

The Mesocolon

A Histological and Electron Microscopic Characterization of the Mesenteric Attachment of the Colon Prior to and After Surgical Mobilization

Kevin Culligan, MRCS,* Stewart Walsh, FRCSEd,* Colum Dunne, PhD,* Michael Walsh, PhD,†
Siobhan Ryan, MB,‡ Fabio Quondamatteo, MD,‡ Peter Dockery, PhD,§ and J. Calvin Coffey, FRCSI*¶

Background: Colonic mobilization requires separation of mesocolon from underlying fascia. Despite the surgical importance of planes formed by these structures, no study has formally characterized their microscopic features. The aim of this study was to determine the histological and electron microscopic appearance of mesocolon, fascia, and retroperitoneum, prior to and after colonic mobilization.

Methods: In 24 cadavers, samples were taken from right, transverse, descending, and sigmoid mesocolon. In 12 cadavers, specimens were stained with hematoxylin and eosin (3 sections) or Masson trichrome (3 sections). In the second 12 cadavers, lymphatic channels were identified by staining immunohistochemically for podoplanin. The ascending mesocolon was assessed with scanning electron microscopy. The above process was first conducted with the mesocolon in situ. The mesocolon was then surgically mobilized, and the process was repeated on remaining structures.

Results: The microscopic structure of mesocolon and associated fascia was consistent from ileocecal to mesorectal level. A surface mesothelium and underlying connective tissue were evident throughout. Fibrous septae separated adipocyte lobules. Where apposed to retroperitoneum, 2 mesothelial layers separated mesocolon and underlying retroperitoneum. A connective tissue layer occurred between these (ie, Toldt's fascia). Lymphatic channels were evident both in mesocolic connective tissue and Toldt's fascia. After surgical separation of mesocolon and fascia both remained contiguous, the fascia remained in situ and the retroperitoneum undisturbed.

Conclusions: The findings demonstrate that the contiguous mesocolon and retroperitoneum are separated by mesothelial and connective tissue layers. These properties generate the surgical planes (ie, meso- and retrofascial planes) exploited in colonic and mesocolic mobilization.

Keywords: colon, histology, mesocolon, mobilization, Toldt's fascia

(*Ann Surg* 2014;00:1–9)

From the *Department of Surgery, Centre for Interventions in Infection, Inflammation and Immunity (4i), Graduate Entry Medical School, University Hospitals Group Limerick, Limerick, Ireland; †Department of Mechanical, Aeronautical and Biomedical Engineering and the Materials and Surface Science Institute, University of Limerick, Limerick, Ireland; ‡Skin and Extracellular Matrix Research Group at Anatomy Unit, School of Medicine and §Anatomy Unit, School of Medicine, National University of Ireland Galway, Galway, Ireland; and ¶Department of Surgery, University Hospital Limerick, Graduate Entry Medical School, University of Limerick, Limerick, Ireland.

Disclosure: Supported by Graduate Entry Medical School, University of Limerick, seed funding alone. No funding was obtained from either National Institutes of Health, Wellcome Trust, Howard Hughes Medical Institute. The authors declare no conflicts of interest.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.annalsofsurgery.com).

Reprints: J. Calvin Coffey, FRCSI, Department of Surgery, University Hospital Limerick, Graduate Entry Medical School, University of Limerick, Limerick, Ireland. E-mail: calvin.coffey@ul.ie.

Copyright © 2014 by Lippincott Williams & Wilkins

ISSN: 0003-4932/14/00000-0001

DOI: 10.1097/SLA.0000000000000323

During fetal development, the dorsal mesentery suspends the entire gastrointestinal tract from the posterior abdominal wall. The mesocolon is the adult remnant of that part of the dorsal mesentery associated with the colon.¹ In the adult human, the transverse and lateral sigmoid portions of the mesocolon are mobile whereas the ascending, descending, and medial sigmoid portions are nonmobile and attached to underlying retroperitoneum.^{2–4} Classic anatomic teaching maintains that the ascending and descending mesocolon “disappear” during embryogenesis.^{5,6} In keeping with this, the identification of a right or left mesocolon in the adult is frequently depicted as anomalous rather than accepted as an anatomic norm.⁷ Accordingly, the ascending and descending portions of the mesocolon are mostly described as “secondarily retroperitoneal” after “fusion” of the associated mesentery with underlying retroperitoneum.⁸

In contrast, the established colonic surgical technique has, for over a century, relied upon the persistence of all portions of the mesocolon.^{9–11} Total mesorectal excision relies on disruption of the plane formed by the mesorectum and surrounding fascia.¹² Mesocolic surgery, as depicted separately by Hohenberger et al. and by West et al., relies on a similar plane formed by the mesocolon and underlying fascia (ie, Toldt's fascia).^{13,14} The separation of the components of this plane (ie, mesofascial separation) is an important technique in colonic and mesocolic surgery. A further plane is formed by the fascia and underlying retroperitoneum, and some authors separate these (ie, retrofascial separation) in mobilizing the colon and mesocolon. Despite the surgical importance of these planes, and of the contiguous structures that generate them, neither mesocolon nor fascia has to date been characterized at light and electron microscopic levels.

As outlined above, a discrepancy persists between that which is taught anatomically and that which is practiced surgically. This arises largely due to the fact that once the fibro-adipose mesocolon has been mobilized, the adopted shape bears little resemblance to the 3-dimensional (3-D) in situ shape. To address this, we recently conducted a formal anatomic appraisal of the mesocolon and associated fascial planes.^{3,4} The study demonstrated that the right and left mesocolon persist into adulthood as distinct anatomic entities. In keeping with this, the mesocolon is in fact contiguous from small intestinal mesenteric to mesorectal level.^{3,4} Recalling mesenteric and mesocolic contiguity greatly helps in the conceptualization of the 3-D structure of the in situ nonmobilized mesocolon.

Given that an understanding of biologic structure provides a basis for improved understanding in general, several opportunities now present. As mentioned above, the light and electron microscopic features of the mesocolon and fascia have yet to be characterized in normality (ie, the nondiseased state). This is surprising given the central importance of these contiguous structures in providing planes for safe colonic resection. Thus the aims of the current study were to determine the histological and electron microscopic appearance of the normal mesocolon at multiple levels (ie, ascending, transverse, descending, and mesosigmoid levels). A further aim was to characterize the relationship of mesocolon to underlying fascial and retroperitoneal structures, both before and after standard colonic

and mesocolic mobilization. A final aim was to discuss the surgical implications of the observations made.

METHODS

The experimental workflow process is summarized in Supplemental Digital Content Figure 1 (available at <http://links.lww.com/SLA/A536>).

The 3-D Mesocolon

To explain/clarify the location from which samples were harvested a 3-D model of the adult human mesocolon, was generated and rendered in 2.5-D format. The model was generated using a 3-D computer graphics software package, Blender (Blender Foundation, Amsterdam, The Netherlands) (Fig. 1A).

Mesocolic Sample Harvest

Mesenteric samples were harvested from 24 adult human cadavers. All material used was bequeathed to the Medical School, National University of Ireland, Galway, Ireland, for advancement of medical knowledge. Associated legislation include the Anatomy Act 1832, the Anatomy Act 1871, Health Order 1949, Medical Practitioners Act 2007, in Ireland. An equal number of cadavers were male and female and age at death ranged from 56 to 97 years (with a mean of 79 years). Three of the cadavers had previously undergone appendectomy; however, no disruption of the mesocolic areas utilized for the study was encountered. There was no evidence of prior colorectal cancer, inflammatory bowel disease, or diverticulitis within the group. All cadavers were previously embalmed with formalin, glycerine, phenol, and methanol (12 L of water + 2.4 L of a 37%–41% of formalin solution + 2 L of phenol + 6 L of glycerine + 6 L of methanol). In each cadaver, a single full-thickness and 1 cm² area of mesocolon was sharply excised at each of the following levels (Fig. 1): (A) ascending mesocolon (midway between the cecum and hepatic flexure); (T) transverse mesocolon (midway between hepatic and splenic flexure); (D) descending mesocolon (midway between the splenic flexure and commencement of the mesosigmoid); (MS) mobile mesosigmoid (ie, the lateral and freely mobile region of the mesosigmoid); (AS) apposed mesosigmoid (ie, the medial and non-mobile region of the mesosigmoid). At each location, samples were taken perpendicular to the longitudinal axis of the mesocolon and to a depth that ensured inclusion of the mesocolon, intervening fascia, and the underlying retroperitoneum (Fig. 1B–D).

Sample Processing

Specimens were pinned to a corkboard after excision to maintain correct orientation throughout the evaluation process (ie, the top edge of the specimen corresponded to the surface facing the peritoneal cavity, whereas the bottom edge corresponded to the surface closer to the retroperitoneum (Fig. 1C)). Specimens were initially fixed in the same embalming fluid mixture outlined above. After fixation, specimens were dehydrated through a series of ethanol solutions of increasing concentration, before being embedded in paraffin wax and sectioned to a thickness of 5 μm. Specimens were oriented such that sections were taken vertically (and not obliquely) through the body of the specimen. For each sample in the first 12 cadavers, sections (n = 3) were stained with hematoxylin and eosin (H&E), and serial sections (n = 3) were stained using Masson trichrome (MT) with Gomori aldehyde fuchsin stain for evaluation of collagen and elastic tissue. In total, 432 sections were thus processed from this cohort. In the second 12 cadavers, 3 sections from each sample were stained immunohistochemically for podoplanin (see the Supplemental Digital Content for methodology for H&E and MT staining and podoplanin immunohistochemistry techniques, available

at <http://links.lww.com/SLA/A536>). Thus in the second cohort, 216 sections were examined. In total, 648 sections were evaluated.

To prepare specimens for scanning electron microscopy (SEM), a thick slice (>30 μm) was sectioned from the wax block. This was then dewaxed using xylene and rehydrated through a series of ethanol solutions of decreasing concentration. Specimens were then fixed using a solution of 2% of glutaraldehyde and 2% of paraformaldehyde in a 0.1 M of sodium cacodylate/HCl buffer pH 7.2. Specimens were then dehydrated through a series of ethanol solutions of increasing concentration prior to being fixed on metal studs and a gold sputter coat applied.

Surgical Mobilization

In 1 cadaver, the entire colon and mesocolon were surgically mobilized as previously described.³ A video recording of the entire process is included in the Supplemental Digital Content for methodology, available at <http://links.lww.com/SLA/A536>. A detailed text-based description is also included in the Supplemental Digital Content for methodology, available at <http://links.lww.com/SLA/A536> with accompanying figures (Supplemental Digital Content Figs. 2 and 3, available at <http://links.lww.com/SLA/A536>). For the purposes of brevity, a brief overview of the process is included in the following.

The right colon and mesocolon were mobilized by first dividing the inferolateral and lateral peritoneal folds. By separating the mesentery/mesocolon from the underlying fascia and thus retroperitoneum (ie, mesofascial separation), the entire small intestinal mesentery and contiguous right mesocolon were mobilized. Mobilization of the hepatic flexure involved division of the hepaticocolic ligament (a lateral condensation of the greater omentum). This in turn enabled mobilization of the contiguous hepatic mesenteric confluence and transverse mesocolon. The process of mesofascial separation was continued over the second part of the duodenum and head of the pancreas, as far medially as the origin of the transverse mesocolon (ie, at the takeoff of the middle colic artery). Mesofascial separation was continued laterally along the body and tail of pancreas toward the splenicocolic ligament (also a lateral condensation of the greater omentum) which was then sharply divided.

Division of the left lateral peritoneal fold permitted left colonic and mesocolic separation from the left-sided retroperitoneal fascia. By extending this process toward the splenic flexure, and onto the splenicocolic ligament, the splenic mesenteric confluence (ie, the splenic flexure) was fully mobilized. The left mesocolon could then be fully medialized. The lateral peritoneal fold associated with the apposed mesosigmoid (ie, at the junction of both apposed and mobile components of the mesosigmoid) was sharply divided, exposing the interface between apposed mesosigmoid and underlying fascia (mesofascial separation). Both were again separated, and the apposed mesosigmoid was fully medialized. To aid this, the upper mesorectum was separated from associated fascia. This completed the mesocolic mobilization in the mesofascial plane, and the mesocolon was evident as a contiguous structure from small intestinal mesentery to the mesorectal level.

Sample Harvest Postsurgical Mobilization

Sample harvest postsurgical mobilization was performed on regions underlying both the ascending and descending mesocolon, as well as beneath the medial or apposed component of the mesosigmoid. The orientation and processing of the samples for sectioning and subsequent evaluation followed an identical process to that described above (Fig. 1). Staining was conducted using H&E and MT as outlined above.

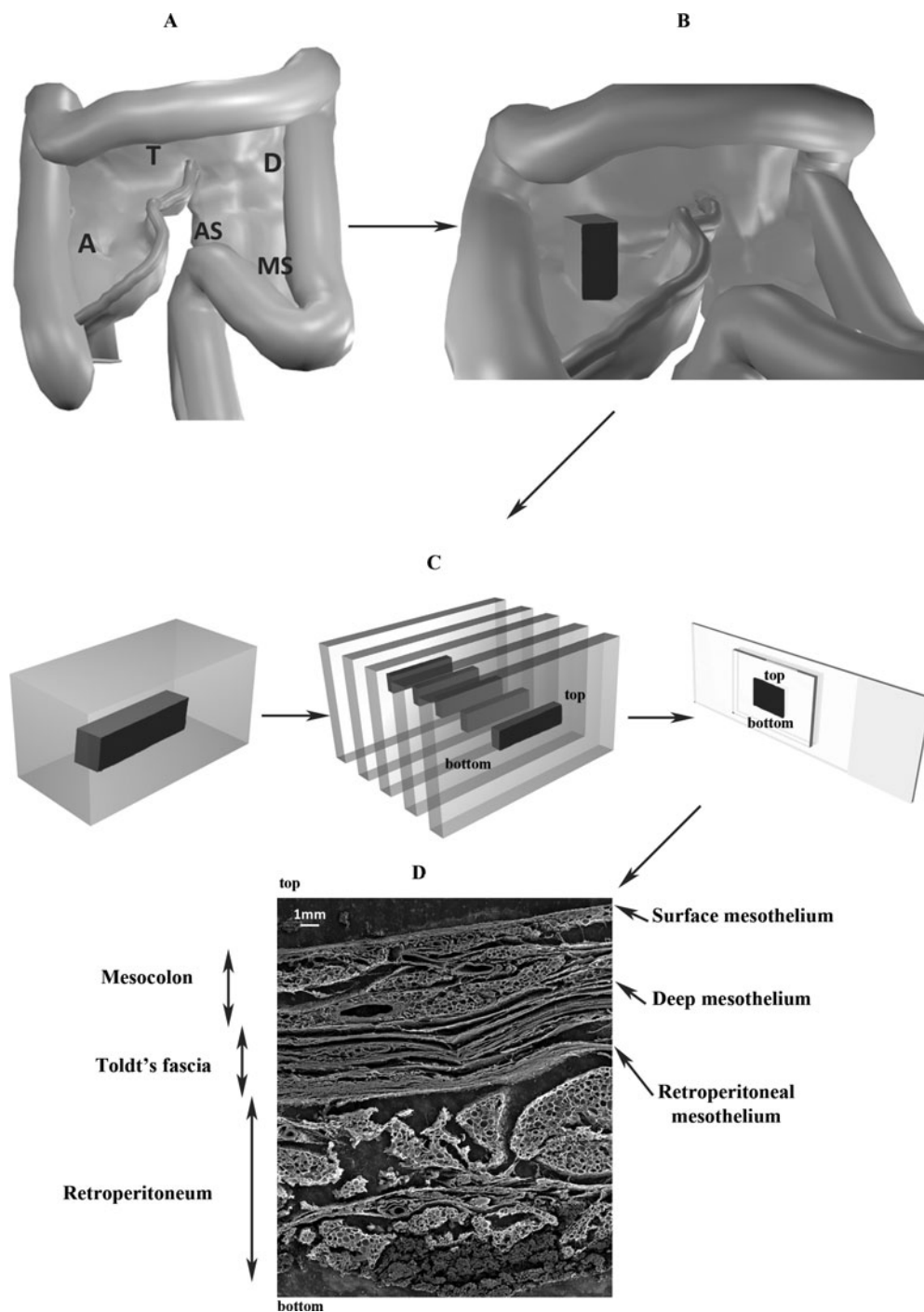


FIGURE 1. Schematic demonstration of the mesocolon, including harvesting and processing of specimens. A, A 2.5-D depiction of the colon and mesocolon, (derived from a 3-D reconstruction of the colon generated in Blender). Mesocolic continuity is apparent from ileocecal to mesorectal levels. Lettering is as follows: “A” refers to ascending mesocolon, “T” to transverse, “D” to descending, “MS” to the mobile portion of the mesosigmoid, and “AS” to the apposed portion of the mesosigmoid. B, Higher magnification view of the ascending mesocolon, with a rectangular block indicating site and orientation of sample harvest. C, Serial images of sample orientation for embedding, sectioning, and mounting. The dark surface represents the cut edge. “Top” refers to the peritoneal surface, whereas “bottom” refers to the retroperitoneal surface of the mesocolon. D, A SEM depiction of the ascending mesocolon, with the underlying fascia and the retroperitoneum.

Slide Review

All slides were reviewed using a Leica DM750 light microscope, with an ICC50 HD camera attachment (Leica Microsystems, Heerbrugg, Switzerland). SEM was conducted using a Hitachi S2600N Variable Pressure Scanning Electron Microscope (Hitachi, Tokyo, Japan). In general, the review process first determined the presence/absence of the following: (a) surface epithelium, (b) intervening adipocytes, (c) deep epithelium, (d) connective tissue fascia outwith the deep epithelial layer, and finally (e) retroperitoneal fat deep to (d) and (f) lymphatic channels. A descriptive characterization of each mesocolic component was conducted at (a) to (e) and at each location (ie, ascending to mesosigmoid levels). As the fascia was preserved in the mobilization procedure, both this and the underlying retroperitoneum provided the focus for this section of the evaluation. This was repeated throughout. Slide review and interpretation were conducted via consensus by K.C. together with 2 anatomists (F.Q. and P.D.) and the principal investigator (J.C.C.) (the reasons for this approach are outlined in the Supplemental Digital Content for methodology, available at <http://links.lww.com/SLA/A536>).

RESULTS

Ascending Mesocolon

Specimens from the ascending mesocolon were harvested from the location indicated by the letter A in Figure 1A. The histological appearance of the ascending mesocolon was similar in all specimens examined (Table 1 and Fig. 2A). A superficial mesothelial layer, comprising a single flat layer of spindle-shaped cells, overlay the mesocolon. A connective tissue layer occurred immediately beneath the surface mesothelium, interposed between this and adipocytes (Fig. 2B). The bulk of the mesocolon comprised adipocyte lobules separated by fibrous septae. At the deep surface of the mesocolon, a further mesothelial cell layer was evident (Fig. 2C). Beneath the latter, a connective tissue layer occurred (ie, Toldt's fascia). Deeper to this layer, a further mesothelial layer overlay retroperitoneal adipocyte populations (Fig. 2C).

Transverse Mesocolon

Specimens from the transverse mesocolon were harvested from the location indicated by the letter T in Figure 1A. The histological appearance of the transverse mesocolon was consistent throughout all specimens examined and is summarized in Table 1. The upper (cranial) surface of transverse mesocolon faces the lesser sac, whereas

the lower (caudal) surface faces the peritoneal cavity. Both upper and lower surfaces were covered by a mesothelial cell layer (Fig. 3A). Fibrous septae were contiguous with a submesothelial connective tissue layer (Fig. 3B), thereby generating a connective tissue lattice. An invagination from the caudal mesothelium was evident in most specimens (Fig. 3C).

Descending Mesocolon

Descending mesocolic specimens were harvested from the location indicated by the letter D in Figure 1A, and histologic observations are summarized in Table 1. Surface and deep mesothelia comprised a monolayer of elongated, spindle-shaped cells (Fig. 4A). The submesothelial connective tissue layer was largely acellular. However, there were foci where numerous cell bodies, with varying morphology, were evident (Fig. 4B). These appeared isolated and not connected to fibrous septae on serial sections. Immediately outside the deep mesothelial layer, Toldt's fascia was present but insubstantial. The latter was interposed between the mesothelial layer of the deep aspect of the mesocolon above, and a further mesothelium covering the retroperitoneum below (Fig. 4A).

Mobile Mesosigmoid

As recently demonstrated, the mesosigmoid comprises a lateral, mobile component (freely mobile with the exception of associated congenital attachments) and a medial, fixed component, apposed to the underlying retroperitoneum.³ Both mobile and apposed components are depicted in the 2.5-D model in Figure 1A (see also Supplemental Digital Content Figs. 2 and 4 available at <http://links.lww.com/SLA/A536>). Biopsy specimens from the mobile component of the mesosigmoid were taken from the area indicated by the letter MS in Figure 1A. Histologic features of both are summarized in Table 1. Histologic features of the mesothelium and connective tissue associated with the mobile mesosigmoid are demonstrated in Figures 5A and B. Importantly, the submesothelial connective tissue layer beneath the lateral surface mesothelium was substantial.

In all cadavers, the intersigmoidal fossa was identifiable lateral to the mobile component of the mesosigmoid, between it and the left iliac fossa (Supplemental Digital Content Figures 4A–G, available at <http://links.lww.com/SLA/A536>). In all cadavers, the fossa was almost entirely obliterated by the presence of peritoneal adhesions that formed between the lateral aspect of the mesosigmoid

TABLE 1. Summary of the Histologic Features of Each Region of the Mesocolon

Mesocolon	Mesocolic Mesothelium (Surfaces)		Connective Tissue Lattice	Submesocolic Fascia	Submesothelial Connective Tissue Layer
Ascending	Upper present	Deep present	Present	Present	Substantial beneath upper surface MST, infrequently evident beneath deep surface MST
Transverse	Cranial present	Caudal present	Present	Absent	Substantial beneath cranial surface MST, Narrow/sometimes absent beneath caudal MST
Descending	Upper present	Deep present	Present	Present	Present but not substantial beneath upper and deep surface MST
Mesosigmoid (mobile)	Lateral present	Medial present	Present	Absent	Substantial beneath lateral surface MST, Narrow/sometimes absent beneath medial MST
Mesosigmoid (apposed)	Upper present	Deep present	Present	Present	Present but not substantial beneath upper and deep surface MST

MST refers to mesothelium.

"Surface" refers to the surface of the mesocolon in question.

Neither the transverse nor mobile mesosigmoid were apposed to the retroperitoneum and thus did not have an associated submesocolic fascia evident.

"Lattice" refers to the finding of connective tissue septations contiguous with submesothelial connective tissue layers.

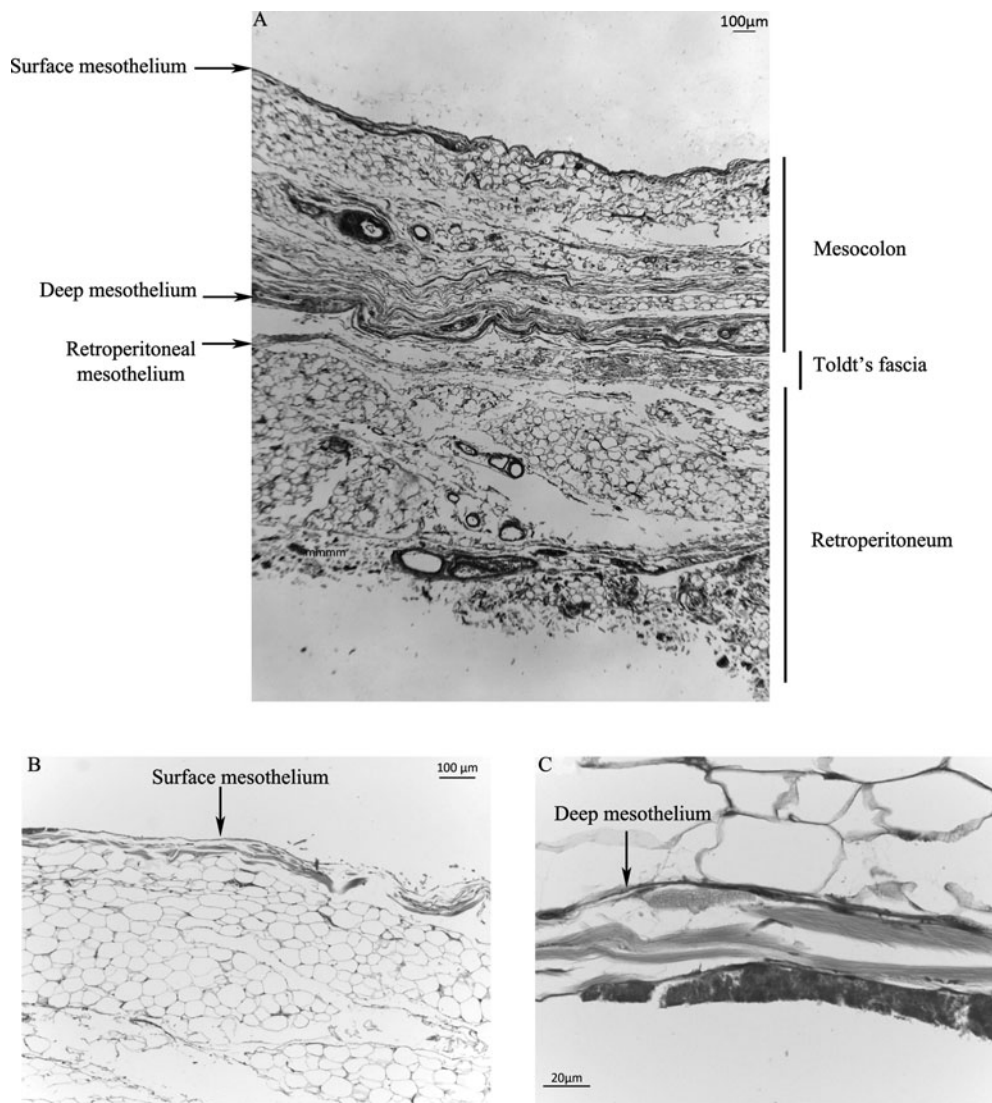


FIGURE 2. A, Photomicrograph (H&E) demonstrating the ascending mesocolon and underlying retroperitoneum. Mesothelial layers were evident on both the superficial and deep surfaces of the mesocolon, and over the retroperitoneum. Scale 100 μm . B, Photomicrograph (MT) showing connective tissue beneath the surface mesothelial layer. The connective tissue was arranged in bundles with a longitudinal orientation. It was variable in thickness and cellularity. Scale 100 μm . C, Photomicrograph (MT) demonstrating the mesocolic connective tissue plane between the deep surface of the mesocolon and underlying retroperitoneum. Scale 20 μm .

the peritoneum of the left iliac fossa. The effect of these was to displace mesosigmoid laterally where it became apposed to the abdominal wall in that location. While the fossa was consistently identifiable, the density and macroscopic features of the adhesions were variable (Supplemental Digital Content Figures 4A–G, available at <http://links.lww.com/SLA/A536>).

Apposed Mesosigmoid

The apposed mesosigmoid refers to the medial portion of the mesosigmoid, which is nonmobile and fixed to the posterior abdominal wall. Until recently, this anatomic arrangement was not acknowledged and the mesosigmoid was interpreted as inserting into the posterior abdominal wall along an inverted V-shaped line.⁷ In this study,

specimens from the apposed mesosigmoid were harvested from the area indicated by the letters AM in Figure 1A. The histologic features of the apposed mesosigmoid are summarized in Table 1 and Figure 5. Of note, the deeper mesothelial layer was frequently observed as folded back on itself (Fig. 5D).

Scanning Electron Microscopy

SEM was performed on the right mesocolon to characterize the component structures in greater detail. Given the histological structural similarity between the ascending, transverse, descending, and sigmoid mesocolon, this analysis was confined to the ascending mesocolon only. The surface mesothelial layer generated a smooth contoured mesocolic surface (Fig. 6A). Immediately beneath the surface

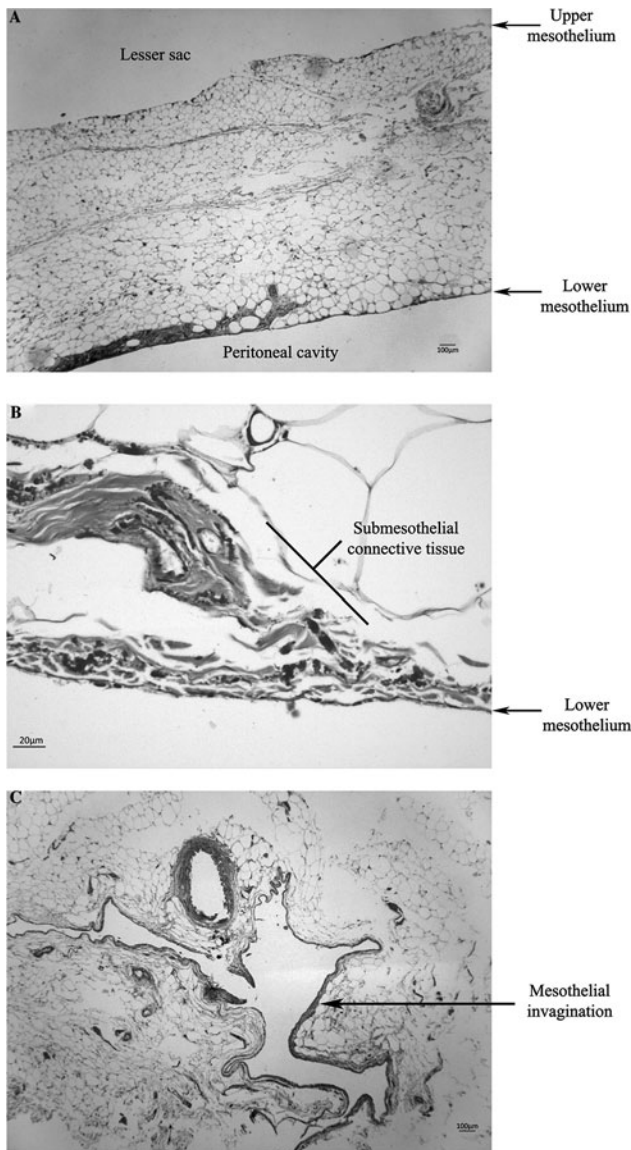


FIGURE 3. A, Photomicrograph (H&E) demonstrating the full thickness of the transverse mesocolon with mesothelial layers on upper and lower surfaces. Adipocytes comprised the main body of the mesocolon and were separated by fibrous septae. Scale 100 μm . B, Photomicrograph (MT) demonstrating the submesothelial connective tissue layer. Fibrous septae separating the adipocytes were contiguous with this layer. Scale 20 μm . (C) In almost all cases, an invagination of the lower mesothelial monolayer was apparent as demonstrated in this photomicrograph (H&E). Scale 100 μm .

mesothelium, adipocytes were packed in close continuity and submesothelial connective tissue reservoirs were identifiable, distributed sporadically. In several areas, the mesocolon was highly vascularized (Fig. 6B) with adipocytes packaged in a honeycomb-like manner in compartments by fibrous septae. The deeper side of the mesocolon was covered with a deep mesothelial cell layer (Fig. 6C), and deeper to this Toldt's fascia was identifiable, interposed between mesocolon and retroperitoneum. Toldt's fascia was composed of multiple lamellae of

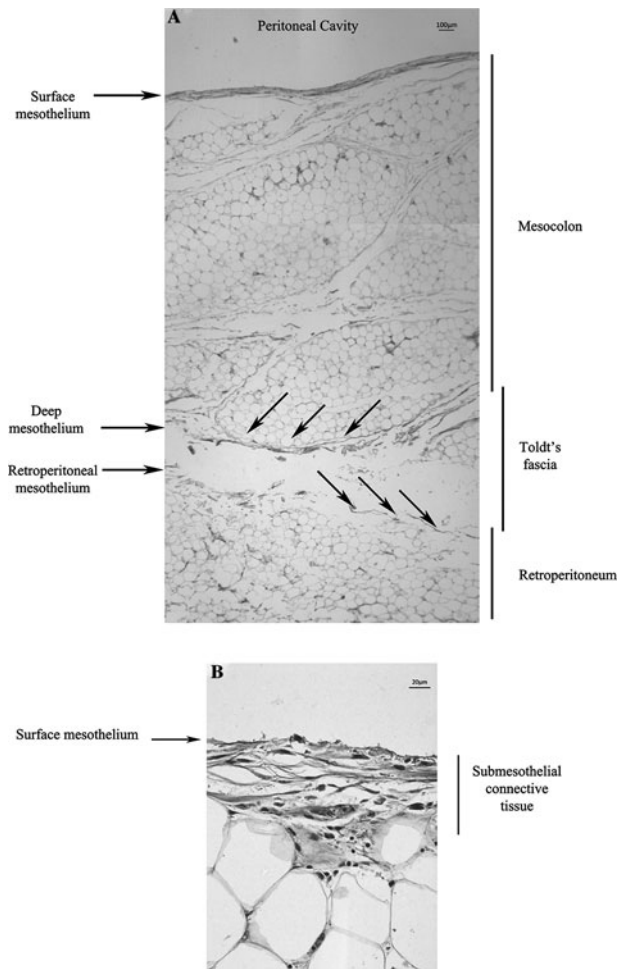


FIGURE 4. A, Photomicrograph (H&E) demonstrating a full thickness descending mesocolon with mesothelial layers on upper and lower surfaces. On the deep surface, a mesothelial layer was present (leftward facing arrows). A thin fascial layer occurred between this and a second mesothelial monolayer (rightward facing arrows) overlying the retroperitoneum. Adipocytes comprised the main body of the mesocolon and were separated into lobules by fibrous septae arising from the submesothelial connective tissue layer. Scale 100 μm . B, Photomicrograph (MT) showing a highly cellular region of the submesothelial connective tissue layer. Scale 20 μm .

connective tissue, which were layered tightly on top of each other. A further mesothelial layer was evident interposed between the lamellae of Toldt's fascia and the retroperitoneum beneath (Fig. 6D). Figure 6D demonstrates the manner in which the adipocyte compartments may be cleaved from the overlying or underlying fascial layers. This figure is included to depict the manner in which the structures that comprise the mesofascial or retrofascial plane (ie, the mesocolon and fascia) can be separated, without disrupting the contiguity of either.

Characterization of Fascia and Retroperitoneum Postsurgical Mobilization

After surgical mobilization of the right mesocolon (in the mesofascial plane), the underlying fascia was retained. Superficial layers of the fascia were fragmented, whereas deeper layers

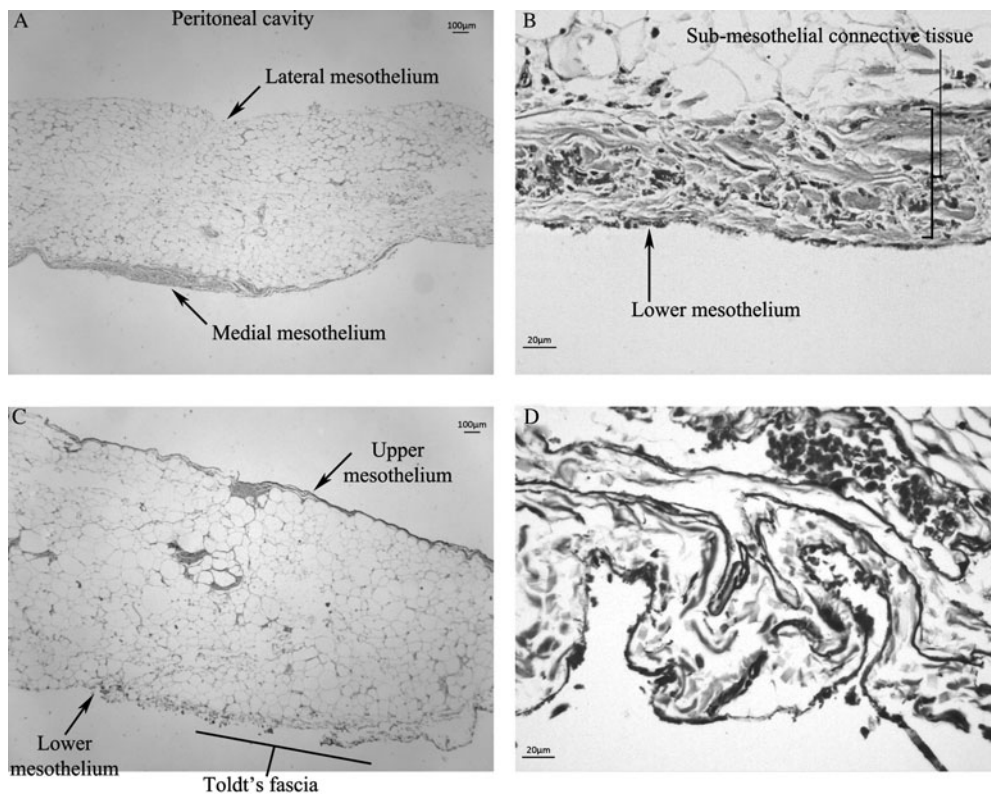


FIGURE 5. A, Photomicrograph (H&E) demonstrating the full thickness of the mobile mesosigmoid with mesothelial layers over medial (upper) and lateral (lower) surfaces. Scale 100 μm . B, (MT) On the lateral surface (but not the medial surface), a connective tissue layer occurred immediately beneath the mesothelium. This layer was variable in thickness and cellular makeup. Scale 20 μm . C, Photomicrograph (H&E) showing full thickness apposed mesosigmoid. Upper and lower mesothelial layers were evident. Connective tissue was evident deep to lower mesothelium. Scale 100 μm . D, (MT) A connective tissue layer occurred immediately deep to the lower mesothelial layer of the apposed mesosigmoid. This connective tissue occurred between 2 mesothelial cell layers. The deeper layer overlying the retroperitoneum. Scale 20 μm .

remained intact (Supplemental Digital Content Fig. 5 available at <http://links.lww.com/SLA/A536>). The connective tissue layer was predominantly collagenous with small vessels interspersed throughout. A mesothelium occurred between the fascia and underlying retroperitoneum. In several instances, the fascia artificially separated from underlying retroperitoneum but in each the retroperitoneal mesothelium remained intact. Similar fascial and mesothelial preservation was seen on the left side and beneath apposed mesosigmoid (Supplemental Digital Content Fig. 5 available at <http://links.lww.com/SLA/A536>).

Podoplanin Immunohistochemistry

Lymphatic channels within the ascending mesocolon were identified by staining immunohistochemically for podoplanin (Supplemental Digital Content Fig. 6 available at <http://links.lww.com/SLA/A536>). A channel was considered lymphatic if (a) it was podoplanin immunopositive and (b) had a lumen, or linear structure representing a collapsed vessel. Lymphatic channels were evident within the submesothelial connective layer (Supplemental Digital Content Fig. 6B, available at <http://links.lww.com/SLA/A536>), in Toldt's fascia (Supplemental Digital Content Fig. 6C available at <http://links.lww.com/SLA/A536>), and in fibrous septations separating adipocyte lobules (Supplemental Digital Content Fig. 6C available at <http://links.lww.com/SLA/A536>).

DISCUSSION

For the past century, the mesocolon has been depicted as fragmented and noncontiguous.^{5,6} This is due to 2 factors: The first are descriptions of Sir Frederick Treves⁶ who postulated that the right and left mesocolon regress and disappear; second, once the mesocolon has been freed from its undisturbed conformation, the resultant shaped structure bears little resemblance to the original topography. Consequently, anatomists, embryologists, and others have long appraised the mesocolon as discontinuous and fragmented.⁵⁻⁷ In contrast, safe colonic resection relies entirely on mesocolic contiguity.⁹⁻¹¹ Most colorectal surgeons disrupt the avascular plane formed between contiguous mesocolon and fascia (ie, mesofascial separation). Others disrupt the plane formed by fascia and underlying retroperitoneum (ie, retrofascial separation). Although meso- and retrofascial separation are integral to complete mesocolic excision (as demonstrated by Hohenberger et al.¹³) neither mesocolon, fascia, nor subfascial retroperitoneum has to date been histologically characterized. This could explain why according to West et al. (reviewing 399 colonic resections) the mesocolic plane was utilized in 32% of cases, whereas intramesocolic and muscularis propria-based resections occurred in 44% and 24%, respectively.¹⁴

This study demonstrated that the mesocolon was histologically similar across all locations. A mesothelium overlay the peritoneal surface of the mesocolon. The mesocolon comprised adipocyte lobules separated by thin fibrous septae. Importantly, a mesothelium occurred

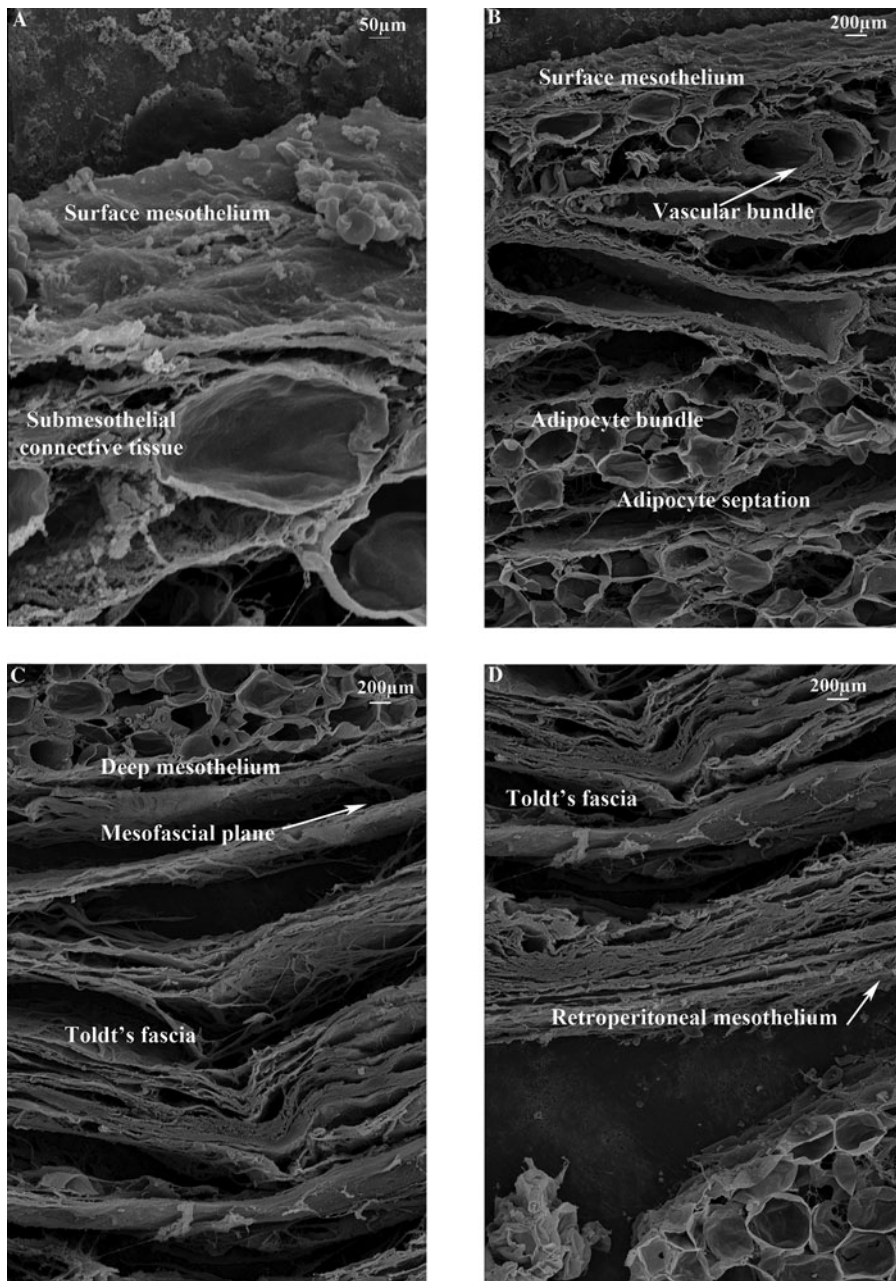


FIGURE 6. A, SEM of the upper layer of the ascending mesocolon. The surface mesothelium of the mesocolon is demonstrated, along with an area of submesothelial connective tissue and subjacent adipocytes. Scale 50 μm . B, SEM view of the right mesocolon extending from the surface mesothelium into the body of the mesocolon proper. This demonstrates compartmentalization of adipocytes, which were packed in a honeycomb-like pattern into lobules between fibrous septae. In several areas, the right mesocolon was highly vascular, with vessels extending from deep within the mesocolon to beneath the surface mesothelium. Scale 200 μm . C, SEM of the ascending mesocolon demonstrating the lowermost portion of the mesocolon and the underlying connective tissue plane (ie, Toldt's fascia). The fascia was composed of tightly packed lamellae of connective tissue. The mesofascial plane was evident and comprised the interface between the deep mesothelium and the underlying fascia (ie, Toldt's fascia). Scale 200 μm . D, SEM demonstrating retrofascial plane components that have separated. Importantly contiguity of both components was retained thus mimicking the surgical technique of retrofascial separation.

on the deep surface of the apposed mesocolon (ie, undersurface of ascending, descending mesocolon, and apposed mesosigmoid). This contradicts classic anatomic teaching that holds that these mesocolic regions “fuse” with the retroperitoneum to become “secondarily retroperitoneal.” Deep to the lower mesothelial layer, a further connective tissue layer occurred corresponding to Toldt's fascia. This entirely separated the mesocolon from subjacent retroperitoneum. A further mesothelium occurred between fascia and retroperitoneum. These findings were confirmed by SEM and demonstrate that, in the adult human, the mesocolon is *extraretroperitoneal*.

Unexpectedly, a further connective tissue layer occurred between surface mesothelium and underlying adipocytes. This submesothelial connective tissue layer was highly cellular in certain locations. In others, continuity occurred between it and connective tissue

septae. When collated, the findings identified a connective tissue lattice within the mesenteric organ. In addition, lymphatic channels were apparent within the lattice, within both the submesothelial component and interlobular septations, and within Toldt's fascia. The clinical and anatomic implications of the above findings require further studies.

This study also demonstrated the mesocolic, fascial, and retroperitoneal components of surgical planes exploited in mesocolic and colonic mobilization. In mesofascial separation mesocolon and fascia are separated, whereas in retrofascial separation the mesocolon/fascial complex is separated from underlying retroperitoneum.³ The SEM findings demonstrated how planar components could be separated without disrupting contiguity of either. Surgical cleavage occurs at the interface between mesothelium and fascia (not between

adipocytes and fascia). The findings thus explain how mesocolic mobilization is achieved without disruption of the mesocolic package and, as such, provide the microscopic basis of current approaches to colonic and mesocolic mobilization.

Numerous questions and hence investigational opportunities arise as to the function of Toldt's fascia and mesocolic adipocytes. Mesenteric pathologies such as nonrotation, and Crohn's disease, could provide important clues. For example, in nonrotation the right mesocolon does not appose with retroperitoneum, Toldt's fascia is absent, and patients are at risk of mesenteric volvulus.¹⁵ Thus the fascia has an adhesive function.¹⁵ Evidence is accumulating that mesenteric adipocytes have immunologic, metabolic, and endocrine roles.^{16,17} Derangements are seen in the mesenteric fat wrapping, thickening, and shortening that characterize Crohn's disease.^{18,19}

This study was performed on cadaveric tissue, in which fixation may be suboptimal. However, as in previous studies,²⁰ architectural preservation was sufficient to satisfactorily characterize the microscopic appearance of mesocolon and related fascia. Cadaveric sampling permitted full thickness sampling of the mesocolon, fascia, and underlying retroperitoneum. This could not safely be performed intraoperatively, without risk to retroperitoneal structures (ie, unethical in the live patient). Notwithstanding these limitations, this study provides the first systematic characterization of the microscopic appearance of mesocolon, underlying fascia, and retroperitoneum.

In summary, a mesothelium overlay both upper and lower mesocolic surfaces throughout the mesocolon. The ascending and descending mesocolon (and apposed mesosigmoid) are separated from retroperitoneum by a connective tissue layer sandwiched between 2 mesothelia (ie, on the deep surface of the mesocolon and overlying retroperitoneum). The mesocolon is extraretroperitoneal throughout its length. These anatomic properties permit separation of contiguous planar components (ie, mesocolon, fascia, and retroperitoneum) during mesocolic and colonic mobilization.

REFERENCES

1. Cochard LR. The GI system and abdominal wall. In: Cochard LR, ed. *Netter's Atlas of Human Embryology*. revised ed. Philadelphia: Saunders; 2012:132–144.
2. Coffey JC. Surgical anatomy and anatomic surgery—clinical and scientific mutualism. *Surgeon*. 2013;11:177–182.
3. Culligan K, Coffey JC, Kiran RP, et al. The mesocolon: a prospective observational study. *Colorectal Dis*. 2012;14:421–430.
4. Culligan K, Remzi FH, Soop M, et al. Review of nomenclature in colonic surgery—proposal of a standardised nomenclature based on mesocolic anatomy. *Surgeon*. 2013;11:1–5.
5. Moore KL. The digestive system. In: Moore KL, ed. *The Developing Human*. 7 ed. Philadelphia: Saunders; 2003:211–241.
6. Treves SF. Lectures on the anatomy of the intestinal canal and peritoneum in man. *Br Med J*. 1885;1:415.
7. Adams A, McConnell T. Abnormalities of fixation of the ascending colon: the relation of symptoms to anatomical findings. *Br J Surg*. 1923;10:532–557.
8. Standring S. Large intestine. In: Standring S, ed. *Gray's Anatomy: The Anatomical Basis of Clinical Practice*. 40th ed. London: Churchill Livingstone; 2008:1137.
9. Jamieson JK, Dobson JF. Lymphatics of the colon: with special reference to the operative treatment of cancer of the colon. *Ann Surg*. 1909;50:1077–1090.
10. Zhang C, Ding ZH, Yu HT, et al. Retrocolic spaces: anatomy of the surgical planes in laparoscopic right hemicolectomy for cancer. *Am Surg*. 2011;77:1546–1552.
11. Williams KA. Anatomy and colonic cancer. In: Keighley MRB, Williams NS, eds. *Surgery of the Anus, Rectum and Colon*. 2nd ed. London: Bailliere Tindall; 2008.
12. Heald RJ, Husband EM, Ryall RD. The mesorectum in rectal cancer surgery—the clue to pelvic recurrence? *Br J Surg*. 1982;69:613–616.
13. Hohenberger W, Weber K, Matzel K, et al. Standardized surgery for colonic cancer: complete mesocolic excision and central ligation—technical notes and outcome. *Colorectal Dis*. 2009;11:354–365.
14. West NP, Morris E, Rotimi O, et al. Pathology grading of colon cancer surgical resection and its association with survival: a retrospective observational study. *Lancet Oncol*. 2008;9:857–865.
15. Coffey JC. Malrotation. In: O'Connell PR, Madoff RD, Solomon M, eds. *Operative Surgery of the Colon, Rectum and Anus*. 6th ed. London: CRC Press. In press.
16. Wozniak SE, Gee LL, Wachtel MS, et al. Adipose tissue: the new endocrine organ? A review article. *Dig Dis Sci*. 2009;54:1847–1856.
17. Kershaw EE, Flier JS. Adipose tissue as an endocrine organ. *J Clin Endocrinol Metab*. 2004;89:2548–2556.
18. Zulian A, Cancellato R, Micheletto G, et al. Visceral adipocytes: old actors in obesity and new protagonists in Crohn's disease? *Gut*. 2012;61:86–94.
19. Peyrin-Biroulet L, Chamaillard M, Gonzalez F, et al. Mesenteric fat in Crohn's disease: a pathogenetic hallmark or an innocent bystander? *Gut*. 2007;56:577–583.
20. Gupta T, Gauba K. Cadaveric tissue histology: A viable alternative. *J Clin Diagn Res*. 2011;5:1505–1509.