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# Physical properties of Scarpa's fascia

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## Abstract

Preservation of Scarpa's fascia has improved clinical outcomes in abdominoplasty procedures and in other body contour surgeries. However, the physical properties of Scarpa's fascia have not yet been described, and grafts are still underexplored. Fresh surgical specimens from five female patients subjected to classical abdominoplasty were dissected and analyzed. A grid was drawn on the fascia surface, dividing it into equal upper and lower halves; four Scarpa's fascia samples (30 $\times$ 10 mm) were collected from each half, 40 mm apart. The thickness was measured with a caliper. A strain/stress universal testing machine was used for mechanical tests. Twenty-five samples were obtained (nine from the upper half, 16 from the lower). The average thickness was 0.56 ± 0.11 mm. The average values for stretch, stress, strain, and Young's Modulus were, respectively, 1.436, 4.198 MPa, 43.6%, and 23.14 MPa. The upper half showed significantly greater thickness and strain values ($p = 0.020$ and $p = 0.048$; Student's $t$-test). The physical and biomechanical properties of Scarpa's fascia can make it a donor area for fascial grafts as an alternative to fascia lata, as it is always available and has minimal donor-site morbidity. Further studies are needed to validate this statement. It seems advantageous to use the lower half of the abdomen instead of the upper part as a donor site.

KEYWORDS
biomechanics, cosmetic surgery, fascia, graft, physical properties, strain, stress

## 1 | INTRODUCTION

Scarpa's fascia is the membranous layer of the superficial abdominal fascia (Lancerotto et al., 2011; Worseg et al., 1997). During the last three decades it has gained interest for body contouring procedures, especially abdominoplasty, as its preservation has shown several clinical advantages such as reduced drainage, earlier drain removal, lower seroma rate, and elimination of long drainers (Correia-Goncalves et al., 2017; Costa-Ferreira et al., 2010; Costa-Ferreira et al., 2013; Costa-Ferreira et al., 2016; Novais et al., 2020). In addition, superficial fascial suspension has been described to improve the aesthetic outcomes of various body lift procedures (Illouz, 1989; Lockwood, 1991; Lockwood, 1993; Lockwood, 1995a; Lockwood, 1995b; Whiteman & Miotto, 2016).

The usefulness of Scarpa's fascia for reconstruction has also been explored. The in-depth investigation by Worseg et al. (1997) included an anatomical study with cadaver dissection, computed tomography (CT) scanning, histological examination, and a clinical study. The latter focused on applications of a new fascial flap based on the superficial epigastric artery, either pedicled or as a free flap, with the advantages of minimal donor-site morbidity and a short and simple surgical procedure (Koncilia et al., 1997; Worseg et al., 1997). Other authors (Koshima et al., 1996; Venkataramakrishnan et al., 1998) have used Scarpa's adipofascial flaps.

The value of Scarpa's fascia as a donor area for fascial grafts is still underexplored (Lonic et al., 2017). In addition, there have been few reports about its physical properties, most studies having focused on histological characteristics (Abu-Hijleh et al., 2006; Costa-Ferreira et al., 2014; Joshi et al., 2022; Worseg et al., 1997) and only one on mechanical properties (Lancerotto et al., 2011).

The present authors have designed an experimental study of the physical properties of Scarpa's fascia's to improve knowledge about its mechanical behavior for applications as a fascial graft and to elucidate its clinical advantages when it is preserved during abdominoplasty.

## 2 | PATIENTS AND METHODS

Surgical specimens from patients who had undergone a classical abdominoplasty at our institution were used for the experiments. The patients included were women who showed an excess of abdominal skin and adipose tissue, and muscle laxity. Exclusion criteria were bariatric patients without weight stabilization, those with major abdominal surgery (laparotomy procedures), and those with a body mass index (BMI) greater than 30 kg/m$^2$.

Five female patients were enrolled in this study, average age 42.4 years (range = 33–55 years), mean BMI 27.6 kg/m$^2$ (range = 24.6–30.0 kg/m$^2$), and mean abdominoplasty specimen mass 1.198 kg (range = 0.650–1.538 kg).

The first author performed the abdominoplasty procedures and dissected the surgical specimens in the lab, isolating the Scarpa's fascia samples and assisting with the mechanical tests.

The current research was approved unanimously by the ethics committee of the Hospital de São João under the number CES-11.6.11. All the procedures followed the clinical ethics of the World Medical Association—Declaration of Helsinki. All patients were informed about the procedures and signed the respective consent. The personal data of all those involved in the research were anonymized.

### 2.1 | Surgical methods

The patients underwent classical abdominoplasty with umbilical transposition and rectus abdominis muscle plication.

Each surgical specimen (Figure 1A) was packed inside a plastic bag (with no fixation) and stored in a carrier box inside a fridge (5°C), according to the procedures defined by the World Organization for Animal Health (WOAH) for correct packaging and transportation of biological specimens (O.T.M, 2018).

### 2.2 | Sample preparation

Within 24 h, the surgeon took the surgical specimens to the mechanical engineering laboratory and started the dissection. First, the Scarpa's fascia layer was identified and isolated using a no. 24 scalpel blade, preserving some surrounding areolar tissue (Figure 1B). Next, the previous location of the umbilicus (U) was identified, and a grid was painted on the specimen with a black marker (Figure 1c). Two lines were drawn at 40 mm above and below the horizontal midline, and then two at similar distances right and left of the vertical midline, creating a grid (Figure 1d). Eight 30 × 10 mm samples of Scarpa's fascia were collected per specimen with a no.15 scalpel blade, four from the upper half (samples A, B, C, D) and four from the lower half (A', B′, C′, D′).

The thicknesses of all samples were measured by the same operator using a caliper with a resolution of 0.01 mm, making uniform contact on the sample surfaces. Three measurements were taken to reduce the error, and their average value was used to calculate the cross-section area.

The orientation of the fibers was examined visually by two independent operators, who described them as horizontal (Otsuka et al., 2018) and, at some points, with a discrete obliqueness of 3°–5°. The direction of the fibers provided a reference for cutting the samples and performing the mechanical tests.

### 2.3 | Mechanical tests

A universal testing machine for biological materials was used for the mechanical experiments. This equipment has four linear motors disposed around the sample, aligned in two perpendicular directions, and two load cells with 50 N capacity. Each sample was clamped at its extremities with two grippers in the same orientation as the fascial fibers. The samples were hydrated with 0.9% saline to mimic natural body conditions and the ambient temperature was stabilized at 22°C.

Before the tensile tests, the samples were subjected to a preload of 0.25 N. The preload guaranteed pre-testing-controlled initial geometry and loading conditions, contributing to the reproducibility of the experiments, as suggested in the studies by Ramião, Martins, Barroso, Santos, and Fernandes (2017) and Ramião, Martins, Barroso, Santos, Pereira, and Fernandes (2017).

The mechanical tensile tests were performed in a single direction (uniaxial loading, aligned to the fascial fibers) by moving the gripper at a constant speed (displacement rate 0.05 mm/s) until sample rupture. Although the equipment allows biaxial testing to be performed, it was decided to apply a uniaxial load as the results would be easier to interpret (Pukšec et al., 2019).

### 2.4 | Mechanical characteristics

The mechanical tests were recorded on video, and the elongation ($\Delta L$, mm) and force ($F$, N) were logged. The stretch ($S$), stress ($\sigma$, MPa), strain ($\varepsilon$, %), and Young's Modulus ($E$, MPa) were then calculated. The stretch (Equation 1) was the ratio between the final ($L + \Delta L$, mm) and the initial ($L$, mm) lengths of the material:

$$S = \frac{L + \Delta L}{L} \quad (1)$$

Stress was calculated by dividing the force by the cross-sectional area, where $T$ stands for the initial thickness (mm) and $W$ for the initial

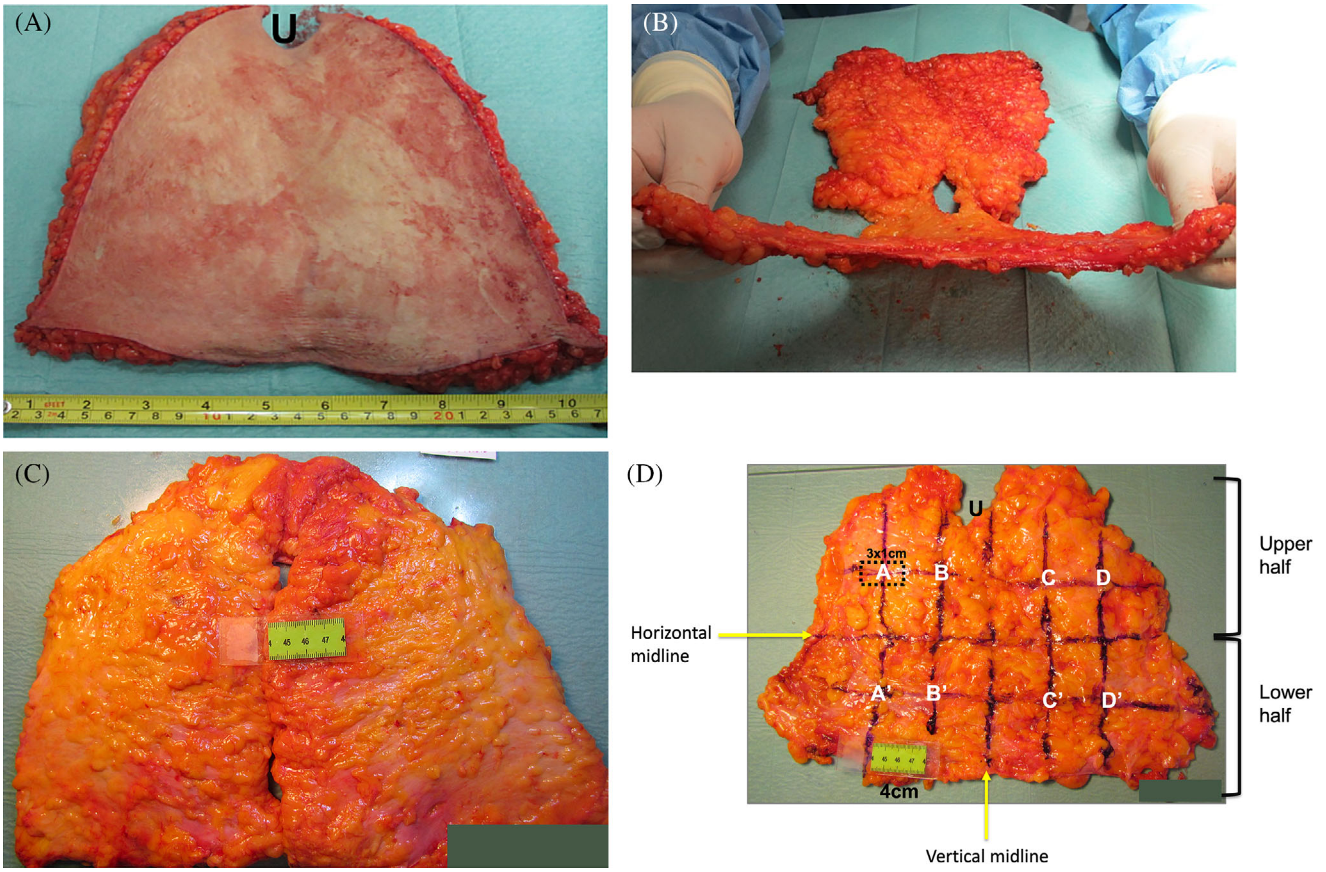


**FIGURE 1** (A) Surgical specimen obtained from the abdominoplasty procedure. U—Previous location/position of umbilicus. (B) Isolation of Scarpa's fascia and surrounding areolar tissue from the adipose tissue. (C) The resultant specimen where the grid was applied after gross dissection of the adipose tissue. (D) The surgical specimen after the application of a predesigned grid. Eight samples of Scarpa's fascia, 30 x 10 mm, were marked per specimen using a plastic template, four in the upper half, and designated respectively as samples A, B, C, and D, starting from the left side of the specimen (which corresponded to the right side of the patient). Similarly, four samples were marked in the lower half, designated as samples A', B,' C', and D′. U—previous umbilicus location.

width (mm), compensated by the stretch factor $S$ as the area is not constant; it decreases during the experiment (Equation 2):

$$\sigma = S \times \frac{F}{T \times W} \quad (2)$$

The strain was calculated using Equation 3:

$$\varepsilon(\%) = \frac{\Delta L}{L} \times 100\% \quad (3)$$

Since the tests were performed until the sample ruptured, Young's Modulus (E) was calculated using data corresponding to the approximately linear part of the curve $\sigma/\varepsilon$, discarding both the first and the last parts of this curve (which has a "S" shape typical of visco-elastic materials) (Equation 4):

$$E = \sigma/\varepsilon \quad (4)$$

The force-elongation characteristic was determined for all the samples.

## 2.5 | Statistical analysis

IBM SPSS version 27.0 was used for the statistical analyses. The significance level was set as $p < 0.05$.

Visual histogram analysis, Shapiro–Wilk, and Levene's tests were used to assess sample normality and homogeneity. Since these were verified, parametric tests were used.

The statistical differences in physical properties between the samples' origin areas (upper and lower halves) were assessed using an independent Student's *t*-test with a 95% confidence interval. ANOVA was used for post hoc Tukey's tests.

# 3 | RESULTS

As specified by the protocol, an attempt was made to collect eight samples from each of the five patients, making a total of 40 specimens. However, several samples had to be discarded owing to problems with preparation, transport, or during mechanical tests. Therefore, only 25 were considered for data analysis, nine from the upper half and 16 from the lower half.

**TABLE 1** The average thickness (mm) per specimen (I-V), according to the patient's BMI.

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| Thickness (mm) ± SD | 0.46 ± 0.14 | 0.82 ± 0.12 | 0.64 ± 0.14 | 0.53 ± 0.12 | 0.71 ± 0.15 |
| BMI (kg/m$^2$) | 30.00 | 26.90 | 24.60 | 29.70 | 26.6 |

Abbreviations: BMI, body mass index; SD, standard deviation.

**TABLE 2** The average length, width, thickness, cross-section, force, stretch, stress, strain, and Young's Modulus per sample location.

| | A | A' | B | B′ | C | C′ | D | D′ | Average |
|---|---|---|---|---|---|---|---|---|---|
| Length (mm) | 13.163 | 16.369 | 12.885 | 15.683 | 13.493 | 13.551 | 17.842 | 18.933 | 15.240 |
| Width (mm) | 7.050 | 6.805 | 5.640 | 6.460 | 6.246 | 6.117 | 4.837 | 6.167 | 6.165 |
| Thickness (mm)+ | 0.618 | 0.518 | 0.475 | 0.412 | 0.748 | 0.580 | 0.470 | 0.635 | 0.557 |
| Cross-section (mm$^2$) | 4.512 | 6.805 | 5.640 | 6.460 | 6.246 | 6.117 | 4.837 | 8.261 | 3.640 |
| Maximum force (N) | 7.039 | 9.884 | 11.678 | 8.781 | 6.518 | 7.833 | 12.096 | 14.659 | 9.811 |
| Stretch[a] | 1.510 | 1.413 | 1.395 | 1.328 | 1.576 | 1.443 | 1.460 | 1.365 | 1.436 |
| Stress (MPa)[a] | 2.836 | 4.421 | 6.225 | 4.597 | 2.123 | 3.396 | 5.695 | 4.291 | 4.198 |
| Elongation (mm) | 6.395 | 6.468 | 5.103 | 5.129 | 7.739 | 5.676 | 8.099 | 6.890 | 6.437 |
| Strain (%)[a]+ | 50.976 | 41.292 | 39.530 | 32.839 | 57.597 | 44.299 | 46.004 | 36.452 | 43.624 |
| Young's Modulus (MPa) | 12.780 | 33.680 | 30.060 | 38.170 | 4.840 | 21.930 | 29.950 | 13.720 | 23.141 |

*Note*: + Samples from the upper half of the fascia (A, B, C, D) were significantly thicker (0.59 vs. 0.52 mm) and had greater strain (48.53% vs. 38.72%) than those from the lower half (A', B', C′, D′) (Student's *t*-test and ANOVA, $p = 0.020$ for thickness and $p = 0.048$ for strain). A, B, C, D—Upper Scarpa's fascia samples. A, B′, C,' D'—Lower Scarpa's fascia samples.
[a]Calculated for the maximum instant force.

The mean thickness of Scarpa's fascia was 0.56 mm (SD ± 0.11) (Table 1). Samples from the upper half of the fascia (A–D) were significantly thicker than those from the lower half (A'–D′) (Student's *t*-test, $p = 0.020$).

The average maximum tolerable force was 9.81 N, with an average maximum elongation of 6.44 mm (Table 2). The stretch, stress, and strain values shown in Table 2 correspond to the maximum instant force. The average stretch was 1.44, the highest value being 1.58 for sample C, and the average stress was 4.20 MPa. The average strain was 43.6%, the highest value (57.6%) being for sample C and the lowest (39.5%) for sample B. The maximum Young's Modulus was 38.17 MPa for sample B′, and the lowest was 4.84 MPa for sample C; the mean was 23.14 MPa (Table 2).

The stress calculated for each sample was averaged over all patients. Location C presented the lowest stress (2.12 MPa) while location B showed the highest (6.23 MPa). Both samples were from the upper part of Scarpa's fascia.

The initial and final lengths (corresponding to the maximum force) for each location were averaged for all patients and are displayed in Figure 2. Samples D and D′ showed the greatest final length, and sample D had the highest displacement (8.099 mm).

When the upper (A, B, C, D samples, $n = 9$) and lower halves (A', B,' C′, D′ samples, $n = 16$) of Scarpa's fascia were compared, we found statistically significant differences in thickness (0.59 vs. 0.52 mm) and strain (48.53% vs. 38.72%) (Table 2), the higher values being for the upper half ($p = 0.020$ and $p = 0.048$, respectively). Student's *t*-test and post hoc tests (ANOVA—Tukey's test) were used.

The graph in Figure 3 presents the data from patient I, who provided the full set of eight specimens. The mechanical stress test on Scarpa's fascia showed a positive relationship between the displacement and the applied force until it the ultimate strength was reached. Thereafter, the force decreased until complete rupture, while the sample continued to elongate.

At the beginning of the test, the force-elongation curve had a low derivative, corresponding to a slight increase of the force with a more significant elongation. Thereafter, the relationship between force and elongation became approximately linear with a higher-derivative slope. Finally, the gradient started to decrease, showing that the sample was failing to tolerate the force.

## 4 | DISCUSSION

To the best of our knowledge, this is the first investigation of the biomechanical properties of Scarpa's fascia in fresh surgical specimens. A previous study briefly mentioned the resistance of Scarpa's fascia to tensile tests (Lancerotto et al., 2011), and another mentioned the usefulness of a fascial graft for stabilizing a simultaneous bone graft in alveolar clefts (Lonic et al., 2017).

Fascial grafts have been used for facial paralysis (Rose, 2005; Wei & Cao, 2013), paralytic lagophthalmos (Pirrello et al., 2007; Tremolada et al., 2001), congenital unilateral lower lip palsy (Kubota et al., 2009), tendon reconstruction (Ponnapula & Aaranson, 2010), dural reconstruction (Ahn & Kim, 2009; Fliss et al., 2002; Pukšec

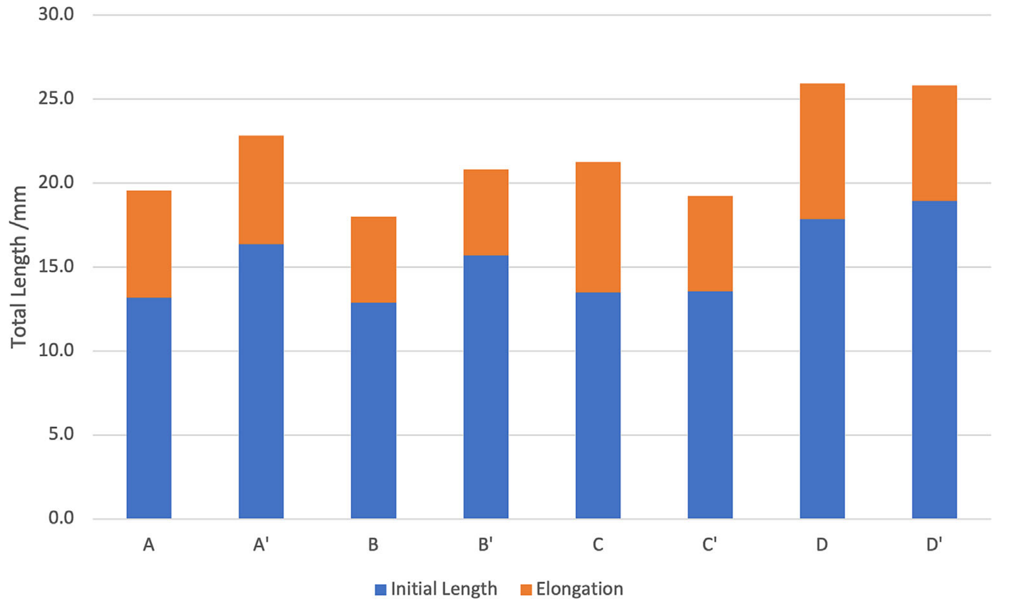


**FIGURE 2** The final length of the samples at the start (length, blue columns) and by the end of the test (length + displacement, blue plus orange columns) averaged for all patients per location. The displacement is represented in orange over the initial length. A, B, C, D—Upper Scarpa's fascia samples; A', B', C', D′—Lower Scarpa's fascia samples.

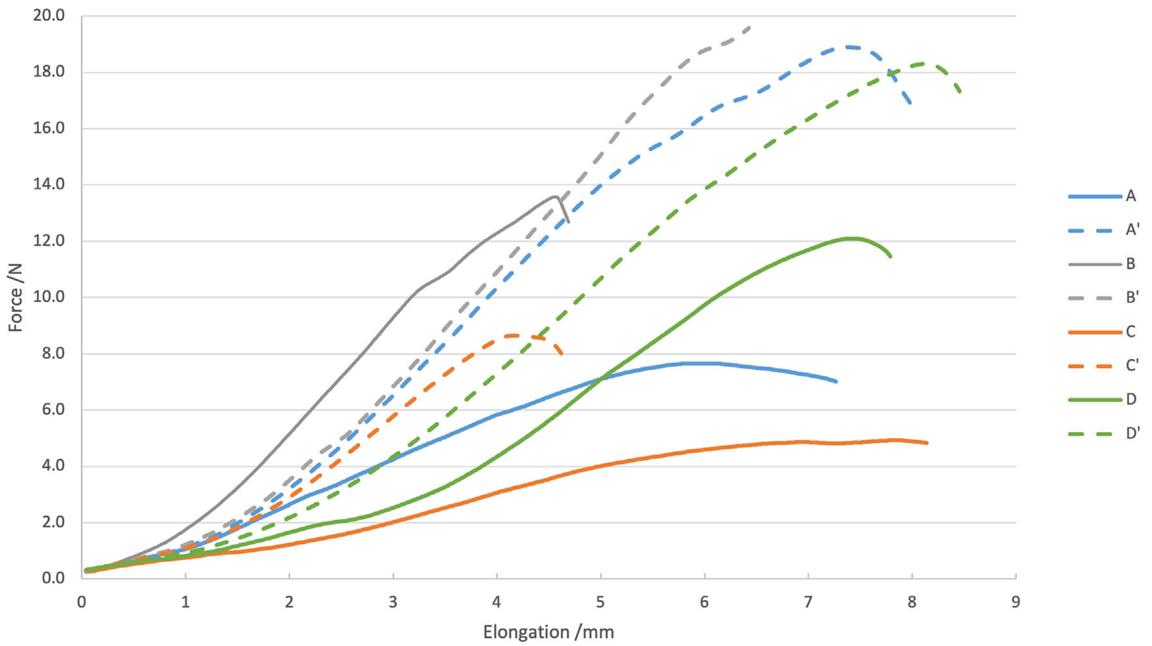


**FIGURE 3** Force-displacement graph from patient I data. The mechanical stress test of Scarpa's fascia showed approximately linear behavior between the displacement and the applied force until the ultimate strength was reached. From that point on, the force decreased until complete rupture.

et al., 2019), palpebral ptosis (Cates & Tyers, 2008), correction of complex facial defects (Jeng et al., 2005), ear, nose, and throat (ENT) surgery (Dinc et al., 2020; Freitas & Oliveira, 2014; Hodgkinson & Valente, 2017), palatal defects (Smolka et al., 2008), and other conditions. Fascia lata is the most common donor site for non-vascularized fascia, and its physical properties have been described in considerable detail. It has a high strength (Gratz, 1931), with values of 10.73 lb per quarter-inch strip (0.0075 MPa) (Crawford, 1968; Gratz, 1931; Thomas et al., 1998; Wei & Cao, 2013). The properties of other autologous tissues such as temporalis fascia have also been described (Dinc et al., 2020; Dost & Maune, 2014; Pukšec et al., 2019; Tarumoto et al., 2020; Thomas et al., 1998; Zwirner et al., 2021).

Puksec et al. (Pukšec et al., 2019) recently compared 15 fresh cadavers and 39 samples of fascia lata ($n = 10$), dura mater ($n = 14$), and temporalis fascia ($n = 15$) for cranial reconstruction. They analyzed 60 × 15 mm samples and found that fascia lata was the stiffest tissue (stress 14.61 MPa), while temporalis fascia was the most elastic (stress 2.09 MPa) (Pukšec et al., 2019). Otsuka et al. (2018), analyzed 40 × 40 mm fascia lata samples from different locations in 12 formalin-fixed cadavers (six males, six females, 17 seven legs). Sample thicknesses ranged from 0.2 to 1.1 mm, stiffness from 3 to 236 N/mm, and Young's Modulus from 2.8 to 264.3 MPa, with maximum values for longitudinal orientation; there were sex differences (Otsuka et al., 2018). Our study revealed average maximum stress and Young's Modulus of 4.2 and 23.14 MPa for Scarpa's fascia. In both Pukšec et al. (2019) and Otsuka et al. (2018) studies, a loading–unloading protocol was used for the tests. We used a different experimental protocol, applying a continuous uniaxial speed/load according to the known parallel orientation of the collagenous fibers (Worseg et al., 1997) until the sample ruptured. It should be noted that these different studies examined different sample sizes, some from fresh and others from fixed cadavers, and applied different protocols for the mechanical tests, so their results are difficult to compare.

Our results confirmed that Scarpa's fascia shows viscoelastic behavior, with an "S" shape curve between force and elongation, approximately linear over the middle range and with low-derivative gradients at the extremities. After the force reaches its maximum it decreases until complete rupture. The elongation capacity of Scarpa's fascia was close to 50% (strain 43.6%). The maximum forces ranged from 6.5 to 14.6 N for the different samples. It should be remembered that the force depends on the sample cross-section (thickness × width), so larger samples tolerate greater forces (Graupner et al., 2021). Lancerotto et al., 2011 macroscopically analyzed the superficial fascia/membranous layer in 10 fresh cadavers and found force values up to 27.5 N in the transverse and 54 N in the craniocaudal direction, sample section not specified.

We found differences between the upper and lower half samples of Scarpa's fascia. The upper half was significantly thicker than the lower one (0.59 vs. 0.52 mm) and more infiltrated by fat, as previously described (Costa-Ferreira et al., 2014; Lancerotto et al., 2011; Worseg et al., 1997). Therefore, it was more challenging to separate from the areolar tissue. Costa-Ferreira (Costa-Ferreira et al., 2014) reported an average Scarpa's fascia thickness of 0.28 mm (SD ± 0.11 mm, lateral) and 0.29 mm (SD ± 0.11 mm, medial) using histological examination and fascial measurements ($n = 31$). The latter were obtained from a single field and considered the maximum and minimum thicknesses of the fascial layer on a segment with parallel collagen bundles, without fat tissue or blood vessels.

In contrast, Lancerotto et al. (Lancerotto et al., 2011) reported a mean histological thickness of 0.847 mm (SD ± 0.295 mm) for the membranous layer. These values differ from the Costa-Ferreira study (Costa-Ferreira et al., 2014) and ours. Interestingly, in the same study, a mean thickness of 2.31 mm was reported using CT scanning, significantly different from the histological value (Lancerotto et al., 2011). No differences were found in a craniocaudal direction, but higher values were reported for obese subjects, especially in the dorsal region (Lancerotto et al., 2011). Lancerotto et al. (2011) raised the possibility that the histological values were underestimated since the samples were fixed and dehydrated, and that the CT values were overestimated because of the low image resolution.

In the present study, the strain values for the upper half were significantly higher (48.53% vs. 38.72%), so the lower half was less deformable and more consistent. This is consistent with what was seen macroscopically during dissection of the samples and was mentioned by previous authors (Lancerotto et al., 2011; Worseg et al., 1997). The lower half is more similar to fascia lata, more accessible, and easier to dissect as it has lower fat infiltration. To corroborate this, only 45% of the potential upper samples (9 in 20) could be analyzed compared to 80% of the lower samples (16 in 20), because the fascia was damaged during dissection.

Scarpa's fascia was shown in a large sample study to be present whatever the degree of adiposity and to have a predominantly compact morphology (Costa-Ferreira et al., 2014). The current investigation provides reference values for its physical properties and mechanical behavior, which could be important for future research and for clinical application as a fascial graft donor site. Harvesting of Scarpa's fascia has minimal donor-site morbidity (Worseg et al., 1997), and, unlike fascia lata, it leaves an inconspicuous scar covered by clothing. Furthermore, even with larger samples, there is no risk of muscle herniation as with fascia lata (Chiu & Edgerton, 1990; Wei & Cao, 2013).

The elasticity of Scarpa's fascia in its middle range elongation could explain the clinical advantages identified for Scarpa-sparing abdominoplasty, as adherence and resistance to shearing forces are improved (Joshi et al., 2022). On the other hand, the high mechanical stress described in the current study explains the improved outcome for flank or thigh contours when this tissue is plicated horizontally (Whiteman & Miotto, 2016) or vertically (Richter & Stoff, 2011).

This study has some limitations, starting with the small number of patients and the fact that all were women. One might expect similar structural behavior in men, but we have no data to confirm that. Further research should be performed on men, obese individuals, and children.

## 5 | CONCLUSION

This study describes the biomechanical behavior of Scarpa's fascia for the first time. It could be a potential donor site for fascial grafts as an alternative to fascia lata, as it is always available and has minimal donor-site morbidity. Further studies are needed to validate this usefulness. It seems to be advantageous to use the lower half of the abdomen as a donor site instead of the upper part.

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