient height, gender, and patellar tendon length and (2) use this correlation, if it exists, to provide parameters for ordering an allograft of specific length given the recipient patient's height.

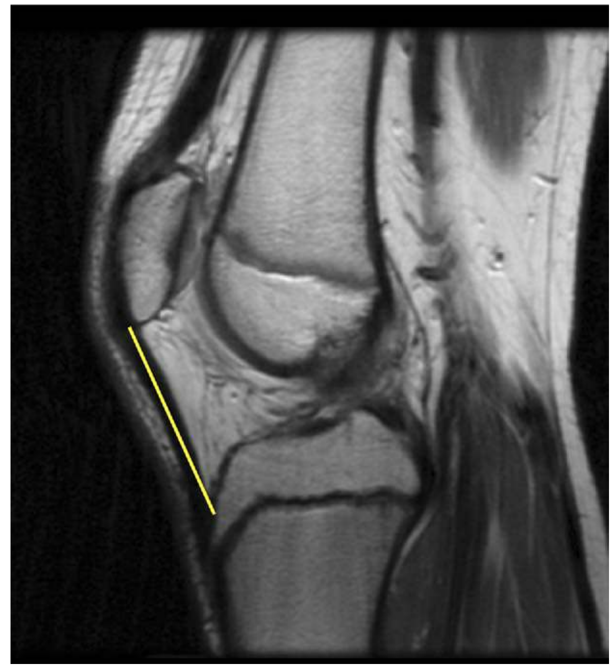

FIGURE 1. A T1-weighted midsagittal MRI scan showing measurement of patellar tendon length. Distance was measured from the inferior pole of the patella to the tibial tubercle (line).

METHODS

After we obtained institutional review board approval, we enrolled 403 consecutive patients (260 men and 143 women) who were undergoing knee MRI (1.5 T) for a variety of pathologies. Skeletally immature patients, patients with patellar tendon ruptures, patients with quadriceps tendon ruptures, and patients who had previous surgery on the affected knee were excluded. The distal pole of the patella and tibial tubercle insertion site on the MRI scan was used as a standardized reference point in the midsagittal plane. By use of the hard copy images, a piece of paper was placed at the posterior margin of the mid patellar tendon. Marks were made proximal and distal on the paper to denote the tendon length. This marked paper was then placed on the scale provided on each MRI scan to ascertain the tendon length (Fig 1). MRI measurements were made by a single fellowship-trained musculoskeletal radiologist. All MRI scans were proton-density images, with a representative repetition time/echo time of 2,295/22 milliseconds.

Patient height, gender, and age were also recorded. Patient height was measured to the closest inch in a standing position. Patients were divided into gender-specific subgroups based on 4-inch increments in height: group 1, 58 to 61 inches; group 2, 62 to 65 inches; group 3, 66 to 69 inches; group 4, 70 to 73 inches; group 5, 74 to 77 inches; and group 6, 78 to 81 inches. Statistical analysis was performed with SPSS software (SPSS, Chicago, IL), including mean, SD, range, and Pearson correlation coefficient. Comparison between genders was conducted with an unpaired t test. Differences in mean patellar tendon length between groups used an analysis of variance with post hoc testing by the Bonferroni method. Statistical significance was defined as $P < .05$.

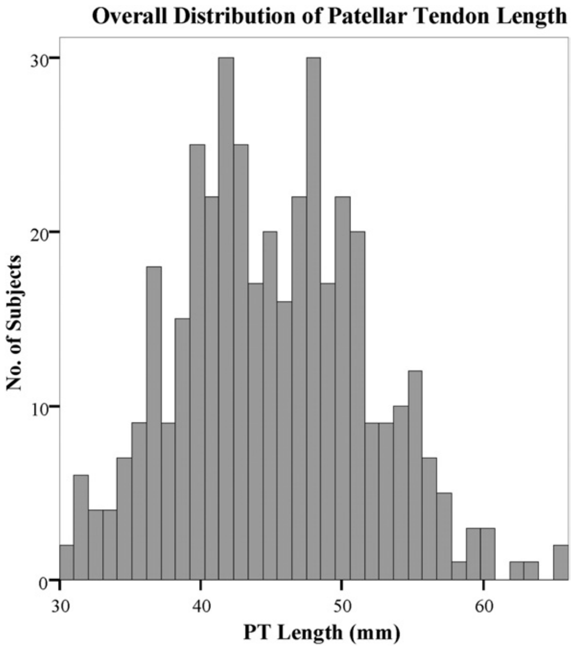

FIGURE 2. Distribution of patellar tendon (PT) lengths for all patients enrolled. Mean tendon length was 45 ± 7 mm (range, 30 to 66 mm).

TABLE 1. *Descriptive Statistics of Patellar Tendon Length by Height Interval Groups for Entire Cohort*

	No. of Subjects	Patellar Tendon Length (mm) Mean	SD	Range	95% CI
Group					
58-61 in	9	38	5	30-48	34-41
62-65 in	80	41	5	31-55	40-43
66-69 in	108	45	6	32-63	44-46
70-73 in	151	46	6	33-66	46-47
74-77 in	49	50	7	35-66	48-51
78-81 in	6	50	3	46-54	46-54
All	403	45	7	30-66	45-46

Abbreviation: CI, confidence interval.

RESULTS

Knee MRI (1.5 T) was performed on 403 consecutive patients who underwent imaging for a variety of pathologies. The patellar tendon lengths were measured (Fig 2). The mean patellar tendon length was 46 ± 6 mm for men and 43 ± 6 mm for women. This difference between genders was significant ($P < .0001$) (Fig 3). Moderate positive correlations were found between height and patellar tendon length for both men (Pearson $r = 0.34$, $P < .001$) and women (Pearson $r = 0.45$, $P < .001$). A Pearson r value of 0.5 is considered a moderate correlation, although the classification of "moderate correlation," depending on context, has been broadly applied to r values of 0.3 to 0.7.[17]

When subcategorized by height, irrespective of gender, there were significant differences in mean patellar tendon lengths between the groups. Mean patellar lengths were recorded (Table 1) and compared with one another. It should be noted that within each height group, there was a wide range of values, but the 95% confidence interval around the mean was much narrower. This means that 95% of the time, the mean patellar tendon length for that height group will fall

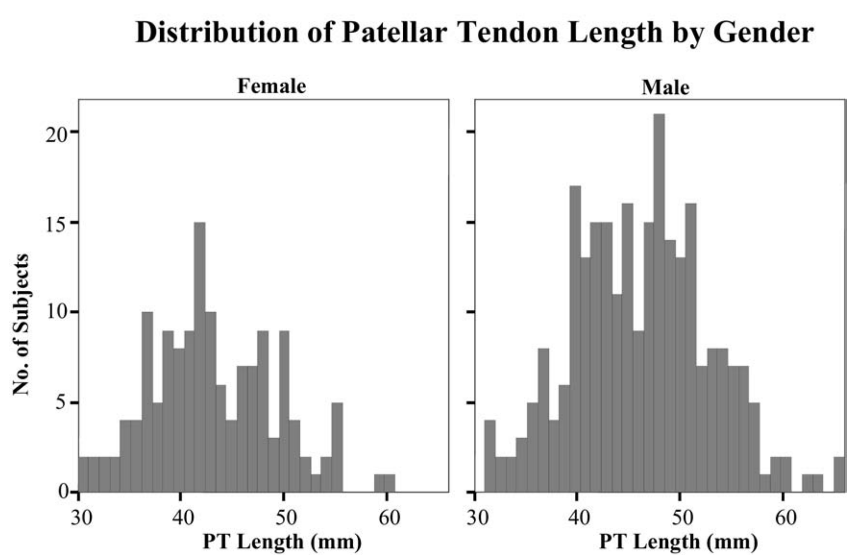

FIGURE 3. A comparison of patellar tendon (PT) length distribution in male (n = 260) and female (n = 143) patients. Mean patellar tendon length was significantly different ($P < .0001$) between men (46 mm) and women (43 mm).

Table 2. *Comparison of Mean Patellar Tendon Length by Height Intervals for All Enrolled Subjects Using 1-Way Analysis of Variance With Post Hoc Testing by Bonferroni Method*

No. of Subjects	Height	58-61 in	62-65 in	66-69 in	70-73 in	74-77 in	78-81 in
9	58-61	—	NS	<.01	<.001	<.001	<.01
80	62-65 in	—	—	<.01	<.001	<.001	<.01
108	66-69 in	—	—	—	NS	<.001	NS
151	70-73 in	—	—	—	—	<.05	NS
49	74-77 in	—	—	—	—	—	NS
6	78-81 in	—	—	—	—	—	—

Abbreviation: NS, not significant.

within the specified confidence interval range. Group 1 differed significantly from groups 3, 4, 5, and 6. Group 2 differed significantly from groups 3, 4, 5, and 6. Group 3 differed significantly from group 5. Finally, group 4 differed significantly from group 5 (Table 2).

The height groups were further subcategorized by gender. Table 3 shows the recorded data for the women, displaying the mean patellar tendon lengths for each corresponding height group. Comparisons between these groups showed significant differences in mean patellar tendon lengths. As noted in Table 4, statistically significant differences were noted between group 1 and groups 3 and 4 and between group 2 and groups 3 and 4.

Table 5 shows the recorded data for the male patients. The mean patellar tendon length in group 2 differed significantly from that in group 5, group 3 differed significantly from groups 4 and 5, and group 4 had a statistically significant difference from group 5 (Table 6).

Table 3. *Female Patellar Tendon Length Compared With Height Intervals Divided Into 4-Inch Height Increments (n = 143)*

	No. of Subjects	Patellar Tendon Length (mm)			
		Mean	SD	Range	95% CI
Group					
58-61 in	9	38	5	30-48	34-41
62-65 in	71	41	5	31-55	40-42
66-69 in	55	46	6	36-60	45-48
70-73 in	7	48	6	38-55	42-54
All	143	43	6	30-60	42-44

Abbreviation: CI, confidence interval.

Table 4. *Comparison of Mean Patellar Tendon Length by Height Intervals for Female Subjects Using 1-Way Analysis of Variance With Post Hoc Testing by Bonferroni Method*

No. of Subjects	Height	58-61 in	62-65 in	66-69 in	70-73 in
9	58-61 in	—	NS	<.001	<.001
71	62-65 in	—	—	<.001	<.01
55	66-69 in	—	—	—	NS
7	70-73 in	—	—	—	—

Abbreviation: NS, not significant.

Figure 4 provides an overview of mean patellar tendon lengths for each gender within each height group, showing the increasing mean patellar tendon length that occurs between groups of increasing height for both men and women.

The linear regression equation for male patellar tendon length (y, in millimeters) as a function of patient height (x, in inches) can be expressed as $y = 0.7402x - 6.4707$ (Fig 5). For women, the equation can be expressed as $y = 0.9858x - 20.822$ (Fig 6).

DISCUSSION

A variety of intraoperative methods of graft measurement have been proposed to decrease the risk of graft-tunnel mismatch. Shaffer et al.[5] proposed using specific measurements made during the procedure to help reduce the chance of mismatch. This technique entails measuring the intra-articular graft distance and the patellar tendon graft length, thereby allowing one to correctly calculate the necessary tibial tunnel length. The "graft-50" formula published by Kenna et al.[18] subtracts 50 from the overall graft length. The net

Table 5. *Male Patellar Tendon Length Compared With Height Intervals Divided Into 4-Inch Height Increments (n = 260)*

	No. of Subjects	Patellar Tendon Length			
		Mean	SD	Range	95% CI
Group					
62-65 in	9	43	6	32-50	38-48
66-69 in	53	43	6	32-63	41-45
70-73 in	144	46	6	33-66	45-47
74-77 in	48	50	7	35-66	48-52
78-81 in	6	50	3	46-54	46-54
All	260	46	6	32-66	46-47

Abbreviation: CI, confidence interval.

TABLE 6. *Comparison of Mean Patellar Tendon Length by Height Intervals for Male Subjects Using 1-Way Analysis of Variance With Post Hoc Testing by Bonferroni Method*

No. of Subjects	Height	62-65 in	66-69 in	70-73 in	74-77 in	78-81 in
9	62-65 in	—	NS	NS	<.05	NS
53	66-69 in	—	—	<.05	<.001	NS
144	70-73 in	—	—	—	<.05	NS
48	74-77 in	—	—	—	—	NS
6	78-81 in	—	—	—	—	—

Abbreviation: NS, not significant.

result is the tibial tunnel length necessary to accommodate the remainder of the graft. Miller and Hinkin[19] published a method using the "N + 7" formula, where *N* equals the length of the patellar tendon and then 7° is added to this to determine the angle of the tibial guide. Subsequently, Olszewski et al.[9] published the "N + 2" formula, where *N* equals the length of the patellar tendon but 2 mm is added to this to determine the length of the tibial tunnel needed. Verma et al.[15] modified the Miller and Hinkin formula, using the "N + 10" rule to determine the angle of the tibial drill guide. These methods focus on correcting the tibial tunnel length based on the graft at hand. However, when using an allograft, one may be able to decrease the risk of graft-tunnel mismatch by ordering an appropriate-length graft. In addition, modifying tibial tunnel length may change the tibial starting point and tunnel obliquity, thus potentially negatively impacting

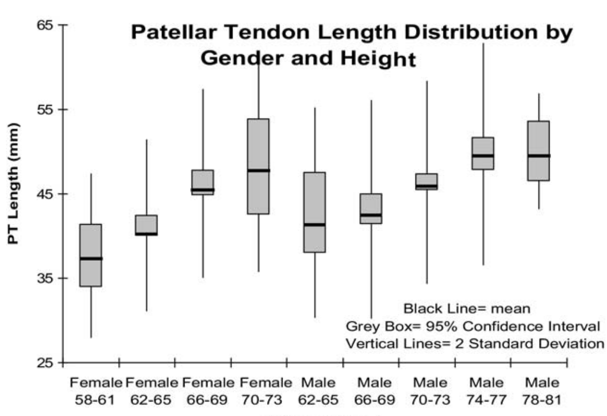

FIGURE 4. Differences in patellar tendon (PT) length distribution when patients are segregated by gender and height. The black line represents mean patellar tendon length, the box is the 95% confidence interval of the mean, and the whiskers delineate 2 SDs.

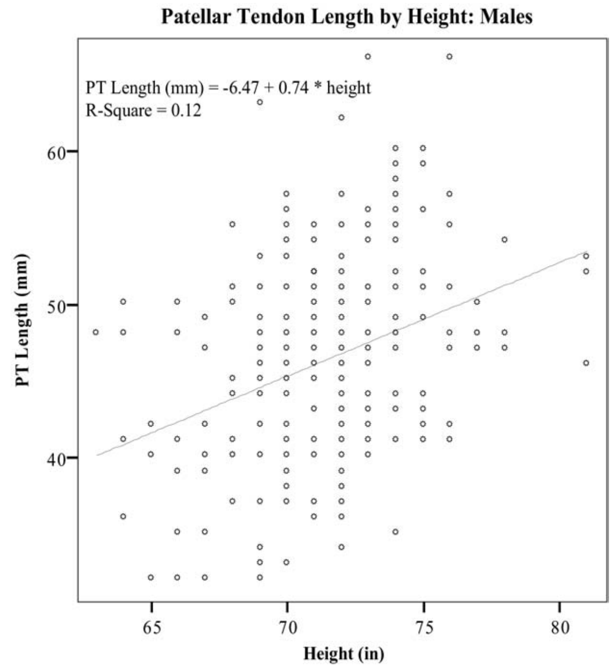

FIGURE 5. Scatter plot of patellar tendon (PT) length versus patient height for men. A least-squares linear regression was determined to estimate tendon length from patient height.

femoral tunnel position in a transtibial technique if a longer tibial tunnel is desired.

In our study a moderate correlation existed for patient height and patellar tendon lengths. The moderate correlation is likely a result of the wide range of values present for any given height. Even though only a moderate correlation exists (which is statistically significant), more notably, a difference in the mean patellar lengths within each height subgroup was clearly evident. This was also shown when the patients were grouped by gender. The mean patellar tendon lengths for each height group displayed in Tables 3 and 5 can be used as a guide when ordering BTB allograft. Because significant differences do exist between the groups, a surgeon can use the recipient patient's height and gender and Tables 3 and 5 to request a BTB allograft with a soft-tissue length at or below the mean for that group. In this manner, surgeons can avoid excessively long grafts in shorter patients and potentially decrease the risk of graft-tunnel mismatch.

Brown et al.[16] performed a similar study looking at 414 knees that underwent MRI and attempted to determine whether a correlation existed between patient height and either patellar tendon length or intra-articular ACL length. They noted a strong association

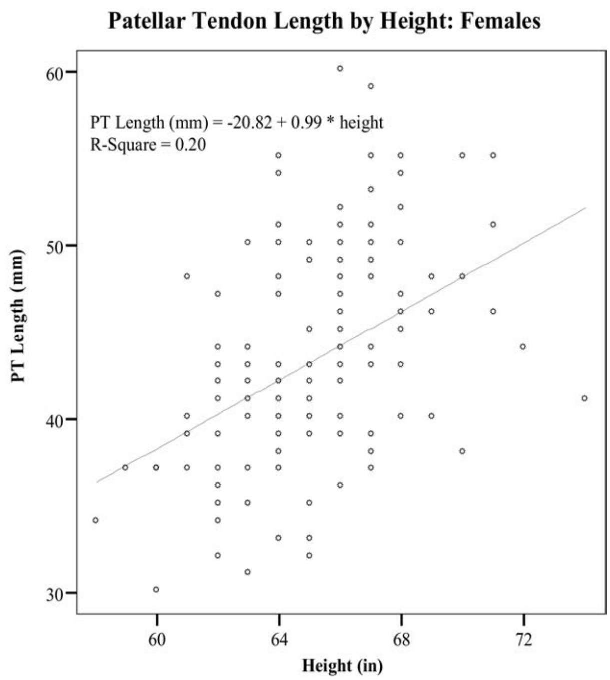

FIGURE 6. Scatter plot of patellar tendon (PT) length versus patient height for women. A regression equation was derived by use of the least-squares method.

between patient height and intra-articular ACL length; however, they reported no correlation between patient height and patellar tendon length or between patellar tendon length and intra-articular ACL length. They formulated an equation based on patient height that predicted the desired intra-articular ACL length. On the basis of this result, they added 10 mm to the predicted length to allow for some flexibility for femoral and tibial fixation and an additional 50 mm (25 mm for each bone plug).[16] They made recommendations for ACL tendon length based on the above methods with 3 groupings: (1) 5 feet to 5 feet 6 inches, 45 mm; (2) 5 feet 7 inches to 6 feet 1 inches, 50 mm; and (3) greater than 6 feet 1 inches, 55 mm.[16] Although their methodology seems reasonable, there is concern about the predicted graft length for groups 2 and 3 because the risk of graft-tunnel mismatch has been shown to be increased in grafts with soft-tissue length over 50 mm.[5] Furthermore, in our study in only men who were 74 inches (6 feet 2 inches) or taller did our mean patellar tendon length equal 50 mm or greater. This would suggest that the recommendations of Brown et al. would result in surgeons ordering grafts that are too long, resulting in increased risk of mismatch.

The possible disparity in estimated graft lengths may be based on the use of MRI to estimate ACL length. There are 2 concerns here. First, the ACL is not a perfectly sagittal structure. Therefore one may miscalculate the true intra-articular ACL length when measuring it with an MRI scan in a single plane. Second, although we attempt to re-create the native insertions during ACL reconstruction, the actual ACL graft reconstruction may not match the native ACL origin and insertion, thereby making the intra-articular distance for the graft different from the actual length of the ligament.

We are uncertain why the study of Brown et al.[16] noted no association between patellar tendon length and height. They used a similar study protocol and included a similar number of study subjects. It would be interesting to compare the gender differences in their study. Having noted an overall significant difference in mean patellar tendon lengths between genders, we evaluated the data in gender-specific groups. By grouping the heights into gender-specific data, we can more specifically address our goal of evaluating for potential differences in patellar tendon length and height, as well as examining their influence on ordering BTB allografts.

As previously mentioned, Denti et al.[8] studied patient height, patellar tendon length, and intra-articular ACL graft length in 50 endoscopically reconstructed patients and 9 cadaveric knees. They noted a weak correlation between patient height and patellar tendon length and no correlation between intra-articular ACL graft length and patient height. This would somewhat contradict the study of Brown et al.,[16] showing a strong correlation between intra-articular ACL length and patient height. However, Denti et al. measured ACL-reconstructed graft lengths (not native) in a small cohort. The mean length of the patellar tendon in their study was 46 mm, whereas in ours it was 45 mm. In the study by Shaffer et al.,[5] the mean patellar tendon length measured was 48 mm. However, again, their study only had a small number of subjects (34 patients). Brown et al. do point out that in both of these articles, the measured patellar tendons did show considerable variability.

In our study we observed broad ranges of values within each subgroup, but our confidence interval around the mean was fairly small for many of the groupings (Tables 1, 3, and 5). When one is requesting an appropriate BTB allograft based on the patient's height, the length of the patellar tendon should fall close to our measured mean for that group, thereby replicating a length similar to an autograft. Certainly, this will not eliminate graft-tunnel mismatch but, rather, may decrease its incidence associated with BTB allograft.

We see potential for using Tables 3 and 5 as guidelines for ordering BTB allograft. Although similar to the study of Brown et al.,[16] our study used patient height and gender to predict appropriate graft length based on patellar tendon length rather than intra-articular ACL length. When ordering grafts, one should measure the patient's height and, taking into account his or her gender, compare it with Tables 3 and 5 to determine the appropriate BTB length. This will more often than not result in a BTB allograft that should be similar to the mean length of a native patellar tendon for a patient of that specific height. This essentially circumvents the issue of shorter patients receiving grafts from tall donors. In addition, we believe that erring on the side of a shorter graft poses little risk whereas erring on the side of using a longer graft increases the risk of mismatch.

There are clearly some limitations to this study. First, even the use of an autograft does not eliminate the risk of graft-tunnel mismatch. However, studies indicate that mismatch is more frequent with allografts.[15] In addition, with the desire to continue to achieve lateral-wall placement of the femoral tunnel, increased obliquity of the tibial tunnel is required during an endoscopic technique. This increased tibial tunnel obliquity results in shortening of the tibial tunnel and increases the risk for mismatch. However, by incorporating these data with regard to mean tendon length, the surgeon can request an appropriate-length graft and decrease the increased risk of mismatch associated with allograft use.

A second criticism may be that the surgeon can simply measure the length of the patient's patellar tendon and order a matching graft length. However, on the basis of our data, this will not provide adequate information because, again, there is significant variability in tendon length among patients of similar height. For example, if a patient with a height of 5 feet 4 inches has a measured patellar tendon length that is equal to the mean patellar tendon length of a patient with a height of 6 feet 1 inch, then just using the measured patellar tendon from the patient with a height of 5 feet 4 inches rather than the mean value for patients of this height may result in a graft that is too long. This fact points to one of the strengths of this study: the number of subjects included. By having so many persons tested, we were able to obtain a good confidence interval around the mean patellar tendon length for each height group. Graft-tunnel mismatch may occur even when using autograft when patients fall at the high ends of the distribution curve for patellar tendon lengths, thereby having longer patellar tendon lengths than the average person of their height. By using the mean value, rather than taking a chance and measuring a single patient's patellar tendon length, one avoids the possibility of having measured a tendon that is at the extreme end of the distribution curve.

Another potential limitation of this article is why we did not measure actual ACL length and attempt to correlate it with patellar tendon length, which may show a more accurate correlation. First, we believed that accurate measurement of the ligament was not possible on a single MRI scan because of the obliquity of the ligament. Second, we believed that correlation with height would provide more clinically useful information as compared with correlation with intra-articular ligament length. Specifically, it is much easier for surgeons to use patient height to request a graft length because patient height is easily obtained information. Measurement of ACL length on MRI is complicated by scaling factors, as well as the difficulty in measuring ligament distance on a single MRI scan. Similarly, we elected to present patient height in inches and tendon length in millimeters to provide an easy, clinically applicable recommendation to surgeons when ordering allograft lengths.

Although there is a possibility of selection bias because all MRI scans were performed at 1 location, this study aimed to provided normative data on the distribution of patellar lengths that allows intergroup and intragroup comparisons. These data provide normative distributions based on patient height and patellar tendon length. Although there is considerable variation for any given height, a statistically significant correlation does exist, and there are significant differences in mean patellar tendon lengths within each height subgroup. On the basis of this study, when ordering BTB allografts, we recommend that tendon lengths less than or equal to the mean length for the gender-specific height subgroup be ordered to reduce the likelihood of construct mismatch.

CONCLUSIONS

This study showed that a correlation exists between patient height, gender, and patellar tendon length. Although variation occurs among patients of the same height, significant differences in mean patellar tendon lengths do exist between patients in different height subgroups.

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