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Proximal and mid-thigh fascia lata graft constructs used for arthroscopic superior capsule reconstruction show equivalent biomechanical properties: an in vitro human cadaver study

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A R T I C L E I N F O

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Fascia lata
Autograft
Minimally invasive
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Harvest
Stiffness

Level of evidence: Basic Science Study; Biomechanics

Background: The proximal fascia lata (FL) graft construct used for arthroscopic superior capsule reconstruction (ASCR) is openly harvested, whereas the mid-thigh FL graft construct is minimally invasively harvested. The purpose of the current study was to compare the biomechanical properties of proximal thigh and mid-thigh-harvested FL graft constructs used for ASCR. The hypothesis was that, despite the different morphological characteristics of the proximal thigh and mid-thigh FL graft constructs used for ASCR, their biomechanical properties would not significantly differ. This information may assist orthopedic surgeons in the choice of the harvest location, technique, and type of graft construct for ASCR.

Methods: Forty FL specimens, 20 proximal thigh and 20 mid-thigh, were harvested from the lateral thighs of 10 fresh human cadavers (6 male, 4 female; average age, 58.60 ± 17.20 years). The thickness of each 2-layered proximal thigh and 6-layered mid-thigh FL graft construct was measured. Each construct was mechanically tested in the longitudinal direction, and the stiffness and Young's modulus were computed. Data were compared by Welch's independent t-test and analysis of variance, and statistical significance was set at $P < .05$.

Results: The average thickness of the proximal thigh FL graft construct (7.17 ± 1.97 mm) was significantly higher than that of the mid-thigh (5.54 ± 1.37 mm) [$F(1,32) = 7.333$, $P = .011$]. The average Young's modulus of the proximal thigh and mid-thigh graft constructs was 32.85 ± 19.54 MPa (range, 7.94 – 75.14 MPa; 95% confidence interval [CI], 23.71 – 42.99) and 44.02 ± 31.29 MPa (range, 12.53 –120.33 MPa; 95% CI, 29.38 – 58.66), respectively. The average stiffness of the proximal thigh and mid-thigh graft constructs was 488.96 ± 267.80 N/mm (range, 152.96 – 1086.49 N/mm; 95% CI, 363.63 – 614.30) and 562.39 ± 294.76 N/mm (range, 77.46 – 1229.68 N/mm; 95% CI, 424.44 – 700.34), respectively. There was no significant difference in the average Young's modulus or stiffness between the proximal thigh and mid-thigh graft constructs ($P = .185$ and $P = .415$, respectively).

Conclusion: Despite the different morphological characteristics of the proximal thigh and mid-thigh FL graft constructs used for ASCR, their Young's modulus and stiffness did not significantly differ.

Ethical committee approval was provided by the local ethics committee of Instituto Nacional de Medicina Legal e Ciências Forenses (no. CE–23/2019).

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Arthroscopic superior capsule reconstruction (ASCR) was originally proposed by Mihata et al, who used the fascia lata (FL) to reconstruct the superior capsule, thereby stabilizing the glenohumeral joint to prevent superior humeral head migration[18] and reversing pseudoparalytic shoulders in irreparable rotator cuff tears (IRCTs).[15] Originally, the FL autograft was harvested through an open approach to the proximal lateral thigh. Later, a modification of the technique was proposed by de Campos Azevedo,[1,5] who harvested the FL autograft through a minimally invasive approach to the middle of the lateral thigh. The clinical studies on ASCR using either the proximal thigh– or mid-thigh–harvested FL autograft reported good shoulder outcomes in IRCTs.[2,5,13,15] However, the morphological characteristics and elastic properties of the FL have been shown to be site dependent.[21] The lateral FL has been shown to be significantly thicker than other sites (0.8 ± 0.2 mm versus 0.2 – 0.3 mm in other sites),[21] and the proximal region of the lateral FL is capable of undergoing elongation that is significantly greater than that of the middle and distal regions.[26] Therefore, the FL harvesting site may influence the biomechanical behavior of the resultant graft construct. Studies comparing the biomechanical properties between the proximal thigh– and mid-thigh–harvested FL graft constructs used for ASCR are lacking. Knowledge of how the mid-thigh FL graft, which is minimally invasively harvested, compares biomechanically with the proximal graft, which is openly harvested, may assist orthopedic surgeons in the choice of the location, harvesting technique, and type of graft construct for ASCR.

The purpose of this study was to compare the morphological and biomechanical properties of the proximal thigh– and mid-thigh–harvested FL graft constructs used for ASCR. The hypothesis was that, despite the different morphological characteristics of the proximal thigh and mid-thigh FL graft constructs used for ASCR, their biomechanical properties would not significantly differ.

Materials and methods

Study design

Historical data were not available for either the Young's modulus or the stiffness of the FL constructs, and pilot studies were not conducted. Therefore, the G*Power 3.1[7] was used for the *a priori* power analysis, the independent 2-tailed t-test was used for the sample size calculation, and the study was designed to achieve a power of 80% at a significance level of $P < .05$, with a beta = 0.2, alpha = 0.05, and Cohen's d effect size = 0.9. The number of subjects required to show a difference between groups was n = 20. The experimental design of the current study was approved by the local ethics committee of Instituto Nacional de Medicina Legal e Ciências Forenses (CE–23/2019) for an anticipated sample size of 40 FL specimens.

From April 12, 2019 through January 31, 2020, 40 specimens of FL were harvested from 10 unembalmed fresh (≤ 72 hours postmortem) adult human cadavers that had both thighs previously intact. A total of 20 thighs were harvested: 12 thighs from 6 males, and 8 thighs from 4 females; average age, 58.6 ± 17.20 years; range, 30 – 88 years. On the same day that each eligible fresh adult human cadaver was available, 4 specimens of FL were harvested, prepared, and put through morphological and mechanical tests for a total period of 6 hours. No specimens were excluded from the study.

Specimen preparation

The specimens of the FL were collected from 2 locations: the proximal part (20 specimens) and the middle part (20 specimens) of the lateral thigh.

The direction from the greater trochanter to the lateral femoral condyle was defined as the longitudinal direction and the direction orthogonal to it was defined as the transverse direction. The proximal thigh specimens were harvested according to the technique described in the studies by Mihata et al,[14,15] beginning 1 cm distal to the greater trochanter. Each proximal thigh specimen was 120 × 30 mm in the longitudinal (proximal–distal) x transverse (anterior–posterior) directions, and in the anterior–posterior direction, the harvesting was centered at the level of the lateral femoral intermuscular septum, which was included in the harvest. The mid-thigh specimens were harvested according to the technique described in the studies by Angelo and de Campos Azevedo[1] and by de Campos Azevedo et al,[5] except that the longitudinal open cutaneous approach was used instead of the minimally invasive cutaneous approach. Each mid-thigh graft was harvested 15 cm distal to the anterosuperior iliac spine, 10 cm proximal to the lateral femoral epicondyle, and 4 cm anterior to the lateral femoral intermuscular septum and was 200 × 30 mm in the longitudinal x transverse directions. The intermuscular septum was not included in the harvest. Figure 1 depicts the FL harvesting techniques used in the current study.

The proximal thigh and mid-thigh FL grafts and the final constructs were harvested and prepared by 2 shoulder surgeons equally experienced in each technique (C.I.d.C.A. and A.C.L.P.G.A.). Adipose and connective tissues were manually removed from the specimens using a rugine. After the FL specimens were harvested, the morphological tests were conducted, followed by mechanical tests. The specimens were kept moist throughout the morphological testing and until the mechanical tests were conducted (described below) by pipetting .9% sodium chloride solution onto them.

Morphological tests

The morphological tests were conducted by the 2 shoulder surgeons (C.I.d.C.A. and A.C.L.P.G.A.). The thickness of each specimen (single layer) of FL was measured using a digital caliper (MacFer® D304, Tavares & E. Faria Tavares, Portugal; precision, 0.02 mm) at 6 different points (anterior–proximal, anterior–middle and anterior–distal; posterior–proximal, posterior–middle and posterior–distal parts) that were randomly selected at each point, and the average value was calculated as the representative of the thickness of that sample.[21] To avoid the deformation of the tissue due to an applied pressure by the caliper, the flat part of the caliper was used, and close attention was paid to provide the lowest possible pressure to the sample.[21] Each step of the proximal FL graft construct preparation was performed according to the technique described in the studies by Mihata et al.[14,15] The proximal thigh FL specimens were folded 1 time, and the harvested lateral femoral intermuscular septum was included between the 2 layers of the FL.[14,15] To avoid graft delamination, the layers and the septum were then united peripherally and mattress suturing in the middle of the graft was performed. Braided absorbable sutures (No. 2 coated Vicryl®, Ethicon) were used. The final thickness of each graft construct sample was measured by C.I.d.C.A. and A.C.L.P.G.A. using the caliper at 6 randomly selected points, and the average value was calculated to represent the thickness of each graft construct sample. Each step of the mid-thigh graft construct preparation was performed according to the technique described in the studies by Angelo and de Campos Azevedo[1] and de Campos Azevedo et al.[5] Each mid-thigh FL specimen was folded 3 times (once in the anterior–posterior direction, and twice in the proximal–distal direction) producing a final 6-layered mid-thigh FL graft construct.[1,5]

The layers of the FL were then united peripherally with a continuous suture (No. 2 HiFi®, Conmed), and the final thickness of the graft construct was measured with the caliper (according to the same procedure described previously). Figure 2 shows the final appearance of the proximal thigh and mid-thigh graft construct samples after folding and suturing the FL layers.

Tensile tests

The tensile tests were conducted by the same technicians (C.Q., S.G., and J.F.), at the Department Mechanical Engineering of Instituto Superior Técnico de Lisboa, on the same day each graft construct was prepared, and in a random order. The proximal thigh and mid-thigh graft construct samples were tested in the longitudinal direction using a single Instron 5544 universal testing machine (Instron) integrated with the Standard Video Extensometer 1 (SVE 1, Instron, USA) and a 2 kN load cell (2530-418, Instron). The proximal and distal ends of each graft construct sample were positioned centrally between the 2 clamps of the pneumatic action grips (BioPuls Submersible Pneumatic Side Action Grips, Instron). To prevent slippage of the sample during loading, 2 pieces of sandpaper were fixed to each clamp using double-sided duct tape.[21] After applying a preload of 3-5 N,[10] the length, width, and thickness of each sample were measured using a digital caliper (Dexter®, France; precision, 0.01 mm). Without compressing the sample with the caliper, cross-sectional measurements were performed at 6 randomly selected sections where the optical strain measurements were to be performed.[21] The average values were calculated as the representative width and thickness of each graft construct sample and were used to compute the cross-sectional area, assuming a rectangular shape.[21,24] Strain-controlled tensile tests were conducted at a strain rate of 0.5%/s for cycling grip-to-grip strains of 12%, 24%, and 30%. Incremental cycling strains were considered to ensure the measurement of the specimens' linear behavior without slippage, which usually occurred for loads above 300 N. For each cycling strain test, 5 loading-unloading cycles were conducted. At the end of each cycling strain test, the samples rested for 180 seconds.[6] The SVE strain (mm/mm) and load (N) of the samples were recorded using the software Bluehill 3 (Instron). Figure 3 illustrates the experimental setup.

Experimental data analysis

Of the 5 loading-unloading cycles conducted for each cycling strain test, the first 2 cycles were considered preconditioning and the last 3 cycles were evaluated.[6] The cycling strain test analyzed for each sample was selected based on the average maximum load (N) reached during these last 3 cycles.

The stiffness and Young's modulus of each sample were computed using a custom Matlab script (Matlab, USA). To determine the stiffness (N/mm) in the toe and linear regions, a bilinear curve fit was applied to the displacement-load data for each loading-unloading cycle.[4; 24] The displacement (mm) was calculated through the multiplication of the SVE strain by the initial length measured by the SVE. The stiffness of each sample was determined in the linear region in each of the last 3 cycles, and the average value was calculated as the representative stiffness for that sample. The Young's modulus was computed as:

$$E(MPa) = \frac{k \times L_0}{A}$$

where k is stiffness, L_0 is the initial length according to the SVE, and A is the cross-sectional area.

Statistical analysis

The independent 2-sample 2-tailed Welch t-test and one-way and factorial analyses of variance (Excel for Mac software, version 16.35 [Microsoft, Redmond, WA], and SPSS software, version 26 [IBM, Armonk, NY]) were used for the statistical analyses. The thickness of each single FL layer, the thickness of the graft construct, the stiffness of the graft construct, and the Young's modulus of the graft construct were the dependent variables; the location of the harvest (proximal or mid-thigh), the side of harvesting (left or right thigh), and the sex of the subject (male or female) were the independent variables. The Bonferroni correction to adjust for multiple comparisons was not necessary because there were fewer than 3 groups. Data are presented as means ± standard deviations of the means, with ranges. Statistical significance was defined as $P < .05$.

Results

Morphological results

As shown in Table I and Table II, the average thickness of the proximal thigh–harvested single FL layer (graft prior to folding) and final FL graft construct was significantly higher than that of the mid-thigh. Table II shows the average thickness of a single layer of the FL and of the final graft construct according to sex, side, and location of the harvest. There was no statistically significant 3-way interaction between sex, side, and location of the harvest with regard to the thickness either of the single FL layer, $F(1,32) = 0.769$, $P = .387$, or of the final graft construct, $F(1,32) = 1.098$, $P = .303$, but there was a statistically significant difference between the proximal thigh and mid-thigh harvest locations with regard to the thickness both of the single FL layer, $F(1,32) = 23.753$, $P < .001$, and of the final graft construct, $F(1,32) = 7.333$, $P = .011$.

Mechanical results

The proximal thigh– and mid-thigh–harvested graft constructs had similar average Young's modulus and stiffness (Table III and Figure 4). There was no statistically significant 3-way interaction between sex, side, and location of the harvest with regard to either the graft construct's Young's modulus, $F(1,32) = 0.895$, $P = .351$, or its stiffness, $F(1,32) = 0.400$, $P = .532$.

The initial length according to the SVE (L_0) and the cross-sectional area (A) used to calculate the Young's modulus of each graft construct are summarized in Table IV.

Discussion

The main findings of this study were that the average values of the stiffness and Young's modulus did not significantly differ between the 2 types of FL graft construct, despite the greater average thickness of a single layer and of the final construct of the proximally harvested versus the mid-thigh–harvested FL. In the present study, while the mid-thigh FL single layers were found to have an average thickness comparable to that of the lateral FL found in the study by Otsuka et al[21] (0.87 ± 0.51 mm and 0.8 ± 0.2 mm, respectively), the average thickness of proximal FL single layers was found to be higher (2.37 ± 1.21 mm). This increased thickness of the proximal FL single layers may be explained by the contribution of lateral femoral intermuscular septum, which is included in the harvest of the proximal graft when performed according to the technique described in the studies by Mihata et al.[14,15] Furthermore, the increased thickness of both proximal thigh and mid-thigh final graft constructs results from the folding of the FL layers included in

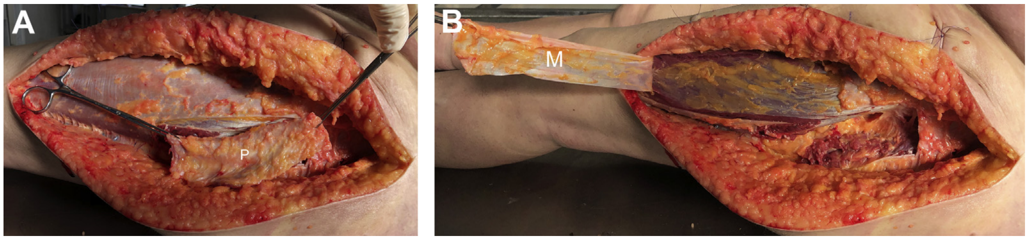

Figure 1 Picture of the (**A**) proximal thigh and (**B**) mid-thigh harvest of the fascia lata (FL) of the left thigh of subject 1. *P*, proximal thigh-harvested FL; *M*, mid-thigh-harvested FL.

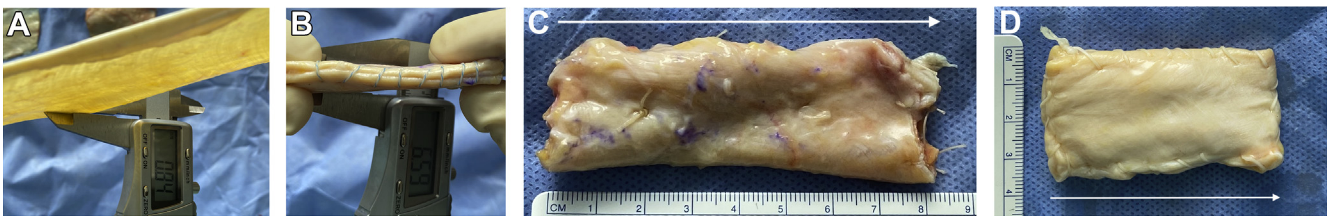

Figure 2 Fascia lata (FL) specimens. Measurement of the mid-thigh FL (**A**) single layer and (**B**) final 6-layered thrice-folded graft construct using the digital caliper, positioned at one of the 6 random points. (**C**) Final proximal thigh graft construct with the mattress suturing in the middle of the graft and peripheral sutures (white-colored sutures), and (**D**) final mid-thigh graft construct with peripheral suturing, showing that the FL layers are folded so that the FL fibers are longitudinally directed (the *white arrows* point from proximal to distal in each graft construct).

the constructs, and the increased thickness of the final proximal construct results mostly from the inclusion of the intermuscular septum. Theoretically, the tension may be unevenly distributed either across the folded layers of FL or the intermuscular septum, despite using a meticulous and reproducible suturing technique; therefore, some of the FL layers or the septum may not have contributed to the stiffness of the whole final graft construct. This might explain why the proximal graft construct, while thicker than the mid-thigh graft construct, does not show increased stiffness. In the biomechanical study conducted by Mihata et al,[16] the authors tested graft constructs that were 4- and 8-mm thick based on the information that the thickness of the superior shoulder capsule was 4.4- to 9.1-mm at the attachment of the greater tuberosity; it was hypothesized that increased graft thickness would lead to increased stiffness, which could explain the decreased superior humeral head translation shown when the thicker graft construct was used. In the study by Nimura et al,[20] it was stated that the superior capsule had an average width of attachment to the greater tuberosity of 4.4 to 9.1 mm, which is different from stating that the thickness of the superior capsule ranged from 4.4 to 9.1 mm throughout. Indeed, in the study conducted by Momma et al,[19] in a color representation through 3-dimensional micro-computed tomography images of the variations in capsular thickness distribution, it was shown that the superior parts of the capsule were consistently thinner, ranging from 0.1 to 0.5 mm, whereas at the glenoid and humeral attachment sites the superior, inferior and anterior parts of the capsule were thicker, ranging from 0.5 to 8.0 mm. The results of the present study suggest that the decreased superior translation of the humeral head shown in the biomechanical studies that used the SCR cadaveric models might have been explained by the influence of other external variables. Further studies should be conducted to compare graft constructs using the

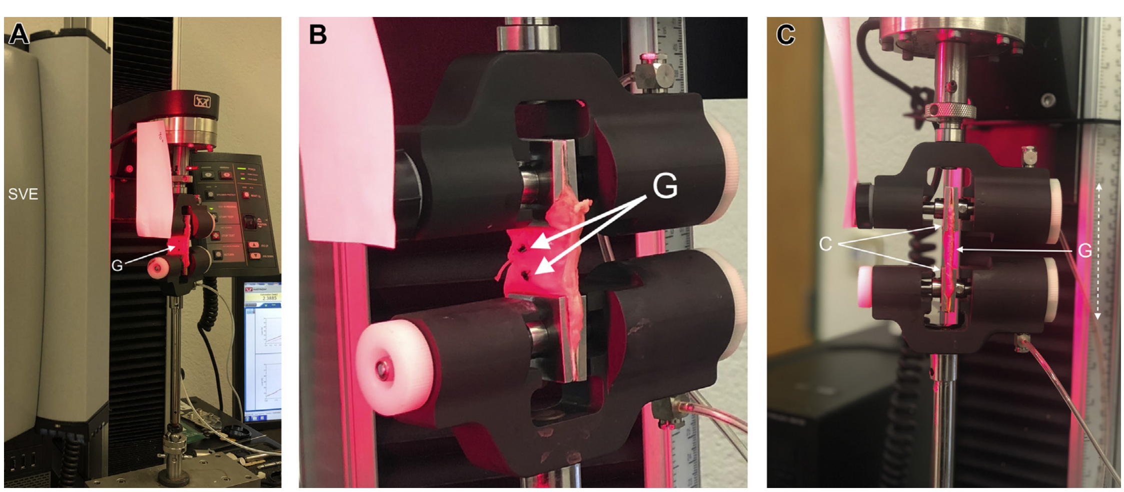

Figure 3 Experimental setup. (**A**) Universal testing machine with the Standard Video Extensometer: the graft construct sample is centrally placed between the pneumatic grips; (**B**) the *white arrows* point to the markings of the 2 control points on the graft construct used for the optical strain measurement. (**C**) The proximal and distal ends of the graft construct are clamped on the pneumatic action grips of the universal testing machine, and the *dashed arrow* represents the longitudinal direction of the fibers of the graft and of the test. *C*, clamps of the pneumatic action grips; *G*, graft construct; *SVE*, Standard Video Extensometer.

Table I
Characteristics of the cadavers and harvested fascia lata specimens.

	Subject	Age, y	Sex	Harvest side	Harvest location: Proximal thigh (N = 20)	Harvest location: Mid-thigh (N = 20)
					Thickness of the fascia lata single-layer specimen, mm	
	1	54	Female	Left	0.74	0.32
	1	54	Female	Right	0.89	0.44
	2	66	Female	Left	1.51	0.79
	2	66	Female	Right	1.05	0.73
	3	55	Female	Left	1.64	0.65
	3	55	Female	Right	1.50	0.99
	4	30	Male	Left	2.88	1.80
	4	30	Male	Right	2.05	0.85
	5	58	Male	Left	2.92	2.33
	5	58	Male	Right	3.72	0.97
	6	55	Male	Left	2.52	0.44
	6	55	Male	Right	1.34	0.18
	7	46	Male	Left	3.08	0.82
	7	46	Male	Right	3.54	0.72
	8	88	Female	Left	4.46	1.39
	8	88	Female	Right	2.28	1.10
	9	87	Male	Left	4.77	1.03
	9	87	Male	Right	3.65	0.67
	10	47	Male	Left	1.08	0.63
	10	47	Male	Right	1.80	0.50
Mean		58.60			2.37	0.87
SD		17.20			1.21	0.51
Minimum		30			0.74	0.18
Maximum		88			4.77	2.33
P value*					< 0.001	

SD, standard deviation.
* Welch's T-test.

Table II
Average thickness of a single layer of the fascia lata and of the final graft construct according to sex, side, and location of the harvest.

Sex	Harvest side	Harvest location	Thickness, mean ± SD, mm: FL single layer	Thickness, mean ± SD, mm: FL graft construct	N
Male	Right	Proximal	2.68 ± 1.07	7.72 ± 2.73	6
		Mid-thigh	0.65 ± 0.28	5.15 ± 1.31	6
	Left	Proximal	2.87 ± 1.18	6.66 ± 1.66	6
		Mid-thigh	1.17 ± 0.74	5.45 ± 1.38	6
	Total	Proximal	2.78 ± 1.08	7.19 ± 2.23	12
		Mid-thigh	0.91 ± .60	5.30 ± 1.29	12
Female	Right	Proximal	1.43 ± 0.62	6.67 ± 1.41	4
		Mid-thigh	0.81 ± 0.29	5.96 ± 0.50	4
	Left	Proximal	2.09 ± 1.63	7.63 ± 1.97	4
		Mid-thigh	0.79 ± 0.45	5.87 ± 2.22	4
	Total	Proximal	1.76 ± 1.20	7.15 ± 1.67	8
		Mid-thigh	0.80 ± 0.35	5.91 ± 1.50	8
Total	Right	Proximal	2.18 ± 1.09	7.30 ± 2.26	10
		Mid-thigh	0.71 ± 0.28	5.47 ± 1.10	10
	Left	Proximal	2.56 ± 1.35	7.05 ± 1.75	10
		Mid-thigh	1.02 ± 0.64	5.62 ± 1.66	10
	Total	Proximal	2.37 ± 1.21	7.17 ± 1.97	20
		Mid-thigh	0.87 ± 0.51	5.54 ± 1.37	20

FL, fascia lata; *SD*, standard deviation.

width of the attachment to the greater tuberosity as the independent variable (4- versus 9-mm-wide attachments).

ASCR using either the openly harvested proximal thigh FL autograft[13,15] or the minimally invasively harvested mid-thigh FL autograft[2,5] has been shown to produce good clinical outcomes, and the present study validates the biomechanical equivalence of the 2 types of FL graft constructs with regard to the stiffness and Young's modulus. Orthopedic surgeons and patients may find the mid-thigh harvesting of the graft advantageous versus the open harvesting technique because the mid-thigh FL autograft can be minimally invasively harvested using a reproducible technique,[3,25] with a low donor site morbidity.[1] This mid-thigh harvest location avoids the risk of damaging both the tensor FL muscle proximally and the iliotibial band distally and posteriorly, thereby preserving both the important postural function of the iliotibial tract and tensor FL, which help extend, abduct, and laterally rotate the hip, as well as preserving the role of the iliotibial band as an anterolateral knee stabilizer.[8] Furthermore, the minimally invasive approach to the mid-thigh is not more technically demanding than the open approach to the proximal thigh, requiring only simple and widely available orthopedic instruments.[1]

The present study has several strengths. First, the proximal thigh— and mid-thigh—harvested graft construct groups were equally sized with regard to the sex and the age of the subjects,

Table III
Young's modulus and stiffness of each graft construct.

Subject	Harvest side	Young's modulus, MPa		Stiffness, N/mm	
		Proximal thigh	Mid-thigh	Proximal thigh	Mid-thigh
1	Left	56.01	56.23	836.48	660.95
1	Right	31.57	15.45	1086.49	418.98
2	Left	75.14	12.53	488.14	77.46
2	Right	23.71	25.53	208.12	256.74
3	Left	39.10	43.28	260.17	276.10
3	Right	69.62	25.96	573.83	334.51
4	Left	9.51	23.99	422.27	570.27
4	Right	7.94	13.20	152.96	207.81
5	Left	46.50	87.76	894.94	1229.68
5	Right	20.59	29.32	367.78	677.20
6	Left	26.53	15.11	425.69	665.01
6	Right	33.84	86.03	155.97	712.25
7	Left	12.00	28.49	350.88	1082.95
7	Right	8.77	120.33	313.72	688.43
8	Left	23.87	23.94	237.06	727.61
8	Right	37.64	26.01	484.48	251.33
9	Left	17.66	39.84	446.22	771.57
9	Right	27.88	95.36	437.97	782.58
10	Left	33.09	46.97	803.41	456.22
10	Right	55.98	65.05	832.67	400.16
Mean		32.85	44.02	488.96	562.39
SD		19.54	31.29	267.80	294.76
Minimum		7.94	12.53	152.96	77.46
Maximum		75.14	120.33	1086.49	1229.68
95% CI		23.71-42.99	29.38-58.66	363.63-614.30	424.44-700.34
P value*		0.185		0.415	

CI, confidence interval; *SD*, standard deviation.
* Welch's T-test.

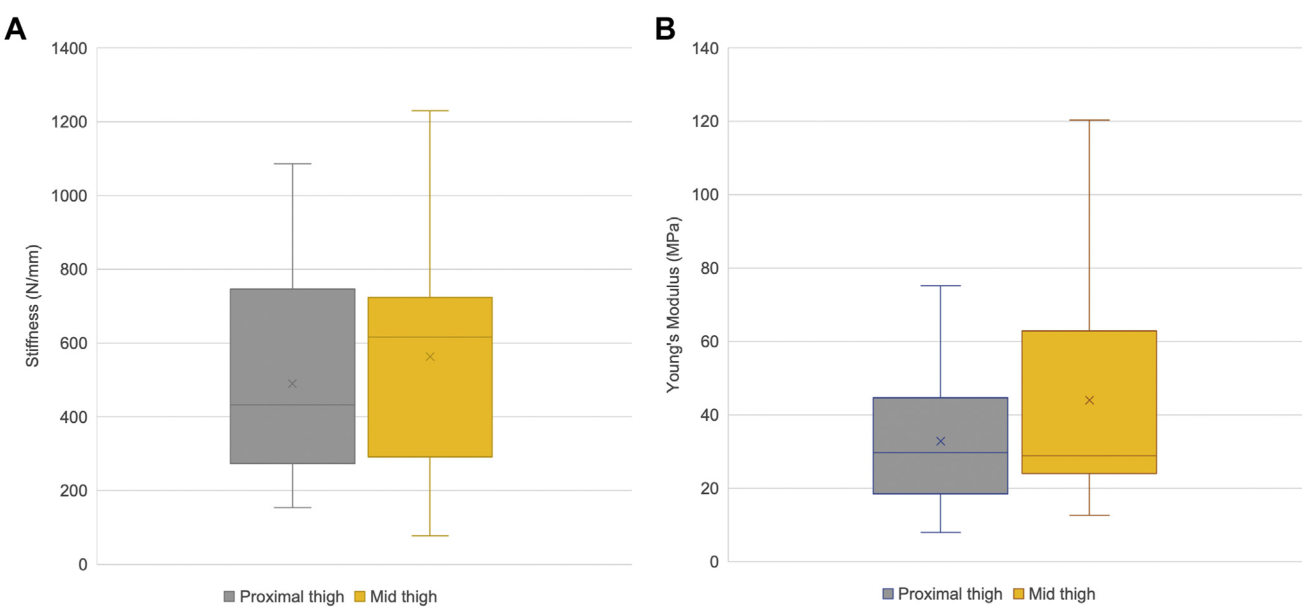

Figure 4 (**A**) Stiffness and (**B**) Young's modulus of the graft constructs according to the location of the harvest. The "X" inside the bars represent the mean values; the horizontal lines inside the bars represent the medians.

thereby avoiding the confounding influence of the sex- and age-dependent morphological and mechanical properties of the FL on the results.[21] Second, the specimens were harvested from fresh cadavers, while fresh-frozen cadaveric samples were used in all the biomechanical studies of SCR cadaveric models to date.[12,16-18,23] Fresh cadaveric specimens are the most suitable substitutes to living tissue when the Young's modulus and the stiffness are the main outcome measures because the average Young's modulus and stiffness of fresh tendons have been shown to be significantly lower than those of either fresh-frozen or embalmed cadaveric specimens,[11] and the mechanical properties of tendons and of the FL have been shown to be significantly influenced by the fixation methods used to preserve the specimens.[9,21] Third, the samples were fixed directly to the clamps, thereby avoiding the influence of

Table IV
Initial length and area of each graft construct[*].

Subject, side	Proximal thigh (N = 20)		Mid-thigh (N = 20)	
	L_0, mm	A, mm^2	L_0, mm	A, mm^2
1, R	9.51	327.35	7.89	213.85
2, R	13.56	119.02	11.04	111.04
3, R	24.77	204.16	18.46	237.94
4, R	14.19	273.44	15.16	238.68
5, R	13.45	240.12	13.38	308.95
6, R	16.27	75.00	14.87	123.08
7, R	15.53	555.24	13.53	77.43
8, R	18.08	232.74	18.86	182.21
9, R	16.46	258.59	17.22	141.29
10, R	17.33	257.71	19.80	121.79
1, L	10.54	157.45	10.33	121.40
2, L	16.14	104.84	10.28	63.52
3, L	18.32	121.89	14.22	90.71
4, L	9.97	442.84	10.73	255.04
5, L	14.09	271.27	17.22	241.28
6, L	16.15	259.05	11.14	490.20
7, L	11.31	330.50	10.98	417.24
8, L	20.23	200.93	16.80	510.56
9, L	13.47	340.28	16.32	315.98
10, L	15.31	371.67	18.21	176.93
Mean	15.23	257.20	14.32	221.96
SD	3.64	118.03	3.49	131.27

[*] *A*, cross-sectional area; L_0, Initial length between the control points according to the Standard Video Extensometer; *L*, Left; *R*, Right; *SD*, standard deviation.

the suture fixation method on the Young's modulus and stiffness of the graft constructs, which were the main outcome measures of the current study.[22]

Limitations

The current study has some limitations. First, a high variance of the morphological and biomechanical properties was found within both groups, which is a consequence of the high variability of the FL morphology according to the age and sex of the subjects. However, this reproduces what is found in the clinical setting of ASCR and increases the generalizability of the findings. Second, no comparison could be made with regard to the theoretical spacer effect that could result from the increased thickness of the proximal thigh graft construct versus the mid-thigh graft construct. A dynamic shoulder model would allow for this comparison and for the assessment of the effects of graft morphometry on the biomechanics of the shoulder, but it would introduce other, external variables and confounding factors, whereas the Young's modulus and stiffness of the graft constructs were the main outcome measures of the current study.

Conclusion

Despite the different morphological characteristics of the proximal thigh and mid-thigh FL graft constructs used for ASCR, their Young's modulus and stiffness did not significantly differ. Knowledge that both graft constructs show equivalent biomechanical properties may assist orthopedic surgeons and patients in the choice of the location, harvesting technique, and type of graft construct for ASCR, because the mid-thigh FL autograft can be minimally invasively harvested.

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