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Ultrasound evaluation of deep fascia thickness: Reliability and association with clinically evaluated changes

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ABSTRACT

Background: There is growing evidence of fascial involvement in musculoskeletal pathologies; thus, measuring the fascia's properties is clinically essential.
Objectives: 1) to evaluate intra- and inter-tester reliability of sonographic measurements of deep fascia thickness in healthy individuals; 2) to assess whether fascial thickness in areas of fascial movement restriction (fascial densification in Stecco's Fascial Manipulation method), differs from contralateral areas with normal fascia.
Methods: Part 1 (reliability study): Fascial thickness was sonographically measured in 10 sites (5 on each side), twice by a single examiner to assess intra-rater reliability and once by a second examiner to evaluate inter-rater reliability.
Part 2 (cross-sectional study): Unilateral fascial movement restrictions were detected in 5 bilateral sites by palpation. The fascial thickness on the ultrasound image was measured at the restriction site and its normal contralateral side by a blinded assessor.
Results: 21 healthy individuals were evaluated in part 1, 15 healthy individuals in part 2. Intra-tester reliability (Interclass correlation – ICC) values ranged from 0.677 to 0.975; inter-tester ICC values ranged from 0.473 to 0.966. No significant differences in fascia thickness between the right and left body sides were observed in most sites. Significant differences were found between the fascial thickness of the site of fascial movement restrictions vs. normal counterpart.
Conclusions: Intra- and inter-rater reliability of sonographic measuring fascial thickness was high, and fascial thickness of the site of fascial movement restrictions was greater than in the normal counterpart. Ultrasonography may be used as a reliable method to evaluate fascial alterations.

1. Introduction

Fascia is the soft tissue component of the connective tissue system that permeates the human body, forming a whole-body continuous three-dimensional matrix of structural support. The fascia interpenetrates and surrounds all organs, muscles, bones, and nerve fibers, creating a unique environment for body functioning (Adstrum and Nicholson 2019; Barnes 1990; Kumka and Bonar 2012).

Prolonged loading or injury of the fascia leads to micro and macro traumas, resulting in tissue reconstruction. These changes can alter the fascia's functional ability and mechanism of action, possibly affecting additional anatomical systems (e.g., muscles), not just limited to the injured/loaded tissues (Zügel et al., 2018). Stecco et al. (2014) found that fascial disturbances can be associated with chronic neck pain, i.e., a significant decrease in neck pain was reported following a fascial manipulation® (FM) treatment. FM manual therapy technique was developed by Luigi Stecco (Stecco, 2004; Stecco and Stecco, 2009). The FM presents a biomechanical model of the role of fascia in musculoskeletal disorders, considering that the myofascial system is a three-dimensional continuum. In FM, the body is subdivided into 14 segments: head, neck, thorax, lumbar, pelvis, scapula, humerus, elbow, carpus, digits, hip, knee, ankle, and foot. Each body segment is served by six myofascial units consisting of monoarticular and biarticular unidirectional muscle fibers, their deep fascia, which includes within the aponeurotic fascia and the epimysium, and the articulation that they move in one direction on one plane (Day et al., 2012).

FM treatment was associated with changes in fascial properties when measured by ultrasonography (fascial thickness). Another study seeking

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to understand fascial mobility when resting versus voluntary muscle contractions found that male subjects with chronic low back pain exhibited significant correlations between measured ultrasonography properties of the fascia and the trunk range of motion (both flexion $r = 0.36$, $P < 0.01$ and extension $r = 0.41$, $P < 0.01$) (Langevin et al., 2011). Furthermore, a case study reported that the positive effect of FM treatment was associated with increased fascial gliding and local viscoelasticity, suggesting that changes in the deep fascia are related to a reduction in pain (Luomala et al., 2014).

Densification of the fascia has been described as an alteration or limitation in the gliding property of the fascial layers resulting from changes in the loose connective tissue between them (Pavan et al., 2014). For example, densification of the deep cervical fascia that occurs due to the increased viscosity of hyaluronic acid may induce neck pain and associated painful symptoms in the upper quarter region (Hughes et al., 2022). In a recent review, Stecco et al. (2022) provided evidence that hyaluronic acid aggregation can occur in the deep fascia, causing densification that can also be represented as changes in fascial thickness.

Clinically, palpation is mainly used for determining fascial densifications, which can indicate a cause of myofascial pain and change in the same tissue. Hence, tactile qualities and palpation reliability are essential in establishing an accurate diagnosis. In this study, an initial attempt was made to support the tactile findings with a reliable empirical tool, i.e., an ultrasound device.

Ultrasound and elastography are well-known imaging methods used to detect the deep fascia's gliding, echogenicity, and elasticity. Ultrasound images can be reliably utilized to display and measure the morphology of the fascia, muscles, ligaments, and tendons (Zügel et al., 2018). Considering that sonography results are assessor-dependent, it is essential to assess the inter- and intra-rater reliability, thus assisting in conducting future research studies and the clinical use of sonography on fascia evaluations (Scheel et al., 2005).

Several publications investigated the reliability of measuring fascial thickness by ultrasonography during different conditions: (1) a study focusing on fascial thickness of individuals diagnosed with dermatomyositis and polymyositis showed that ultrasonography measurements were reliable and sufficient for diagnostic purposes (intraclass correlation coefficient (ICC) > 0.7) (Bhansing et al., 2015); (2) a case study found that with the aid of ultrasound and elastography images, densification and movement dysfunction in the deep fascia was visible particularly, myofascial pain, which was found associated with fascial changes (levels of gliding between sublayers and quality of elasticity of the deep fascia) (Luomala et al., 2014); (3) a study investigating fascia thickness measured with ultrasonography and flexibility, rated with a functional sit-and-reach test and Schober's test (amount of flexion of the lower back), reported that specific qualities of fascia were associated with age (younger individuals exhibited thicker fascia in the lower leg and abdominal wall, whereas, older individuals displayed higher thickness in the fascia of the lumbar spine) and measured flexibility (Wilke et al., 2019).

Thus, the aims of our study were: (1) to measure the intra- and inter-tester reliability of sonographic readings of the measurements of the deep fascia thickness in healthy subjects; (2) exploratory aim – to measure the differences in fascial thickness between the right and left sides of the body; (3) to examine whether areas of fascial densifications exhibit a different thickness than contralateral areas with normal fascia.

2. MATERIALS and METHODS

2.1. Design and participants

This study consisted of two parts: part 1 (aims 1 and 2) - a repeated measurement reliability study, and part 2 (aim 3) - a cross-sectional analytic study. Participants were recruited via physical therapy and a medical rehabilitation center. Exclusion criteria included diabetes, skin diseases in the evaluation area, history of operations, scars, and edema in the evaluated area. In part 2 of the study, the same exclusion criteria itemized in part 1, was implemented. Participation in the study was voluntary. No invasive or potentially harmful interventions were performed. Data obtained during the study was held separately from the identification of participants. Consent forms were signed according to the approval obtained from the Ethical Committee of the Faculty of Health Sciences, Ben Gurion University of the Negev, Beer Sheva, Israel.

2.2. Examiners and measurements

The study took place in a physical therapy clinic. It was conducted by two licensed physical therapists who performed the evaluations: (KW, a senior physical therapist with over 30 years of experience in manual therapy and an internationally certified instructor of the FM method), and SSL, a senior physical therapist certified to practice Stecco's FM). Both had been trained over a six-month period by a certified musculoskeletal sonographer with more than 20 years of experience from Reut Hospital, Tel Aviv, Israel, on the use of ultrasound when measuring and evaluating musculoskeletal tissues.

Prior to the commencement of the study, the two examiners (KW, SSL) assessed five volunteers to establish a precise method of sonographic evaluation for each examination site, including the position of the subject and the measured limbs. The quality of the agreed method was further verified on an additional five volunteers to become acquainted with the evaluation order and limit possible drawbacks. The final method of sonographic evaluation was later discussed and implemented throughout the study. For sites on the anterior side of the body, subjects lay supine with knees extended and a pillow under their head. For the biceps muscle examination, arms were kept in supination. For sites on the posterior side of the body, subjects lay prone with their feet hanging freely over the edge of the examination bed.

A DP30 Mindray ultrasound machine (Mindray; Shenzhen China) with 5–10 MHz linear array transductors was used. The device's settings were kept constant (B-mode, depicted depth 30 mm) during all measurements to avoid potential changes in the images. The power and overall gain of the ultrasound machine were adjusted to optimize visualization of the fascial planes and obtain the best scans possible. Care was taken not to exert excessive pressure on the tissue being imaged to avoid distorting the underlying tissue, inducing pain, or overlooking the presence of small amounts of fluid (Gibbon 1996). Each image (with the appropriate thickness value) was saved (Fig. 1). The examined sites were analyzed randomly.

Fascial thickness was measured by software on the Mindray ultrasound machine. To eliminate the influence of possible thickness variations, each image was measured in three equidistant points representing the best visibility, and the resulting values were averaged for analysis.

2.3. Sample size calculation

Our aim was to implement a repeated measurement study of a continuous response variable (fascia thickness). Data received from the first ten subjects indicated that the difference in the response was normally distributed (standard deviation of 0.3). If the true difference in the mean response was 0.2 (a minimal value that we could clearly detect), we needed to study 20 subjects to reject the null hypothesis. This response difference was zero with a probability (power) of 0.8. The type I error probability associated with testing this null hypothesis was 0.05. For the 2nd part of the study, we planned a study of a continuous variable (measurement of fascial thickness) from the matched points of the same subjects. Data from the 1st part of the study indicated that the difference in the response was normally distributed (standard deviation of 0.5). If the difference in the mean response was 1, we would need to study 4 subjects to reject the null hypothesis. This response difference was zero with a probability (power) of 0.8. The type I error probability associated with the null hypothesis was 0.05. We recruited 15 subjects to allow more pairs of asymmetrical fascial densification points to be

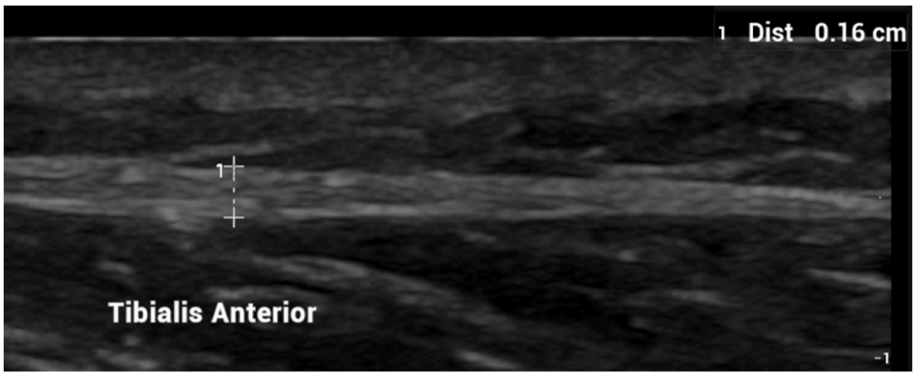

Fig. 1. Fascial thickness measurement example.
Deep fascial was measured at the anterior part of the tibialis anterior muscle (AN-TA).

collected.

2.4. Study protocol

When verifying the reliability of a sonographic evaluation of deep fascia thickness, the latter was measured bilaterally by an ultrasonography device in five sites. Specific sites measured are listed in the Procedures and Measured sites section. Each subject was evaluated twice by the same examiner (to measure intra-rater reliability) and one more time by the second examiner (to measure inter-rater reliability). The measurements were performed in a single, 1-h session. Evaluations were performed while the subject lay in a supine or prone position, with measured sites on the anterior/posterior parts of the body uncovered. The subjects were asked to breathe normally, refrain from speaking, and remain prone on the testing bed during all phases of the tests. All evaluations were performed without pressure on the transducer with a layer of 100 μm of gel between the ultrasound transducer and the skin. The settings of the ultrasound scanner were kept constant during all measurements to avoid potential changes in the images. Each image with the appropriate thickness value was saved, and the measured thickness was recorded on the study forms. Only one examiner was present in the testing room during each measurement segment.

Initially, the first examiner (SSL) measured the ten included sites (five on each side of the subject's body) in random order. Subsequently, the second examiner (KW) also measured the same sites in random order. The first examiner finished the session with repeated measurements of the sites. Once a measurement segment was completed, the examiners were blinded to the study forms and saved ultrasound images.

2.5. Procedures and Measured sites

An FM method using the unique classification of body movements. All movements are considered in terms of directions on spatial planes and are defined as follows: antemotion (AN), retromotion (RE), lateromotion (LA), mediomotion (ME), intrarotation (IR), and extrarotation (ER) (Fig. 2). Within each body segment, in a precise location of the deep muscular fascia a specific point, termed center of coordination (CC), is identified. Each CC is located at the point of convergence of the vectorial muscular forces that act on a body segment during a precise movement (Day et al., 2012; Stecco and Stecco, 2009). Based on this functional classification, a systematic objective examination together with an analysis of three-dimensional movements of the implicated segments can pinpoint.

The diagnosis of the fascial densification points, termed CC in the FM method, is performed by palpation following the diagnostic criteria established by Stecco (Stecco, 2004; Stecco and Stecco, 2009; Day et al., 2012):

- The presence of a palpable gliding restriction and the feeling of jumping or "lump" or "road bump" during manipulation gliding movements.
- The presence of a hypersensitive, painful area during tissue gliding manipulation.
- Reproduction of referred pain in response to the gliding manipulation, especially if projecting to the patient complaint area.

Although fascia can be measured on any body part, sites were selected where adjacent tissue involvement was limited. Moreover, these sites were easy to identify, thus limiting the examiner's bias. In the 1st part of the study the measured sites comprised two in the upper limb: the fascia of the biceps (ante cubitus - AN-CU), and the fascia of the deltoid, and the long head of biceps at the convergence of the fascia on the apex of the deltoid muscle (lateral humerus - LA- HU); one in the abdomen region: the fascia of the rectus abdominis evaluated at the level of the umbilicus (ante lumbi - AN-LU); two in the lower limb: the antelateral part of the fascia lata located at the middle third of the thigh, lateral to rectus femoris (ante genu - AN-GE) and the fascia of the lateral head of the gastrocnemius (retro talus - RE-TA).

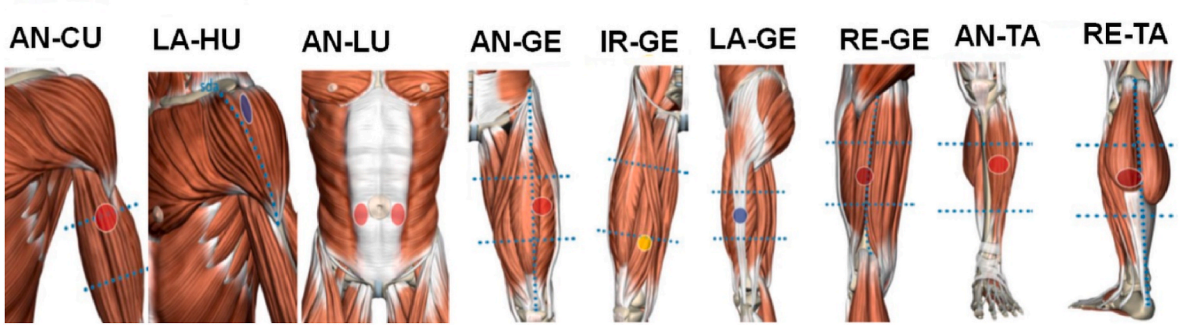

Fig. 2. Fascial thickness measurement sites according the Stecco's Fascial Manipulation nomenclature.

As for the association between fascial densification and thickness (part 2 of the study), we observed that in addition to the criteria enumerated in part 1, fascial densification asymmetry (according to Stecco's FM method) was present in at least three of the measured sites. A single examiner (KW) performed screening for this criterion. Deep fascia thickness was measured bilaterally by an ultrasound device (using the same methods and parameters as in part 1 of the study) in five sites (four sites measured in part 2 were different from those measured in part 1). Each subject was evaluated twice in a single testing session (for ~30 min). The first examiner (KW) performed palpation measurements of the fascial densifications (according to Stecco's FM method) in the ten measured sites. The results were recorded on a study form; the second examiner remained blinded. Subsequently, the second examiner (SSL) entered the room and measured the same sites using ultrasonography. Each image with the appropriate thickness value was saved. Measured thickness was also recorded on the study forms.

The measured sites in the 2nd part of the study: (1) The ante-lateral part of the fascia lata (ante genu - AN-GE); (2) the vasto-adductor membrane located over the vastus medialis (intra genu - IR-GE); (3) over the anterior crural fascia, located midway between the knee and ankle (ante talus-AN-TA); (4) over the fascia lata of the posterior thigh, located midway between the hip and the knee (retro genu - RE-GE); (5) the lateral part of the fascia lata over the iliotibial tract (lateral genu - LA-GE). The exact locations of these sites were described by Stecco (Stecco, 2004; Stecco and Stecco, 2009).

2.6. Statistical analysis

Data analyses were performed by SPSS Statistics 23 (SPSS Inc, Chicago, IL). Descriptive statistics characterized the studied sample (Table 1). The fascial thickness at the site of fascial densification vs. normal counterpart was compared by a paired *t*-test. ICC statistics assessed the reproducibility of ultrasound measurements of the fascia thickness in each site and classified as follows: 0.00–0.25, slight; 0.26–0.49, low; 0.50–0.69, moderate; 0.7–0.89, high; and 0.9–1.0, very high (Munro, 2004). A paired *t*-test was used to compare the fascial thickness of the left and right sides of the body, as well as between fascial densification site vs. normal counterpart. Effect sizes were evaluated using Cohen's d, which classified effect sizes as small ($d = 0.2$), medium ($d = 0.5$), and large ($d \geq 0.8$) (Lakens, 2013).

3. Results

3.1. Part 1

3.1.1. Sample characteristics

Part 1 comprised 21 healthy individuals (10 females), mean age of 39.81 ± 13.43 years, and a body mass index (BMI) of 24.42 ± 3.93 kg/m^2. Demographics as detailed in Table 1 were distributed almost equally in terms of gender: males (n = 11, 52.4%) and females (n = 10, 47.6%). The average age was 39.81 ± 13.43, ranging from 21 to 65. The BMI average was 24.42 ± 3.93, ranging from 17.57 to 32.85. Only four subjects (19.0%) reported smoking. Table 2 presents ICCs for all ultrasound assessments, both intra- and inter-tester, as well as separately for intra- and inter-tester evaluations. ICC values for overall fascial thickness (ICC range 0.818–0.987), as well as for right (ICC range 0.818–0.987) and left measurements (ICC range 0.827–0.986), revealed excellent (high and very high) inter-tester reliability (all p-values <0.001). The intra-tester ICC values ranged from 0.677 to 0.975 (moderate to very high levels). However, the inter-tester ICC ranged from 0.473 to 0.966, (low to very high levels). Nevertheless, only one measurement was <0.6 ICC (AN-LU left).

Table 1
Descriptive statistics.

Variable	Part 1 (N = 21)	Part 2 (N = 15)
	Mean ± SD (Range)	Mean ± SD (Range)
Age (years)	39.81 ± 13.43 (21–65)	45.40 ± 0.48 (21–65)
BMI (kg/m^2)	24.42 ± 3.93 (17.57–32.85)	25.93 ± 6.24 (17.63–38.06)
	N (%)	**N (%)**
Sex (females)	10 (47.6%)	5 (33.3%)
Smoking	4 (19.0%)	

SD - standard deviation, BMI - body mass index.

T-tests for paired samples compared the fascial thickness between the right and left sides at AN-CU, LA-HU, AN-LU, AN-GE, and RE-TA locations. As presented in Table 3, in accordance with the second hypothesis, most of the t-tests demonstrated no significant differences. Cohen classified effect sizes were small ($d = 0.2$), medium ($d = 0.5$), and large ($d \geq 0.8$). However, all effect sizes were small and meaningless (all d's = 0.001, which is smaller than Cohen's d assumptions of 0.20 for small effect size). The only significant differences were for the LA- HU $t(20) = 2.14$, $p = 0.045$ with higher values on the left side (M = 1.11 SD = 0.29) compared to the right side (M = 1.01 SD = 0.20). However, the effect size revealed that this effect is meaningless and not implicative. The means of AN-CU, AN-LU, AN-GE, and RE-TA did not differ between the right and left sides (p-values ranged from 0.090 to 0.863).

3.2. Part 2

3.2.1. Sample characteristics

Part 2 comprised 15 healthy individuals (5 females), mean age was 45.40 ± 0.48 years and a mean BMI of 25.93 ± 6.24 kg/m^2. Table 1 presents the descriptive statistics of the examined population. As presented in Table 4, significant differences were found between fascial thickness of the site of the fascial densification vs. the normal counterpart for the associated areas AN-GE ($t(8) = 3.92$ $p < 0.01$, for the RE-GE ($t(7) = 6.56$ $p < 0.01$, and LA-GE ($t(7) = 7.22$ $p < 0.01$. All three effect-size values were medium to large (Cohen's $d = 0.30$). In addition, differences were also revealed for the associated areas of IR-GE $t(4) = 2.98$ $p < 0.05$ with a small effect size of 0.15. The differences were not significant for the associated area AN-TA $t(7) = 1.71$ $p > 0.05$.

4. Discussion

The reliability of three fascia thickness sonographic measurements in the tested sites was high (ICC range 0.818–0.987). The intra-tester ICC values for the two measurements (performed by a single examiner) ranged from 0.677 to 0.975 (moderate to very high levels); the inter-tester ICC values ranged from 0.473 to 0.966 (low to very high levels). However, only one site showed low reliability, with an ICC<0.6 (AN-LU left). Our results correspond with Pirri et al.'s previous findings (Pirri et al., 2019) of good inter-rater reliability when measuring the abdominal wall fascia. We confirmed that ultrasonography is a reliable tool when measuring fascial thickness and may be valuable in investigating the relationship between musculoskeletal pain or dysfunction and an underlying fascia condition. On the other hand, it has lesser value noting that the ICC values exhibited significant variations depending on the specific region under measurement. We posit that this variability may be attributed to the relative positioning of the measurement site and the assessor. In certain instances, achieving precise transducer placement proved to be more challenging, potentially leading to reduced measurement reliability. Future studies should endeavor to establish optimal sonographic evaluation positions for fascial sites to address this issue comprehensively.

No difference in fascial thickness between the right and left sides of the body was found in most measured sites (p-values ranged from 0.090 to 0.863). The only statistically significant differences were found at LA-HU ($p = 0.045$). We found no other studies that reported similar results. Hence, this is the first study indicating that fascial thickness is symmetrical in most sites, and comparing the sites can help detect fascial

Table 2
Interclass correlation of fascial thickness ultrasound measurements.

Tested area	1st tester 1st evaluation	1st tester 2nd evaluation	2nd tester evaluation	ICC, Significance	Intra-tester ICC (95% CI)	Inter-tester ICC (95% CI)
AN-CU right	1.18 ± 0.46	1.14 ± 0.37	1.19 ± 0.36	0.930, p > 0.001	0.863 (0.69–0.94)	0.846 (0.65–0.94)
AN-CU left	1.24 ± 0.60	1.23 ± 0.56	1.26 ± 0.52	0.975, p > 0.001	0.933 (0.84–0.97)	0.926 (0.82–0.97)
LA-HU right	0.97 ± 0.27	1.12 ± 0.21	1.09 ± 0.25	0.818, P < 0.001	0.786 (0.54, 0.91)	0.600 (0.23–0.82)
LA-HU left	1.09 ± 0.35	1.11 ± 0.29	1.12 ± 0.35	0.922, P < 0.001	0.900 (0.77–0.96)	0.782 (0.53–0.91)
AN-LU right	1.35 ± 0.4	1.35 ± 0.32	1.34 ± 0.38	0.920, P < 0.001	0.908 (0.78–0.96)	0.751 (0.47–0.89)
AN-LU left	1.33 ± 0.4	1.4 ± 0.35	1.35 ± 0.36	0.827, P < 0.001	0.677 (0.35–0.86)	0.473 (0.05–0.75)
AN-GE right	1.50 ± 0.61	1.45 ± 0.57	1.37 ± 0.58	0.987, P < 0.001	0.975 (0.94–0.99)	0.966 (0.92–0.99)
AN-GE left	1.54 ± 0.68	1.58 ± 0.65	1.45 ± 0.63	0.986, P < 0.001	0.963 (0.91–0.99)	0.961 (0.91–0.98)
RE-TA right	1.17 ± 0.33	1.11 ± 0.32	1.15 ± 0.3	0.911, P < 0.001	0.848 (0.66–0.94)	0.712 (0.41–0.88)
RE-TA left	1.13 ± 0.34	1.16 ± 0.35	1.13 ± 0.32	0.947, P < 0.001	0.883 (0.73–0.95)	0.842 (0.65–0.93)

ICC - inter-class correlation; Inter-tester reliability compared the 2nd measurements of the 1st assessor to the measurements of the 2nd assessor.
AN-CU - Ante cubitus; LA- HU - Lateral humerus; AN-LU - Ante lumbi; AN-GE - Ante genu; RE-TA - Retro talus.

Table 3
The comparison between measurements of the right and left sides (N = 21).

Tested area	Right side (Mean ± SD)	Left side (Mean ± SD)	Comparison (paired *t*-test)	Correlation	Cohen's d
AN-CU	1.14 ± 0.36	1.22 ± 0.55	T = 1.15, P = 0.263	R = 0.802, P < 0.001	0.001
LA-HU	1.01 ± 0.20	1.11 ± 0.29	T = 2.14, P = 0.045	R = 0.725, P < 0.001	0.001
AN-LU	1.35 ± 0.32	1.39 ± 0.34	T = 0.70, P = 0.492	R = 0.652, P = 0.001	0.002
AN-GE	1.45 ± 0.57	1.58 ± 0.65	T = 1.78, P = 0.090	R = 0.854, P < 0.001	0.001
RE-TA	1.11 ± 0.32	1.16 ± 0.34	T = 0.23, P = 0.234	R = 0.863, P < 0.001	0.001

SD - standard deviation; AN-CU - Ante cubitus; LA- HU - Lateral humerus; AN-LU - Ante lumbi; AN-GE - Ante genu; RE-TA - Retro talus.

Table 4
Mean comparison between the fascial thickness of the site of fascial densification vs. normal counterpart.

Associated areas	N	Thickness on the densified side (mm) (mean ± SD)	Thickness on the non-densified side (mm) (mean ± SD)	Comparison	Significance
AN-GE	9	1.81 ± 0.51	1.38 ± 0.33	T = 3.92	P = 0.004
IR-GE	5	1.60 ± 0.44	1.10 ± 0.15	T = 2.98	P = 0.040
AN-TA	8	1.21 ± 0.24	1.07 ± 0.16	T = 1.71	P = 0.130
RE-GE	8	1.71 ± 0.58	1.28 ± 0.47	T = 6.56	P = 0.000
LA-GE	8	1.91 ± 0.26	1.33 ± 0.32	T = 7.22	P = 0.000

SD - standard deviation, AN-CU - Ante cubitus; LA- HU - Lateral humerus; AN-LU - Ante lumbi; AN-GE - Ante genu; RE-TA - Retro talus.

abnormalities. Comparing fascial thickness at the sites of fascial densification (clinically assessed by an experienced FM practitioner) vs. normal counterpart showed statistically significant differences at AN-GE, RE-GE, and LA-GE ($p < 0.01$ for all sites) with a medium to high effect size (Cohen's $d = 0.3$). At IR-GE, the difference was statistically significant ($p < 0.05$) with a low effect size (Cohen's $d = 0.15$), and at the AN-TA site, differences were not statistically significant ($P > 0.05$).

Current practice relies on palpation to diagnose fascial alterations. We recommend ultrasonography as a valuable tool in estimating possible alterations in examined sites. This is the first study that showed that fascial densification detected by palpation, represents an actual alteration of the deep fascia that can be objectively assessed, thus providing validation to fascial palpation used in the FM method.

4.1. Limitations

Several limitations may affect the results reported in this study. Firstly, the FM methods to estimate fascial restrictions are subjective and, as such, limited. This study was based on a single evaluation of performing palpation verification in selected sites, and there is a possibility of a false-positive or false-negative diagnosis of fascial densification. Secondly, measured site borders (i.e., specific points measured in a selected site) were not precisely defined in line with the current practice; therefore, they may have resulted in differences in the reported measurements.

5. Conclusions

Intra and inter-rater reliability when measuring fascial thickness by sonography was high and may be used to evaluate fascial alterations. Future studies of deep fascia's normal and pathological parameters will enable clinicians to investigate its association with various pathologies in the locomotor system, in addition to providing a level of confidence in the sonographic evaluation of the deep fascia. This is the first study that showed that fascial densification detected by palpation represents an actual alteration of the deep fascia that can be objectively assessed, thus, providing validation to fascial palpation used in the FM method.

Clinical relevance

- Intra- and inter-rater reliability of sonographic measuring fascial thickness is high and, therefore, sonography may be used as a reliable quantitative method to evaluate fascial alterations.
- The fascial thickness of the site of fascial densification (Stecco's Fascial Manipulation method) is greater than in the normal counterpart.
- This is the first study that showed that fascial densification by palpation represents an actual alteration of the deep fascia that can be objectively assessed, thus providing validation to fascial palpation used in the FM method.

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CRediT authorship contribution statement

Shir Schadmy Levy: Writing – original draft, Investigation, Formal analysis, Conceptualization. **Kobi Weiss:** Writing – review & editing, Validation, Investigation. **Leonid Kalichman:** Writing – review & editing, Supervision, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

There are no known conflicts of interest associated with this paper.

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References

Adstrum, S., Nicholson, H., 2019. A history of fascia. Clin. Anat. 32 (7), 862–870. https://doi.org/10.1002/ca.23371.

Barnes, J.F., 1990. Myofascial Release: the Search for Excellence–A Comprehensive Evaluatory and Treatment Approach (A Comprehensive Evaluatory and Treatment Approach, tenth ed. Rehabilitation Services.

Bhansing, K.J., Van Rosmalen, M.H., Van Engelen, B.G., Vonk, M.C., Van Riel, P.L., Pillen, S., 2015. Increased fascial thickness of the deltoid muscle in dermatomyositis and polymyositis: an ultrasound study. Muscle Nerve 52 (4), 534–539. https://doi.org/10.1002/mus.24595.

Day, J.A., Copetti, L., Rucli, G., 2012. From clinical experience to a model for the human fascial system. J. Bodyw. Mov. Ther. 16 (3), 372–380. https://doi.org/10.1016/j.jbmt.2012.01.003.

Gibbon, W.W., 1996. Musculoskeletal ultrasound. Bailliere's Clin. Rheumatol. 10 (4), 561–588. https://doi.org/10.1016/S0950-3579(96)80052-5.

Hughes, E., Koenig, J., Lee, R., McDermott, K., Freilicher, T., Pitcher, M., 2022. Pilot study assessing the effect of Fascial Manipulation on fascial densifications and associated pain. European Journal of Translational Myology 32 (1). https://doi.org/10.4081/ejtm.2022.10369.

Kumka, M., Bonar, J., 2012. Fascia: a morphological description and clasification system based on literature review. J. Can. Chiropr. Assoc. 56 (3), 179–191.

Lakens, D., 2013. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Front. Psychol. 4, 1–12. https://doi.org/10.3389/fpsyg.2013.00863.

Langevin, H.M., Fox, J.R., Koptiuch, C., Badger, G.J., Greenan- Naumann, A.C., Bouffard, N.A., Konofagou, E.E., Lee, W.N., Triano, J.J., Henry, S.M., 2011. Reduced thoracolumbar fascia shear strain in human chronic low back pain. BMC Muscoskel. Disord. 12 https://doi.org/10.1186/1471-2474-12-203.

Luomala, T., Pihlman, M., Heiskanen, J., Stecco, C., 2014. Case study: could ultrasound and elastography visualized densified areas inside the deep fascia? J. Bodyw. Mov. Ther. 18 (3), 462–468. https://doi.org/10.1016/j.jbmt.2013.11.020.

Munro, B., 2004. Statistical Methods for Health Care Research, fifth ed. Lippincott William and Wilkins.

Pavan, P.G., Stecco, A., Stern, R., Stecco, C., 2014. Painful connections: densification versus fibrosis of fascia. Curr. Pain Headache Rep. 18 (8) https://doi.org/10.1007/s11916-014-0441-4.

Pirri, C., Todros, S., Fede, C., Pianigiani, S., Fan, C., Foti, C., Stecco, C., Pavan, P., 2019. Inter-rater reliability and variability of ultrasound measurements of abdominal muscles and fasciae thickness. Clin. Anat. 32 (7), 948–960. https://doi.org/10.1002/ca.23435.

Scheel, A.K., Schmidt, W.A., Hermann, K.G.A., Bruyn, G.A., D'Agostino, M.A., Grassi, W., Iagnocco, A., Koski, J.M., Machold, K.P., Naredo, E., Sattler, H., Swen, N., Szkudlarek, M., Wakefield, R.J., Ziswiler, H.R., Pasewaldt, D., Werner, C., Backhaus, M., 2005. Interobserver reliability of rheumatologists performing musculoskeletal ultrasonography: results from a EULAR "Train the trainers" course. Ann. Rheum. Dis. 64 (7), 1043–1049. https://doi.org/10.1136/ard.2004.030387.

Stecco, L., 2004. Fascial Manipulation for Musculoskeletal Pain. Piccin Nuova, Libraria S.

Stecco, A., Cowman, M., Pirri, N., Raghavan, P., Pirri, C., 2022. Densification: hyaluronan aggregation in different human organs. Bioengineering (Basel) 9 (4), 159. https://doi.org/10.3390/bioengineering9040159.

Stecco, A., Meneghini, A., Stern, R., Stecco, C., Imamura, M., 2014. Ultrasonography in myofascial neck pain: randomized clinical trial for diagnosis and follow-up. Surg. Radiol. Anat. 36 (3), 243–253. https://doi.org/10.1007/s00276-013-1185-2.

Stecco, L., Stecco, C., 2009. Fascial Manipulation: Practical Part. Piccin Nuova, Libraria S.

Wilke, J., Macchi, V., De Caro, R., Stecco, C., 2019. Fascia thickness, aging and flexibility: is there an association? J. Anat. 234 (1), 43–49. https://doi.org/10.1111/joa.12902.

Zügel, M., Maganaris, C.N., Wilke, J., Jurkat-Rott, K., Klingler, W., Wearing, S.C., Findley, T., Barbe, M.F., Steinacker, J.M., Vleeming, A., Bloch, W., Schleip, R., Hodges, P.W., 2018. Fascial tissue research in sports medicine: from molecules to tissue adaptation, injury and diagnostics: consensus statement. Br. J. Sports Med. 52 (23), 1497. https://doi.org/10.1136/bjsports-2018-099308.