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Prediction of semitendinosus–gracilis graft diameter in children and adolescents using anthropometric measures

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Abstract
Purpose The aim of this study was to evaluate whether the anthropometric and demographic measures of patients under 18 years can be used to predict the diameter of STG autograft in ACL reconstruction surgery.
Methods Retrospective series of 169 patients under 18 years (112 men, 57 women, average age 15.8 years) underwent ACL reconstruction surgery with STG autograft. We recorded anthropometric measures (weight, height and BMI), demographics (age and gender) and autograft diameter used. Correlation coefficients, linear regression and unpaired *t* test were used to determine the relationship between anthropometric/demographic variables and the diameter of the graft. *p* values <0.05 were considered statistically significant.
Results Correlation analysis showed a significant positive relation between height and graft diameter ($r = 0.483$, $p < 0.0001$) as well as between weight and graft diameter ($r = 0.248$, $p = 0.001$). However, age and BMI did not correlate with graft thickness ($r = 0.098$ and $p = 0.203$, $r = 0.009$ and $p = 0.905$, respectively). The mean graft diameter in men was 8.2 (range 6–10) and 7.5 in women (range 6–9), a difference that was statistically significant ($p < 0.001$).
Conclusions Prediction of the STG graft diameter according to the height of the patient is an easy and reliable method in children and adolescents. These data may provide relevant preoperative information about the need of an alternative graft source and can be useful when counselling patients.
Level of evidence IV.

Keywords Anterior cruciate ligament reconstruction · Semitendinosus–gracilis autograft · Graft diameter prediction · Anthropometric measures · Children · Adolescents

Introduction

Injuries to the anterior cruciate ligament (ACL) in children and adolescent patients are becoming frequent [1, 11, 14]. This is explained by several factors, including an increasing participation of children and adolescents in contact sports activities, a better understanding of the disease by health teams and the availability of better diagnostic methods [1].

Multiple options for graft choice exist to perform ACL reconstruction, including allografts and autografts such as the bone-patellar tendon-bone, quadriceps tendon and hamstring tendon. These choices have inherent advantages and disadvantages that must be considered before clinical use. Semitendinosus–gracilis (STG) autograft has been used with an increasing frequency because of good clinical results, low donor site morbidity and improved fixation methods [4, 8, 10, 20].

The diameters of the STG tendons have a high anatomical variability [16]. The difficulty in predicting its diameter can affect their use as grafts and hence possibly the result of the surgery. In a recent systematic review, Conte et al. [6] determined that ACL reconstruction with a quadrupled-strand hamstring autograft with a diameter equal to or larger than 8 mm has less risk of failure compared with thinner grafts. This systematic review considered studies

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of patients between 11 and 61 years. Furthermore, the anatomical features of the STG graft tendons are essential when selecting a type of femoral or tibial fixation [9]. For these reasons, it seems relevant to the surgeon to have tools to predict graft diameter preoperatively and thus do a better surgery plan. This seems to be particularly relevant in children and adolescent patients due to the significant increase in the rate of ACL reconstructions in the last decades and due to the great variability of this population in their stages of growth and development [7].

In the literature, there are many studies correlating the anatomical characteristics of the STG graft with anthropometric and demographic measures of the patient [2, 3, 5, 12, 15, 17, 19, 21–23]. However, these studies have been performed in adult population and, according to our knowledge, no data exist in children and adolescent population, which it is the novelty of this work. The aim of this study was to evaluate whether the anthropometric and demographic measures of patients under 18 years can be used to predict the diameter of STG autograft in ACL reconstruction surgery.

Materials and methods

The Institutional Review Board of Clínica Alemana Santiago (Chile) approved this retrospective study. Inclusion criteria consisted of ACL reconstruction with STG autograft and patients aged less than 18 years at the time of the surgery. We searched our departmental orthopaedic database and identified 169 patients (112 men and 57 women) from March 2005 to October 2013.

Anthropometric and demographic measures including height (m), weight (kg), BMI (kg/m^2), age (years) and gender were documented. All measurements were taken by the same team of technicians to standardize data collection and maximize measurement precision. The information about the STG autograft diameter (mm) was obtained from the surgical records and is described below.

All STG autografts were harvested in a similar manner, as described by Wolf [24]. After obtaining the STG tendons, the diameter of the graft was measured at a side table with a soft tissue graft caliper (Arthrex®, Naples, FL, USA) with 0.5-mm increments between holes. The same team performed the diameter measurements in a quadruple graft arrangement (Fig. 1).

Statistical analysis

To detect a positive correlation between parameters ($r = 0.3$) with a 5 % significance level ($\alpha = 0.05$) and 90 % power ($\beta = 0.1$), the sample size calculation was 113 patients. Correlation coefficients (Pearson's r), linear regression and unpaired t test were used to determine the relationship between the outcome variable (STG autograft diameter) and the predictor variables (height, weight, BMI, gender and age). p values less than 0.05 were considered statistically significant. Statistical analysis was done using Prism 6 program (GraphPad Software Inc, California, USA).

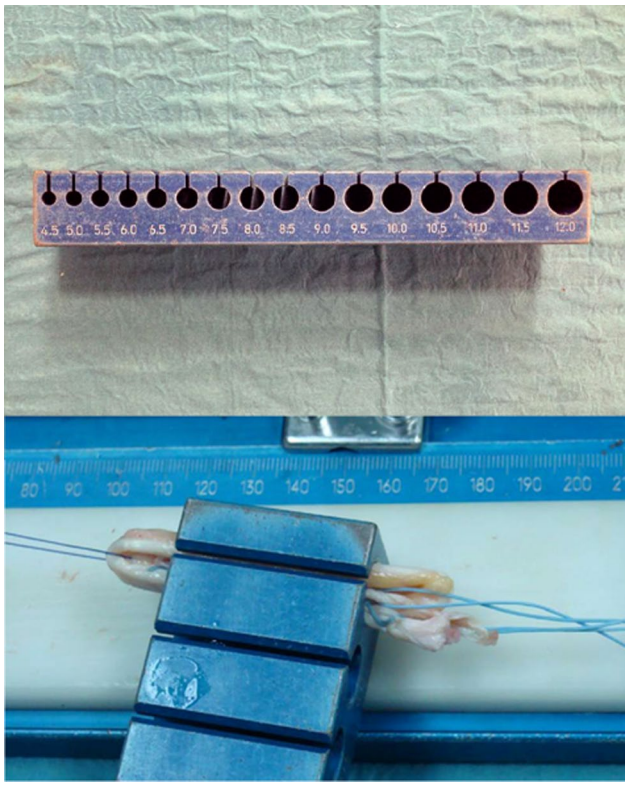

Fig. 1 Intraoperative data collection of STG autograft diameter with soft tissue graft caliper

Table 1 Demographic and anthropometric measures (mean ± SD) in general and by gender

	Total	Males	Females	*P* value*
STG graft diameter (mm)	7.9 ± 0.8	8.2 ± 0.8	7.5 ± 0.7	<0.0001
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.6 ± 0.1	<0.0001
Weight (kg)	64.3 ± 12.7	68 ± 13.1	57.1 ± 7.7	<0.0001
BMI (kg/m^2)	22.1 ± 3.2	22.4 ± 3.5	21.5 ± 2.6	n.s.
Age (years)	15.8 ± 1.1	15.8 ± 1.2	15.7 ± 1.1	n.s.

STG semitendinosus–gracilis, *BMI* body mass index

* p values correspond to unpaired t test between measures in males and females

Table 2 Correlation coefficients (Pearson) between anthropometric/demographic variables and STG graft diameter

	STG graft diameter (mm)			
	r	*p*	95 % CI	R^2
Height (m)[a]	0.483	<0.0001	0.359 to 0.591	0.23
Weight (kg)	0.248	0.001	0.101 to 0.385	0.06
BMI (kg/m^2)	−0.009	n.s.	−0.159 to 0.142	0.00008
Age (years)	0.098	n.s.	−0.053 to 0.203	0.009

STG semitendinosus–gracilis, *BMI* body mass index

[a] Regression analysis yielded the following predictive equation: STG graft diameter = 4.465 × height (m) + 0.3336

Results

The mean age of the patients was 15.8 ± 1.1 years (range 12–17). The male to female ratio was almost 2:1 (66.3 vs. 33.7 %). The average weight of the patients was 64.3 ± 12.7 kg (range 37.5–109). The mean height was 1.7 ± 0.1 m (range 1.46–1.91). Average BMI was 22.1 ± 3.2 kg/m^2 (range 15.8–34.7). The average STG autograft diameter was 7.9 ± 0.8 mm (range 6–10). Summary of all data is presented in Table 1.

We found a positive relation between height and graft diameter ($r = 0.483$, $p < 0.0001$) as well as between weight and graft diameter ($r = 0.248$, $p = 0.001$). However, age and BMI did not correlate with STG autograft diameter ($r = 0.098$, $p < 0.05$ and $r = -0.009$, $p < 0.05$, respectively) (Table 2). From linear regression, we constructed the following equation to predict the diameter of the graft based on the height of the patient:

$$\text{STG graft diameter} = 4.465 \times \text{height}\,(m) + 0.3336$$

According to this equation, patients with height less than 1.49 m are at greatest risk of a STG graft diameter less than 7 mm (Fig. 2).

While a correlation between age and the diameter of the graft was not observed, when analysing the results in two age groups (12–14 vs. 15–17 years), a difference was observed in graft diameter; however, it was not statistically significant ($p < 0.05$).

When performing an analysis of the diameter of the graft according to gender, it was observed that the diameter of the graft in men was 8.2 ± 0.8 mm, while in women it was 7.5 ± 0.7 mm ($p < 0.001$). The main variable related to the diameter of the graft, both male and female, was the height of the patient ($r = 0.375$, $p < 0.0001$ and $r = 0.368$, $p = 0.004$) (Table 3). No significant correlation between all other anthropometric variables and graft diameter was observed in the analysis in males and females separately (Table 3).

Discussion

The most important finding of our study was to find a positive correlation between height and weight with the STG autograft diameter in patients under 18 years undergoing ACL reconstruction.

The ACL injury in children and adolescents has increased in the recent times, and thus, there is a need for a surgical treatment in these patients [1, 11, 14]. The STG autograft has become a popular choice in ACL reconstruction; however, an increase in the failure rate has been observed in younger patients with smaller final graft sizes [6, 13]. For this reason, it seems relevant to the surgeon to have tools to predict graft diameter preoperatively and thus do a better surgery plan. There are reports that have evaluated the use of anthropometric measures as predictors of graft diameter in adults [2, 3, 5, 12, 15, 17, 19, 21–23]. However, according to our knowledge, there are no reports of this kind in the paediatric population.

In our series, less than 8-mm graft diameter was observed in 31.9 % of patients. This was particularly evident among women, in which 52.6 % of them had a STG graft less than 8 mm in diameter (data not shown). This is critical because in a recent systematic review, Conte et al. [6] showed that patients with graft diameter less than 8 mm had a higher risk of failure than those with ≤8 mm diameter. While this has been accepted for adults, it seems relevant for us to consider it in skeletally immature patients, since they have a higher rate of revision surgery, which could be related to an insufficient graft diameter. According to our data, in a significant percentage of children and adolescents, it would be necessary to use a technique to increase the diameter of the graft in ACL reconstruction, using either a tripled autograft or a hybrid graft (auto-/allograft).

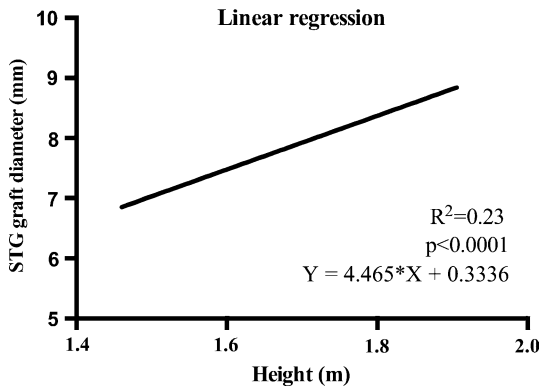

Fig. 2 Linear regression analysis plot showing relationships between height and STG graft diameter. R^2 correlation coefficient, *p* value and equation obtained are included. *STG* semitendinosus–gracilis

Table 3 Correlation coefficients (Pearson) by gender

	STG graft diameter (mm)							
	Male				Female			
	R	*P*	95 % CI	R^2	*R*	*P*	95 % CI	R^2
Height (m)*	0.375	<0.0001	0.203 to 0.524	0.14	0.368	0.004	0.119 to 0.574	0.135
Weight (kg)	0.127	n.s.	−0.059 to 0.306	0.016	0.169	n.s.	−0.095 to 0.412	0.028
BMI (kg/m^2)	−0.041	n.s.	−0.225 to 0.145	0.001	−0.064	n.s.	−0.32 to 0.199	0.004
Age (years)	0.135	n.s.	−0.051 to 0.313	0.018	−0.021	n.s.	−0.28 to 0.24	0.0004

STG semitendinosus–gracilis, *BMI* body mass index

Our results showed that in children and adolescents, individual anthropometric variables as height and weight were correlated with the STG autograft diameter. We found that height was the main predictor for graft diameter, which is similar to that reported by previous studies in adults [5, 12, 15, 17, 19, 21, 23]. However, BMI and age did not show correlation with the graft diameter.

Tuman et al. [23], in a retrospective series of 106 patients (32.9 ± 13.0 years age), found that between anthropometric measures assessed, the strongest correlation with the diameter of the graft was the height. In the conclusions, the authors note that patients with height less than 140 cm have a higher risk of a graft less than 7 mm in diameter. These results are similar to our findings. From the equation obtained in linear regression analysis, it can be predicted that patients with height less than 149 cm are at increased risk of having a graft lesser than 7 mm in diameter and therefore in these patients might consider graft augmentation. In the same line, Treme et al. [22] validated the equation obtained from a previous work of the same group, in a prospective series of 50 patients (31.6 ± 13.6 years). In this study, the predicted graft diameters were, on average, 0.5 ± 0.5 mm different from graft diameters obtained during surgery. This corresponds to a 6.7 % error rate in predicting graft diameter from patient height. The value of R^2 in equation obtained in the mentioned study was 0.13, while ours was 0.23. This suggests that the predictive model according to the height of the patient proposed in this study would be even better.

The data about the correlation between BMI and graft diameter in ACL reconstruction are controversial. In a series of 132 patients (average age 17.9 years), Boisvert et al. [2] found a significant correlation between BMI and hamstring graft diameter. However, the authors showed that this correlation was stronger in patients with high BMI. Thus, one would predict a greater graft diameter in patients with high BMI but not a graft diameter <7 mm in patients with a low BMI. In our study, we found no correlation between BMI and the diameter of the graft. What we saw was a positive correlation between patient weight and graft diameter. This would indicate that a patient with a greater weight and a specific BMI would have a greater graft diameter than a patient with a lower weight and the same BMI. However, in a patient with a specific weight and a high BMI, the graft diameter could be the same as that of a patient with the same weight and a low BMI.

It has been reported that women have greater clinical laxity after an ACL reconstruction [18]. There are several theories that explain this, one of which would be that women have smaller tendons than men and therefore grafts of smaller diameters. In our study, we found that men had greater graft diameter than women (8.2 ± 0.8 vs. 7.5 ± 0.7 mm, $p < 0.001$). That difference is comparable with that reported in the literature [3, 17, 19, 21]. Schwartzberg et al. [19] showed a statistically significant difference in the STG graft diameter between men and women, with values very similar to those reported in this study (8.17 vs. 7.52).

The main strength of this study is to be the first series that attempts to determine a way to predict the STG graft diameter in children and adolescents. Our study has some limitations. The first is to be a retrospective study, and therefore, their validity in a prospective series must be tested. The second is that the measurements and predictions presented here are based on chronological age and not physiological age. This is relevant since two patients of the same age may have different physiological states and therefore require different reconstruction techniques and different graft diameters needs. Finally, another weakness is the lack of comparison with another prediction method as ultrasound or MRI.

Conclusion

In conclusion, the prediction of the STG graft diameter according to the height of the patient is an easy and reliable method in children and adolescents. The clinical relevance of this study is to detect preoperatively, those patients who present an insufficient autograft diameter. This could help in surgical planning and assess the need for another graft source or autograft augmentation.

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