UDC 611.959:616-018.2-076.4
DOI http://doi.org/10.30978/GS-2026-2-8

ISSN 2786-5584 print
ISSN 2786-5592 online

Morphological types of the external oblique abdominal muscle aponeurosis: a morphometric and histological justification

L. Y. Markulan[1], K. V. Halperin[1], S. V. Pakrishen[2]

[1] Bogomolets National Medical University
[2] KNP «St. Michael's Clinical Hospital of Kyiv»

Leonid Markulan: markulan@ukr.net

L. Y. Markulan, http://orcid.org/0000-0003-2879-5012
K. V. Halperin, http://orcid.org/0009-0002-9453-5104
S. V. Pakrishen, http://orcid.org/0009-0007-0560-9703

Objective – to investigate the histological and morphometric characteristics of the external oblique aponeurosis in the region associated with the linea semilunaris (the Ambivium zone).

Materials and methods. The study included 34 women aged 22–54 years (mean age: 36.2 ± 7.3 years) who underwent abdominoplasty for cosmetic defects of the anterior abdominal wall. During surgery, standardized fragments of the external oblique aponeurosis were obtained from symmetrical regions adjacent to the lateral border of the rectus sheath. Histological, histochemical, and morphometric analyses were performed, including assessment of collagen bundle thickness, width of the endotenonium and peritenonium, parameters of the microcirculatory bed, and the relative areas occupied by collagen, peritenonium, and vessels. Hierarchical cluster analysis and the k-means method were applied to systematize the identified structural variants.

Results. Morphometric analysis revealed substantial variability in the structural organization of the aponeurosis: the proportion of collagen fibers ranged from 61.1 % to 91.2 %, the proportion of peritenonium from 7.3 % to 33.9 %, and the compactness coefficient from 0.64 to 0.93. Cluster analysis enabled the identification of three morphotypes: compact (35.3 %), transitional (26.5 %), and disorganized (38.2 %). The compact morphotype was characterized by a high proportion of collagen (89.32 ± 1.52 %), minimal content of peritenonium (8.86 ± 1.15 %), and the highest compactness coefficient 0.91 ± 0.01. In contrast, the disorganized morphotype demonstrated the lowest proportion of collagen (68.18 ± 4.04 %), the highest content of peritenonium (26.87 ± 4.11 %), a low compactness coefficient 0.72 ± 0.05, widening of interfascicular spaces, remodeling of the vascular component, and signs of pronounced histostructural reorganization. The transitional morphotype occupied an *intermedia*te position. All intercluster differences were statistically significant ($p < 0.001$).

Conclusions. Morphometric and cluster analysis of the external oblique aponeurosis revealed substantial structural variability and enabled the identification of three morphotypes–compact, transitional, and disorganized–which differed in the proportions of collagen fibers, peritenonium, vascular component, and compactness parameters. The identified morphological heterogeneity of the aponeurosis reflects different degrees of structural remodeling and may represent one of the factors contributing to variability in the outcomes of surgical correction of the anterior abdominal wall, thereby supporting the rationale for further individualization of surgical strategy.

Keywords
external oblique aponeurosis, EIT Ambivium, linea semilunaris, Spigelian zone, morphometry, histology, morphotypes, abdominoplasty.

ARTICLE • Received 2026-03-15 • Received in revised form 2026-04-18 • Published 2026-05-31
© 2026 Authors. Published under the CC BY-ND 4.0 license

The anterior abdominal wall is a complex anatomical and functional system in which the interaction of muscular and aponeurotic structures ensures the transmission of mechanical forces, the stabilization of the trunk, and the formation of the external abdominal contour [21, 22]. An important anatomical landmark is the lateral border of the rectus abdominis muscle, commonly referred to as the *linea semilunaris* (semilunar or Spigelian line). This structure is historically associated with Adriaan van den

Spieghel [24]. The term *linea semilunaris* has since been established to denote the arcuate tendinous line corresponding to the lateral border of the rectus abdominis muscle or its sheath, extending from the costal arch to the pubic region [21, 22].

Alternative interpretations of this structure have also been identified in the literature. In particular, some surgical textbooks define the *linea semilunaris* as the zone where the transversus abdominis muscle transitions into its aponeurosis, whereas the area between this line and the lateral border of the rectus abdominis muscle is termed the *Spigelian fascia* [6, 10]. These perspectives reflect clinical interpretations but do not completely align with classical anatomy.

Contemporary anatomical studies have refined the traditional understanding of the organization of the lateral portions of the anterior abdominal wall. M. Vierstraete et al. demonstrated that the lateral border of the rectus sheath does not correspond to an isolated anatomical line, but rather to a zone of fusion of the aponeuroses of the external oblique, internal oblique, and transversus abdominis muscles. The authors designated this region as the EIT (External–Internal–Transversus) *Ambivium*, emphasizing its origin from the three lateral abdominal wall muscles. The EIT *Ambivium* is a complex aponeurotic structure that integrates multiple musculofascial components [24].

In contrast to the classical interpretation of the *linea semilunaris* or Spigelian line as a conventional anatomical line, the *Ambivium* is regarded as a spatially extended zone with distinct morphological and functional characteristics. This approach suggests that the region should be viewed not as a geometric line of tissue transition, but as an area of interaction between aponeurotic structures. Importantly, the authors propose this term as a more precise anatomical definition that integrates and harmonizes the morphological and functional aspects of the organization of this zone [24].

From a biomechanical perspective, the anterior abdominal wall functions as a composite system, with its mechanical properties determined by the interaction of its individual layers [2, 3, 5, 11, 15, 24]. Contraction of the transversus abdominis and oblique abdominal muscles generates a system of tension with force vectors directed both medially and laterally [4, 17, 23]. The aponeurotic structures provide the transmission and redistribution of these forces [2, 3, 5, 19].

Experimental and clinical studies have demonstrated that transection of the external oblique aponeurosis reduces lateral tension in the abdominal wall and alters the distribution of mechanical forces [12, 16].

Despite advances in contemporary anatomical and biomechanical concepts, the morphological characteristics of the lateral aponeurotic region remain insufficiently studied. Data from computed tomography morphometry also confirm substantial individual variability in the components of the abdominal wall, including its muscular and aponeurotic structures. These findings underscore the need for a quantitative approach to assessing its structural organization [7].

Most studies have focused primarily on the *linea alba* [9], whereas the lateral structures have received considerably less attention. Clinical observations suggest a potential role of the lateral abdominal wall in shaping the abdominal contour, particularly the waistline [14, 18, 12, 13, 20].

Given these findings, the investigation of individual components of the fusion zone of the lateral abdominal wall aponeuroses is particularly relevant. Special attention should be paid to the aponeurosis of the external oblique muscle, which is integral to the transmission of mechanical forces. To date, no systematic data are available regarding the morphological organization of the external oblique aponeurosis in this region.

Objective – to investigate the histological and morphometric features of the external oblique aponeurosis in the region associated with the *linea semilunaris* (the *Ambivium* zone).

Materials and methods

The study included 34 women aged 22 to 54 years (mean age: 36.2 ± 7.3 years) who underwent abdominoplasty for cosmetic defects of the anterior abdominal wall.

The study was conducted in accordance with the principles of the World Medical Association. All patients provided written informed consent for participation in the study and for the use of biological material for scientific purposes. The study protocol was approved by the local Ethics Committee of Bogomolets National Medical University (Protocol No 188 dated October 28, 2024).

Histological, histochemical, and morphometric analyses were performed on fragments of the external oblique aponeurosis obtained during surgery. Tissue specimens measuring 1.0 × 1.0 × 0.3 cm were harvested from symmetrical regions of the anterior abdominal wall at a distance of 0.5 cm from the lateral border of the rectus sheath, along a line located 1.0 cm inferior to the umbilicus.

The specimens were fixed in 10 % neutral buffered formalin and subjected to standard histological processing followed by paraffin embedding.

Sections 4 μm thick were stained with hematoxylin and eosin. Histochemical methods were also applied to evaluate collagenous and elastic structures.

Morphometric analysis was performed on digital microphotographs obtained using a light microscope (Leica DM LS2) under standardized imaging conditions. Image calibration was carried out using a micrometric scale. Collagen fibers, peritenonium, and microcirculatory vessels were identified according to their morphological characteristics.

The thickness of collagen fiber bundles, the width of the endotenonium and peritenonium, the diameter of capillaries, as well as the relative area occupied by collagen fibers, peritenonium, and vessels were determined. The relative area of each component was calculated as the percentage ratio of the area of the corresponding structure to the total field area according to the following formula:

$$\text{Relative area (\%)} = \frac{\text{Structure area}}{\text{Field area}} \cdot 100\,\%.$$

For each patient, fragments of the aponeurosis obtained from symmetrical regions on both sides of the rectus sheath were examined. In each specimen, at least five microscopic fields were analyzed. Thus, the total number of fields examined per patient was at least ten. The obtained values were averaged for each patient and subsequently used for statistical analysis. The sum of the relative areas of the assessed components approached 100 %.

Additionally, a compactness coefficient was calculated as the ratio of the area occupied by collagen fibers to the combined area of collagen and peritenonium:

$$\text{Compactness coefficient} = \frac{S_{\text{Collagen}}}{S_{\text{Collagen}} + S_{\text{Peritenonium}}},$$

which reflects the degree of density and organization of the collagen structures.

Table 1. **Generalized morphometric characteristics of the external oblique aponeurosis (n = 34)**

Parameter	M ± SD	Min–Max
Thickness of collagen fiber bundles, μm	27.1 ± 11.7	13.4–46.7
Width of the endotenonium, μm	15.2 ± 5.9	8.1–23.1
Width of the peritenonium, μm	85.9 ± 37.6	45.8–143.5
Capillary diameter, μm	12.2 ± 3.6	8.0–19.5
Relative area of collagen fibers, %	78.5 ± 9.6	61.1–91.2
Relative area of peritenonium, %	18.2 ± 8.3	7.3–33.9
Relative area of vessels, %	2.9 ± 1.5	1.3–5.6
Compactness coefficient	0.81 ± 0.10	0.64–0.93

Statistical data analysis was performed using IBM SPSS Statistics software (version 22.0). Quantitative variables are presented as mean values and standard deviations (M ± SD).

Cluster analysis was performed to identify structural groups. At the first stage, hierarchical cluster analysis (Ward's method with squared Euclidean distance) was applied to determine the optimal number of clusters. At the second stage, k-means clustering with a fixed number of clusters ($k = 3$) was performed. Prior to clustering, all variables were standardized using Z-scores.

One-way analysis of variance (ANOVA) was used to compare parameters between clusters. Differences were considered statistically significant at $p < 0.05$.

Results

Morphometric analysis of the external oblique aponeurosis revealed a wide range of values for the investigated parameters, indicating substantial heterogeneity within the study sample (Table 1).

Considerable variability was identified in both the linear and area-related characteristics. In particular, the relative area occupied by collagen fibers ranged from 61.1 % to 91.2 %, whereas the proportion of peritenonium varied from 7.3 % to 33.9 %. The compactness coefficient also demonstrated a broad range of values (0.64–0.93).

Analysis of the individual parameter values showed that this variability was not random, but rather formed distinct combinations of morphometric features. Specifically, a decrease in the proportion of collagen fibers was associated with an increase in the area occupied by the peritenonium and a reduction in the compactness coefficient.

The identified patterns indicated the presence of structurally distinct variants of aponeurotic organization, thereby supporting the rationale for the application of cluster analysis for their systematization.

To identify morphologically homogeneous groups, cluster analysis of the morphometric parameters was performed. At the first stage, hierarchical cluster analysis determined the optimal number of clusters to be three. At the second stage, k-means clustering with a fixed number of clusters ($k = 3$) was applied.

Three clusters were identified, differing in the pattern of combination of morphometric characteristics: the compact morphotype (cluster 1), the transitional morphotype (cluster 2), and the disorganized morphotype (cluster 3) (Fig. 1).

The distribution of specimens according to the standardized values (Z-scores) of the relative areas occupied by collagen fibers and peritenonium

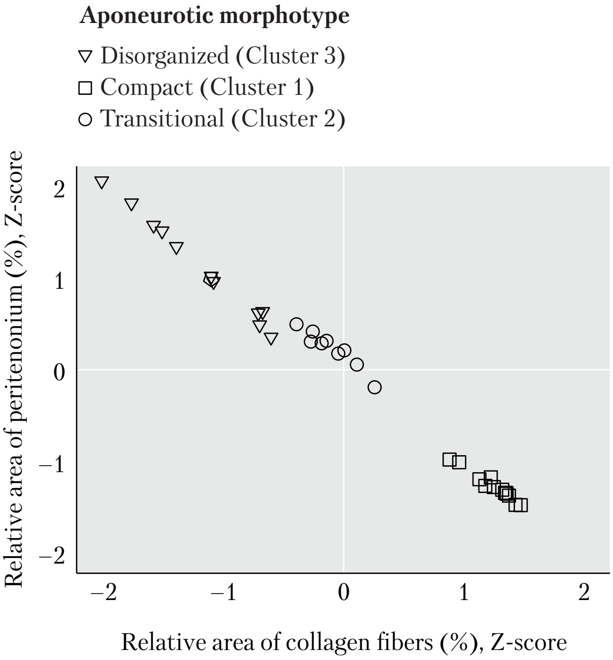

Fig. 1. **Distribution of aponeurotic specimens according to the morphotypes identified by cluster analysis. Each point corresponds to an individual specimen. Parameter values are presented in a standardized form (Z-score), where 0 corresponds to the mean value of the study sample**

demonstrated a clear separation between clusters, indicating the presence of structurally distinct variants of aponeurotic organization. Thus, cluster analysis of the morphometric parameters enabled the identification of three groups of specimens differing in the structural characteristics of the aponeurosis (Tables 2, 3).

Cluster 1 (n = 12, 35.3 %) was characterized by the highest proportion of collagen fibers, the lowest content of peritenonium, and the highest compactness coefficient, corresponding to the most dense and organized aponeurotic architecture. This cluster was also characterized by the greatest thickness of collagen bundles, minimal width of interfascicular spaces, and the smallest vessel diameter, indicating preserved structural integrity of the tissue.

In contrast, Cluster 3 (n = 13, 38.2 %) demonstrated the lowest proportion of collagen fibers, the highest content of peritenonium, and the lowest compactness coefficient, indicating pronounced disorganization of the aponeurotic structure. These changes were accompanied by a marked reduction in collagen bundle thickness, substantial widening of interfascicular spaces, and an increase in capillary diameter, reflecting remodeling of the microcirculatory bed.

Cluster 2 (n = 9, 26.5 %) occupied an intermediate position between the two extreme variants and was characterized by moderate values of both area-related and linear parameters. This cluster demonstrated a partial reduction in the proportion of collagen, accompanied by a corresponding increase in the content of peritenonium, which was associated with moderate widening of interfascicular spaces and minor alterations of the vascular component.

For morphological interpretation of the identified clusters, histological analysis was performed, allowing

Table 2. **Morphometric characteristics of the aponeurotic clusters (mean ± SD)**

Parameter	Cluster 1 (compact; n = 12)	Cluster 2 (transitional; n = 9)	Cluster 3 (disorganized; n = 13)	p (ANOVA)
Collagen, %	89.32 ± 1.52	77.62 ± 1.77	68.18 ± 4.04	< 0.001
Peritenonium, %	8.86 ± 1.15	20.17 ± 1.53	26.87 ± 4.11	< 0.001
Vessels, %	1.82 ± 0.48	2.21 ± 0.52	4.95 ± 0.41	< 0.001
Compactness coefficient	0.91 ± 0.01	0.80 ± 0.02	0.72 ± 0.05	< 0.001

Table 3. **Linear morphometric parameters of the aponeurosis, μm (mean ± SD)**

Parameter	Cluster 1 (compact; n = 12)	Cluster 2 (transitional; n = 9)	Cluster 3 (disorganized; n = 13)	p (ANOVA)
Thickness of collagen bundles	40.58 ± 3.64	23.42 ± 3.96	15.00 ± 1.05	< 0.001
Width of the endotenonium	10.92 ± 3.97	13.47 ± 5.73	21.00 ± 1.47	< 0.001
Width of the peritenonium	54.48 ± 8.53	69.94 ± 23.60	132.00 ± 8.53	< 0.001
Capillary diameter	9.40 ± 1.01	10.88 ± 1.58	16.27 ± 2.74	< 0.001

correlation of the quantitative parameters with the microstructural organization of the aponeurosis.

Histological examination of fragments of the external oblique aponeurosis within the *Ambivium* zone revealed that the structural organization of the tissue was not binary (intact/pathological), but rather represented a continuum of changes which, based on cluster analysis, were grouped into three morphotypes: compact, transitional, and disorganized.

Compact Morphotype (Cluster 1)

At the light microscopic level, the aponeurosis was characterized by an organized structural architecture. The majority of the tissue consisted of densely packed bundles of collagen fibers arranged in a parallel or slightly intersecting pattern. First-order bundles formed larger structural units that preserved their compactness and well-defined contours.

The interfascicular spaces (endotenonium) were represented by narrow clefts containing a small amount of amorphous substance and isolated fibroblast-lineage cells. The spaces between second-order bundles (peritenonium) were moderately expressed and consisted of loose connective tissue containing a small number of vessels.

The vessels of the microcirculatory bed were sparse and showed no signs of remodeling; their walls were preserved, and the lumina were not dilated. Aponeurotic fibers occasionally contained elastic components interwoven with the collagen bundles without disrupting their structural organization.

Morphometrically, this type was characterized by a large relative area occupied by collagen fibers, a low content of peritenonium, and the highest values of the compactness coefficient, reflecting high tissue density and preserved functional capacity of the aponeurosis (Fig. 2, 3).

Transitional Morphotype (Cluster 2)

The transitional type was characterized by moderate structural alterations of the aponeurosis, with preservation of the general architectonics despite signs of structural disturbance.

Collagen bundles partially lost their organized arrangement: their orientation became less parallel, with focal initial fiber dissociation and irregularity in bundle thickness. In some areas, fragmentation of individual fibers was observed.

The interfascicular spaces were widened, accompanied by an increase in the proportion of endotenonium and peritenonium. The latter was represented by loose connective tissue containing a moderate number of cells and vessels.

The vessels of the microcirculatory bed could be mildly dilated; however, pronounced signs of vascular remodeling or neoangiogenesis were absent or minimal.

Morphometrically, the transitional type occupied an intermediate position between the compact and disorganized morphotypes: the relative area of collagen was reduced compared with the compact type, whereas the proportion of peritenonium was increased; the compactness coefficient demonstrated intermediate values.

This morphotype reflects a stage of structural remodeling of the aponeurosis (Fig. 4, 5).

Disorganized Morphotype (Cluster 3)

The disorganized type was characterized by pronounced restructuring of the aponeurotic architecture with loss of its structural integrity and compact organization.

Collagen bundles were markedly thinned, lost their distinct organization, and demonstrated dissociation and fragmentation. In a number of cases, the bundles disintegrated into individual fibers exhibiting a wavy, irregular course. Areas of hyalinosis

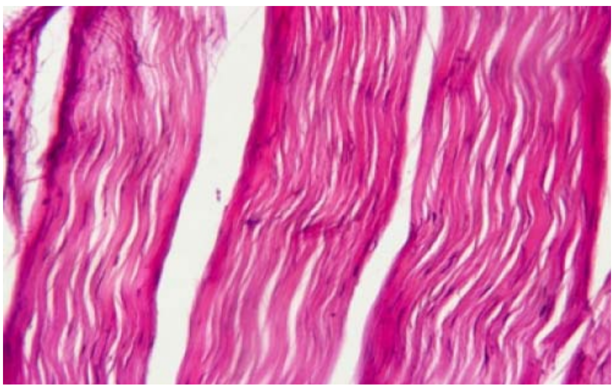

Figure 2. **Parallel arrangement of collagen fiber bundles with thin interfascicular spaces.** Hematoxylin and eosin staining. × 200

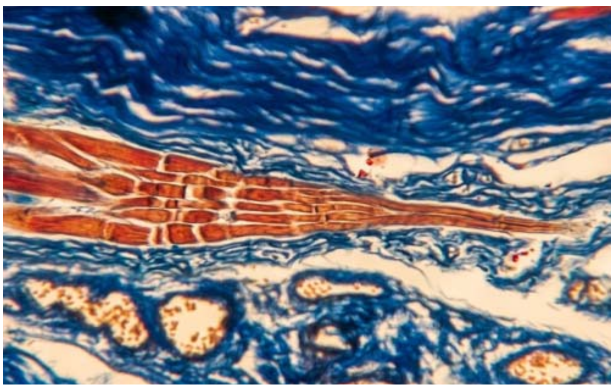

Figure 3. **Neurovascular bundle within the thickness of the peritenonium.** Landrum's picro-Mallory staining. × 200

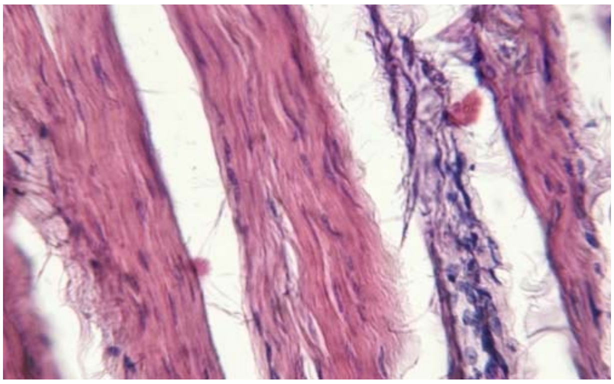

Figure 4. **Partial atrophy of collagen fiber bundles with widening of interfascicular spaces.** Hematoxylin and eosin staining. × 400

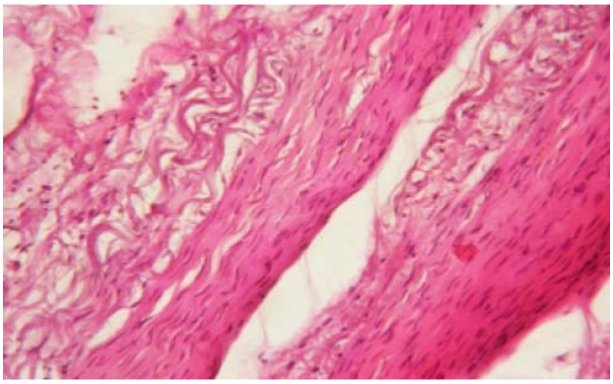

Figure 5. **Dissociation, waviness, and fragmentation of collagen fibers.** Hematoxylin and eosin staining. × 200

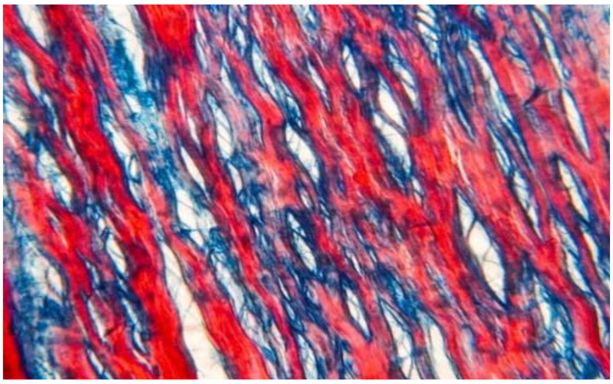

Figure 6. **Hyalinosis of collagen fibers.** MSB staining. × 100

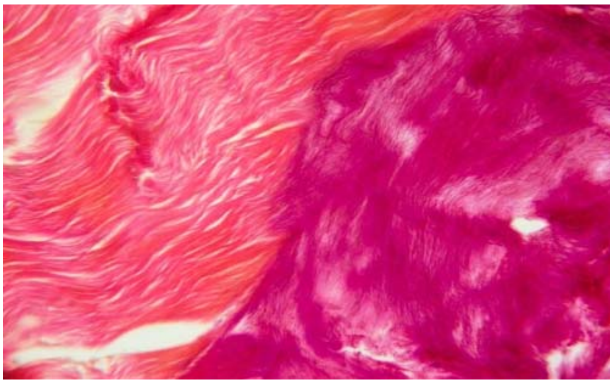

Figure 7. **Fibrinoid necrosis of collagen fibers.** P.A.S. staining according to Hotchkiss–McManus. × 400

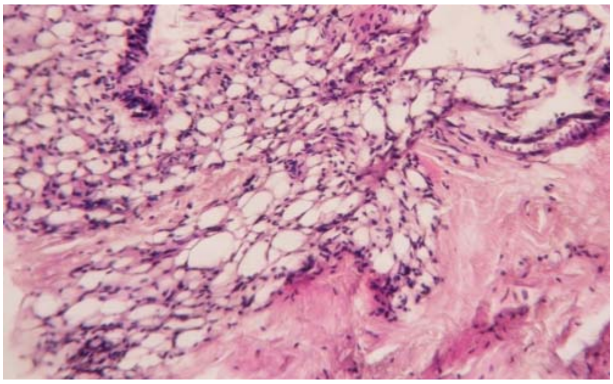

Figure 8. **Fatty infiltration of the interfascicular spaces within the Spigelian line region.** Hematoxylin and eosin staining. × 100

and homogenization of collagen structures were identified, indicating chronic ischemic changes.

The interfascicular spaces were markedly widened. The endotenonium and peritenonium occupied a substantial proportion of the tissue area and were represented by loose, unstructured connective tissue with a pronounced cellular component. Foci of fatty infiltration were frequently identified within these regions.

The vessels of the microcirculatory bed were numerous and dilated, with signs of impaired hemodynamics. Vascular walls were thickened and focally sclerotic; signs of neoangiogenesis, including newly formed thin-walled vessels, were also observed.

Foci of myxoid degeneration, fibrinoid changes, and necrobiotic processes within the collagen fibers were identified. The number of fibroblast-lineage cells was increased; these cells exhibited signs of functional activation and were distributed in a disorganized manner.

Morphometrically, this type was characterized by the minimal thickness of collagen bundles, maximal widening of the endotenonium and peritenonium, increased diameter and number of vessels, as well as a reduced compactness coefficient.

These changes reflect profound disorganization of the aponeurosis accompanied by loss of its mechanical integrity (Fig. 6–8).

The obtained results indicate that the aponeurosis within the region of the Spigelian line undergoes gradual structural remodeling, which may be represented by three morphotypes reflecting different stages of remodeling, ranging from a compact structure to its disorganization.

This approach allows a transition from a binary assessment of the aponeurotic condition to a stratified evaluation of its structural alterations, thereby providing a basis for clinical interpretation and individualization of surgical strategy.

Discussion

The obtained results should be interpreted in the context of contemporary concepts regarding the anatomical and functional organization of the lateral abdominal wall. The traditional interpretation of the *linea semilunaris* as an isolated anatomical landmark does not fully reflect the complex interaction of aponeurotic structures within this region. According to current anatomical data, the lateral border of the rectus sheath corresponds to the fusion zone of the aponeuroses of the lateral abdominal wall muscles (the EIT *Ambivium*), which is not identical to the *linea semilunaris* in the narrow anatomical sense [24].

From a biomechanical perspective, the anterior abdominal wall functions as a composite system in which the mechanical properties are determined by the interaction of its individual layers rather than by their simple summation [2, 3, 5, 19, 11]. This implies that even localized structural alterations of individual aponeurotic components may influence the mechanical behavior of the entire system.

The function of the lateral abdominal wall is based on the coordinated activity of the transversus abdominis and oblique muscles, which form an integrated system responsible for trunk stabilization [4, 17, 23]. These muscles have been shown not to function in isolation, but rather to interact through aponeurotic structures that ensure the transmission and redistribution of mechanical forces [2, 3, 5, 19]. A particularly important role in this process is attributed to the transversus abdominis muscle, the activation of which is associated with alterations in the tension of fascial and aponeurotic structures as well as with the regulation of intra-abdominal pressure [4, 17, 23]. It has also been demonstrated that different portions of this muscle may be activated differentially depending on the functional load, reflecting the complexity of force transmission mechanisms.

Within the concept of the fascial continuum, the aponeuroses of the lateral abdominal wall muscles are regarded as components of a unified mechanical system in which structural alterations of one component may affect the functional state of the entire construct [19]. In this context, the fusion zone of these aponeuroses (*Ambivium*) may be considered an interface for the transmission and redistribution of forces between individual musculoaponeurotic components.

Clinical and experimental observations indicate that disruption of the integrity of the aponeurotic structures of the lateral abdominal wall is associated with reduced tissue tension, thereby emphasizing their role in maintaining the mechanical stability of the system [12, 16].

In light of our findings, the morphological alterations of the external oblique aponeurosis–including disorganization of collagen fibers, reduction in their density, and fatty infiltration–may indicate decreased mechanical strength of the tissue. Within the framework of the composite model, such changes may correspond to impaired ability of the tissue to effectively withstand and transmit mechanical loads.

The identified alterations were not random, but rather formed relatively stable combinations of morphometric features that were systematized into three morphotypes: compact (35.3 %), transitional (26.5 %), and disorganized (38.2 %). The transition from the compact to the disorganized morphotype was accompanied by a decrease in the proportion of collagen fibers from 89.32 % to 68.18 %, an increase in the proportion of peritenonium from 8.86 % to 26.87 %, and a reduction in the compactness coefficient from 0.91 to 0.72.

A similar approach has previously been applied to the *linea alba*. It has been established that the thickness and density of collagen fibers correlate with its mechanical strength, whereas the combination of thin fibers and low density may form a morphologically weak type of aponeurotic structure [1, 9]. These findings support the concept that the morphological organization of aponeurotic structures is directly related to their functional properties.

These results acquire particular significance in the context of abdominal contour formation. Clinical observations in aesthetic surgery indicate that interventions involving the lateral portions of the abdominal wall may alter abdominal contours, particularly contributing to the formation of a more pronounced waistline [12–14, 18, 20]. Although these effects are generally described at the macroscopic level, the underlying mechanisms remain insufficiently understood.

From a biomechanical standpoint, it may be assumed that structural impairment of the aponeurotic components of the lateral abdominal wall, particularly the external oblique aponeurosis, is associated with reduced lateral tension and altered force distribution within the system. In turn, this may influence the formation of abdominal contours, including the definition of the waistline [12, 16, 20].

Thus, the identified morphological alterations may be regarded as one of the potential structural factors involved in shaping the external appearance of the anterior abdominal wall. Given that the disorganized morphotype was identified in 38.2 % of cases and the transitional morphotype in 26.5 %, structural heterogeneity of the aponeurosis may have a clinically significant impact on the variability of surgical outcomes following correction of the anterior abdominal wall.

Therefore, the lateral aponeurotic zone (*Ambivium*) should be considered as part of an integrated functional complex in which structural alterations of the external oblique aponeurosis may influence the mechanical and morphological characteristics of the entire abdominal wall.

The obtained results provide a foundation for further studies aimed at integrating morphological, biomechanical, and clinical data in order to develop individualized approaches to surgical correction of the anterior abdominal wall.

Study Limitations

The study had several limitations. First, the analysis was performed exclusively on material obtained from women undergoing abdominoplasty, which may limit extrapolation of the results to other patient groups, particularly men or individuals without alterations of the anterior abdominal wall.

Second, the morphological investigation was limited to only one component of the lateral aponeurotic zone–the external oblique aponeurosis–without a comprehensive assessment of the other components, including the aponeuroses of the internal oblique and transversus abdominis muscles. This limitation restricts the interpretation of the findings within the context of the entire functional system.

Third, the study used a cross-sectional design and therefore did not allow for the assessment of causal relationships between the identified morphological alterations and the functional characteristics of the abdominal wall.

The absence of direct biomechanical measurements also limits the ability to quantitatively assess the impact of morphological changes on tissue mechanical properties, underscoring the need for further experimental studies.

Conclusions

Morphometric and cluster analysis of the external oblique aponeurosis revealed substantial structural variability and enabled the identification of three morphotypes–compact (35.3 %), transitional (26.5 %), and disorganized (38.2 %)–which differed in the proportions of collagen fibers, peritenonium, vascular component, and compactness parameters.

The disorganized morphotype was characterized by the lowest proportion of collagen fibers (68.18 ± 4.04 %), the highest content of peritenonium (26.87 ± 4.11 %), a reduced compactness coefficient 0.72 ± 0.05, widening of interfascicular spaces, and remodeling of the microcirculatory bed.

The identified morphological heterogeneity of the aponeurosis reflects different degrees of structural remodeling and may represent one of the factors contributing to variability in the outcomes of surgical correction of the anterior abdominal wall, thereby supporting the rationale for further individualization of surgical strategy.

Declaration of interests

The authors declare no conflict of interest.

Funding. The study was conducted without external financial support.

Authors contributions

L. Y. Markulan: study concept and design, statistical analysis, critical revision of the manuscript; K. V. Halperin: data collection and analysis, drafting the manuscript; S. V. Pakrishen: histological and histochemical examination of the material, preparation and verification of histological specimens, microscopic analysis, and interpretation of morphological changes.

References

1. Axer H, von Keyserlingk DG, Prescher A. Collagen fibers in linea alba and rectus sheaths. I. General scheme and morphological aspects. J Surg Res. 2001;96(1):127-134. doi: 10.1006/jsre.2000.6070.
2. Brown SH, McGill SM. How the inherent stiffness of the in vivo human trunk varies with changing magnitudes of muscular activation. Clin Biomech (Bristol). 2008 Jan;23(1):15-22. doi: 10.1016/j.clinbiomech.2007.08.011. Epub 2007 Oct 1. PMID: 17910898.
3. Hodges PW, Eriksson AE, Shirley D, Gandevia SC. Intra-abdominal pressure increases stiffness of the lumbar spine. J Biomech. 2005 Sep;38(9):1873-80. doi: 10.1016/j.jbiomech.2004.08.016. PMID: 16023475.
4. Hodges PW, Moseley GL. Pain and motor control of the lumbopelvic region: effect and possible mechanisms. J Electromyogr Kinesiol. 2003 Aug;13(4):361-70. doi: 10.1016/s1050-6411(03)00042-7. PMID: 12832166.
5. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther. 1997 Feb;77(2):132-42; discussion 142-4. doi: 10.1093/ptj/77.2.132. PMID: 9037214.
6. Huttinger R, Sugumar K, Baltazar-Ford KS. Spigelian hernia. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan–. Available from: https://www.ncbi.nlm.nih.gov/books/NBK538290/.
7. Jourdan A, Soucasse A, Scemama U, Gillion JF, Chaumoitre K, Masson C, et al. Abdominal wall morphometric variability based on computed tomography: influence of age, gender, and body mass index. Clin Anat. 2020 Nov;33(8):1110-1119. doi: 10.1002/ca.23548.
8. Katsaros I, Papapanou M, Kontogeorgi E, Tsakotos G, Filippou D, Papaconstantinou D, Paspala A, Chatzimavroudis G, Kykalos S, Schizas D. Spigelian hernias in the adult population: a systematic review of the literature. Langenbecks Arch Surg. 2024 Jul 29;409(1):230. doi: 10.1007/s00423-024-03427-4. PMID: 39073648.
9. Korenkov M, Beckers A, Koebke J, Lefering R, Tiling T, Troidl H. Biomechanical and morphological types of the linea alba and its possible role in the pathogenesis of midline incisional hernia. Eur J Surg. 2001;167(12):909-14. doi: 10.1080/110241501753361596.
10. Larson DW, Farley DR. Spigelian hernias: repair and outcome for 81 patients. World J Surg. 2002;26(10):1277-1281. doi: 10.1007/s00268-002-6605-0.

11. Levillain A, Orhant M, Turquier F, Hoc T. Contribution of collagen and elastin fibers to the mechanical behavior of an abdominal connective tissue. J Mech Behav Biomed Mater. 2016;61:308-317. doi: 10.1016/j.jmbbm.2016.04.006.
12. Lockwood T. High-lateral-tension abdominoplasty with superficial fascial system suspension. Plast Reconstr Surg. 1995 Sep;96(3):603-15. doi: 10.1097/00006534-199509000-00012. PMID: 7638284.
13. Matarasso A, Matarasso DM, Matarasso EJ. Abdominoplasty: classic principles and technique. Clin Plast Surg. 2014 Oct;41(4):655-72. doi: 10.1016/j.cps.2014.07.005. PMID: 25283453.
14. Nahas FX. An aesthetic classification of the abdomen based on the myoaponeurotic layer. Plast Reconstr Surg. 2001;108(6):1787-1795. doi: 10.1097/00006534-200111000-00043.
15. Nessel R, Lesch C, Vollmer M, Kallinowsk F. Biomechanical principles of a permanently durable abdominal wall reconstruction: current status and potential future development. Mini-invasive Surgery. 2023;7(1):21. doi: 10.20517/2574-1225.2023.21.
16. Ramirez OM, Ruas E, Dellon AL. «Components separation» method for closure of abdominal-wall defects: an anatomic and clinical study. Plast Reconstr Surg. 1990 Sep;86(3):519-26. doi: 10.1097/00006534-199009000-00023. PMID: 2143588.
17. Richardson CA, Hodges PW, Hides JA. Therapeutic Exercise for Lumbopelvic Stabilization. 2nd ed. Churchill Livingstone; 2004.
18. Saldanha OR, Federico R, Daher PF, Malheiros AA, Carneiro PRG, Azevedo SFD, Saldanha Filho OR, Saldanha CB. Lipoabdominoplasty. Plast Reconstr Surg. 2009 Sep;124(3):934-942. doi: 10.1097/PRS.0b013e3181b037e3. PMID: 19730314.
19. Schleip R, Findley TW, Chaitow L, Huijing PA. Fascia: The Tensional Network of the Human Body. Elsevier; 2012.
20. Shestak KC, Rios L, Pollock TA, Aly A. Evidenced-based approach to abdominoplasty update. Aesthetic Surg J. 2019;39(6):628-642. doi: 10.1093/asj/sjy215.
21. Skandalakis JE, Colborn GL, Weidman TA, Foster RS, Kingsnorth AN. Skandalakis' surgical anatomy: the embryologic and anatomic basis of modern surgery. Athens: Paschalidis Medical Publications; 2004.
22. Standring S, ed. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 42nd ed. London: Elsevier; 2021.
23. Urquhart DM, Hodges PW, Allen TJ, Story IH. Abdominal muscle recruitment during a range of voluntary exercises. J Orthop Res. 2005;23(2):463-470. doi: 10.1016/j.math.2004.08.011.
24. Vierstraete M, Pereira Rodriguez JA, Renard Y, Muysoms F. EIT Ambivium, Linea Semilunaris, and Fulcrum Abdominalis. J Abdom Wall Surg. 2023 Dec 22;2:12217. doi: 10.3389/jaws.2023.12217. PMID: 38312427; PMCID: PMC10831682.

Морфотипи апоневрозу зовнішнього косого м'яза живота: морфометричне та гістологічне обґрунтування

Л. Ю. Маркулан [1], К. В. Гальперин [1], С. В. Пакришень [2]

1 Національний медичний університет імені О. О. Богомольця, Київ

[2] КНП «Свято-Михайлівська клінічна лікарня м. Києва»

Мета — вивчити гістологічні та морфометричні особливості апоневрозу зовнішнього косого м'яза живота (ЗКМЖ) в ділянці, асоційованій з лінією півмісяця (зона Ambivium).

Матеріали та методи. У дослідження було залучено 34 жінки віком 22—54 роки (середній вік — (36,2 ± 7,3) року), яким виконали абдомінопластику з приводу косметичних дефектів передньої черевної стінки. Під час операції отримували стандартизовані фрагменти апоневрозу ЗКМЖ із симетричних ділянок біля латерального краю піхви прямого м'яза живота. Проводили гістологічне, гістохімічне та морфометричне дослідження з визначенням товщини колагенових пучків, ширини ендотенонію та перитенонію, параметрів мікроциркуляторного русла, відносної площі колагену, перитенонію та судин. Для систематизації структурних варіантів застосовано ієрархічний кластерний аналіз та метод k-середніх.

Результати. Морфометричний аналіз виявив значну варіабельність структурної організації апоневрозу: частка колагенових волокон становила 61,1—91,2 %, перитенонію — 7,3—33,9 %, коефіцієнт компактності — 0,64—0,93. Кластерний аналіз дав змогу виділити три морфотипи: компактний (35,3 %), перехідний (26,5 %) і дезорганізований (38,2 %). Компактний морфотип характеризувався високою часткою колагену ((89,32 ± 1,52) %), мінімальним вмістом перитенонію ((8,86 ± 1,15) %) та максимальним коефіцієнтом компактності (0,91 ± 0,01); дезорганізований морфотип — мінімальною часткою колагену ((68,18 ± 4,04) %), максимальним вмістом перитенонію ((26,87 ± 4,11) %), низьким коефіцієнтом компактності (0,72 ± 0,05), розширенням міжпучкових просторів, ремоделюванням судинного компонента й ознаками виразної гістоструктурної перебудови. Перехідний морфотип посідав проміжне місце. Усі міжкластерні відмінності були статистично значущими ($p < 0,001$).

Висновки. Морфометричний і кластерний аналіз апоневрозу ЗКМЖ виявив значну структурну варіабельність та дав змогу виділити три морфотипи: компактний, перехідний і дезорганізований, які відрізняються за співвідношенням колагенових волокон, перитенонію, судинного компонента та показниками компактності. Виявлена морфологічна неоднорідність апоневрозу відображує різні ступені його структурного ремоделювання та може бути одним із чинників варіабельності результатів хірургічної корекції передньої черевної стінки, що обґрунтовує доцільність подальшої індивідуалізації хірургічної тактики.

Ключові слова: апоневроз зовнішнього косого м'яза живота, EIT Ambivium, лінія півмісяця, спігелева зона, морфометрія, гістологія, морфотипи, абдомінопластика.

FOR CITATION

Markulan LY, Halperin KV, Pakrishen SV. Morphological types of the external oblique abdominal muscle aponeurosis: a morphometric and histological justification. General Surgery (Ukraine). 2026:(2);8-16. http://doi.org/10.30978/GS-2026-2-8.