Meyers' Dynamic Radiology of the Abdomen

Sixth Edition

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Meyers' Dynamic Radiology of the Abdomen

Normal and Pathologic Anatomy

Sixth Edition

With 531 Figures, in 729 Parts, 22 in Color

Springer

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To Bea, Amy,
Richard, Karen,
Sarah, and Sam

I couldn't wish for a more loving family

Morton A. Meyers

To my teachers: Professor Milton Elkin who encouraged me to use multimodality approach and to apply physiology and pathology in Diagnostic Imaging, and to Professor Sidney Wallace who taught me how to be a clinician

To my wife and children: Tanitra, Chutapom, Tonyamas, Nalinda, Sirynda, and Larissa who endured my long hours at work

To my parents: Chow and Usa who would like their children to be successful and secure a better life

Chusilp Charnsangavej

To Phyllis, Melissa,
Jason, Bradley, and Ella
All my love always.
In memory of Molly Sara

Michael Oliphant

There are some things which cannot be learned quickly, and time, which is all we have, must be paid heavily for their acquiring. They are the very simplest things; and, because it takes a man's life to know them, the little new that each man gets from life is very costly and the only heritage he has to leave.

Ernest Hemingway

Death in the Afternoon

Preface to the Sixth Edition

The preface to the first edition of *Meyers' Dynamic Radiology of the Abdomen: Normal and Pathologic Anatomy* stated that this book introduces a systematic application of anatomic and dynamic principles to the practical understanding and diagnosis of intraabdominal diseases. The clinical insights and rational system of diagnostic analysis stimulated by an appreciation of the dynamic intraabdominal relationships outlined in previous editions have been universally adopted. Literally thousands of scientific articles in the literature have attested to their basic precepts. Formulations and analytic approaches introduced in the first edition are now widely applied in clinical medicine so that many of the terminologies, definitions, and concepts of pathogenesis have solidly entered the scientific domain. These insights lead to the uncovering of clinically deceptive diseases, the evaluation of the effects of disease, the anticipation of complications, and the determination of the appropriate diagnostic and therapeutic approaches. Spanish, Italian, Japanese, and Portuguese editions have encouraged more widespread application of the principles, which in turn has led to further contributions to our understanding of the features of spread and localization of intraabdominal diseases. These principles have been applied to the full range of imaging modalities – from plain films and conventional contrast studies to CT, US in all its modes (endoscopic, laparoscopic, and intraoperative), MRI, and PET-CT – leading to this sixth edition after 34 years.

In the pursuit of comprehending the pattern, all methods of investigation have been used, including (a) anatomic cross-sectioning of cadavers frozen to maintain relationships; (b) cadaver injections and dissections performed to determine preferential planes of spread along ligaments, mesenteries, and extraperitoneal fascial compartments; (c) selected clinical cases with the fullest range of imaging studies; (d) peritoneoscopy and peritoneography; and (e) surgical operations, surgical pathology, and autopsies.

The basic aims in writing this book have not changed from the first edition, and it is produced in the same spirit as its predecessors. The quest of science has always sought the identification of a pattern of circumstances. With this recognition, there follows insight and understanding into the nature and dynamics of events and thereby their predictability, management, and consequences. This book establishes that the spread and localization of diseases throughout the abdomen and pelvis are not random, irrational occurrences but rather are governed by laws of structural and dynamic factors.

In the past, radiology books have traditionally dealt with highly focused topics limited to a particular organ or imaging modality. Often, these have typically been collections of cases illustrating the range of diseases affecting that organ or the advantages and limitations offered by a particular imaging technique. However, in a clinical setting, patients often present in a manner challenging the physician's thinking

patterns: to determine not only "what?" but "how?" and "why?" and "where?"

The first edition was hailed as "the book that revolutionized abdominal radiology." One reviewer enthused: "In literature there are favorite 64 thousand dollar questions, namely, which three books would a man choose if he had to live alone on a deserted island. If one narrows the field to radiological abdominal texts, I wouldn't hesitate to take *Meyers' Dynamic Radiology of the Abdomen*...The book would be an intellectual challenge that would make the loneliness bearable." An author's pride that critical insights had been formulated was furthered by another reviewer's tribute: "Morton Meyers has opened up a whole new world for many of us... Meyers on the abdomen is like Armstrong on the moon."

While hewing to the fundamental theme, this sixth edition is not simply a revision, not merely a compendium of the observations and experiences reported by others. Rather, it is decidedly a virtually new presentation. Its authorship has been enlarged by two international authorities who have pioneered groundbreaking perspectives in the precise recognition of a wide spectrum of intraabdominal disease processes. To satisfy these aims, completely new chapters have been added and others have been extensively updated and enlarged. This edition includes more than 680 new images and illustrations.

The insights introduced by Morton Meyers in the first edition and developed over the subsequent editions ensured the critical position of the radiologist in establishing the diagnosis, often redirecting the course of investigation, and in indicating the prognosis and determining the management. Clearly established are the dynamics and pathways of spread and localization of intraperitoneal infections and malignancies, and the anatomic–pathologic delineation of the three extraperitoneal spaces. What had been woefully described as a "hinterland of straggling mesenchyme with its shadowy fascial boundaries" is now seen as clearly demarcated compartments with pathognomonic features.

As useful as these have been, much has been gained by broadening a vision to encompass global anatomic continuity throughout the abdomen and pelvis: just as a loop of ribbon twisted once or several times, as in a Möbius strip, yields a structure with continuity of planes. The unifying concept of the subperitoneal space of the abdomen and pelvis devised and refined by Michael Oliphant and colleagues in the scientific literature, including the fifth edition, is here now elegantly elaborated for clinical applications. It serves both to illuminate the potential of bidirectional spread of disease – predominantly cancer but also benign conditions, e.g., inflammation and trauma – and to explain what has long been thought of as illogical and mysterious circumstances. On this basis, the role of diagnostic imaging is vastly extended.

Many new chapters meticulously detail the pattern of lymphatic spread of cancer from primary organs in the abdomen and pelvis. Chusilp Charnsangavej illustrates exquisitely precise identification based on analysis of huge clinical material at the M.D. Anderson Cancer Center in Houston.

With a known primary lesion, it may be critical to anticipate the likely sites of spread. On the other hand, a patient may present with a lesion at a remote site, in which case it becomes important to think backward in order to reveal the occult primary site. Charnsangavej shows that an intimate knowledge of the vascular distributions characteristic of each organ provides the template for identifying its lymphatic pathways. He emphasizes that the benefits of understanding the pathways of lymphatic drainage of each individual organ are threefold. First, when the primary site of the tumor is known, it allows precise identification of the expected sites of nodal metastases by following the arterial supply or venous drainage in the ligaments, mesentery, or mesocolon attached to that organ. Second, when the primary site of tumor is not clinically known, identifying abnormal nodes allows tracking the arterial supply or venous drainage in that region to the primary source. Third, it also allows identification of the expected site of recurrent disease or nodal metastasis or the pattern of disease progression after treatment by looking at the nodal station beyond the treated site. Accurate assessment is crucial for planning treatment regarding neoadjuvant therapy and surgery and may impact the outcome of treatment.

Additional value is occasionally encountered. An incidentally noted abnormal-appearing lymph node not in the expected pathway from a known primary site may be discounted to represent a metastasis. And today, with increased patient longevity achieved following treatment of a primary cancer, second and even third primaries may arise. In this setting, if a lymph node metastasis is identified at a distant site, knowledge of the pathways of spread may help in accurately determining the particular primary site from which the recurrence has taken origin.

As in previous editions, great care has been taken with the layout to give prominence to selected illustrations and, most importantly, to position the figures as closely as possible to their citation in the text so that the reader's time and effort are not wasted referring to pages some distance apart.

The color images detail anatomic features of clinical significance.

The references have been expanded and continue to include both classic articles and recent citations. They

are not restricted to the English language and, when pertinent, refer to the original descriptions. A lengthy index with cross-references provides immediate access to the detailed material presented.

We wish to express our gratitude to the contributing authors who have added luster to this edition:

- Drs. Yong Ho Auh of the Weill Cornell Medical College – New York Presbyterian Hospital, New York City; Jae Hoon Lim of the Sungkyunkwan University School of Medicine, Samsung Medical Center, Seoul, Korea; and Sophia T. Kung of the Weill Cornell Medical College – New York Presbyterian Hospital, who contributed Chapter 7 on The Extraperitoneal Pelvic Compartments;
- Drs. Maarten S. van Leeuwen and Michiel A.M. Feldberg of the University Medical Center, Utrecht, The Netherlands, who contributed the section on Compartmentalization of the Anterior Pararenal Space in Chapter 6.

We also wish to thank Dr. Jae Hoon Lim for his generous cooperation in providing many state-of-the-art images depicting extraperitoneal anatomy and pathology.

We have submitted this manuscript to Springer, confident that their skills have produced another edition of high technical quality.

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Contents

A New Paradigm

1

Science is characterized by discoveries. While the discovery of new facts is reportable, facts alone do not constitute the entirety of science. "Facts are the enemy of truth!" cried Don Quixote de la Mancha. Certainly, unprocessed facts, facts taken at face value, may limit our grasp of fundamental relationships. Understanding comes from making connections between many disparate facts. Such pattern recognition need not require immense data sets. In his insightful *The Art of Scientific Investigation*, W.I.B. Beveridge declares: "More discoveries have arisen from intense observations of a very limited material than from statistics applied to large groups, for only by being familiar with the usual can we notice something as being unusual or unexplained."[1] This is especially true in the biological sciences, where progress is achieved not only by new information but also by the improved understanding of puzzling phenomena, the removal of contradictions, the making of better predictions, and the determination of connections between previously unconnected phenomena. Essential is the development of new concepts often integrating the new with the previously established facts.

A paradigm is a universal adoption of scientific achievements that for a period of time provides the model for problem solving. One can become so invested into the prevailing paradigm that revolutionary advances making their appearance are categorically denied. Nothing illustrates this more dramatically than the utterances of false prophets.

Hear the prediction of Yale Professor Irving Fisher just before the 1929 stock market crash. Fisher declared that stocks had reached "what looks like a permanently high plateau." As we all know, the plateau abruptly turned into an abyss.

Economics is accepted for its dubious accuracy, but science is regarded as, well, scientific. But despite stunning breakthroughs in medicine over the past century, false prophets have long trumpeted the end of scientific advances.[2] Consider these

X-rays will prove to be a hoax.

Lord Kelvin, English physicist and President of the Royal Society, 1896

Everything that can be invented has been invented.

Charles H. Duell, commissioner of the U.S. Patent Office, in a letter to President William McKinley, urging him to close the office, 1899

We can surely never hope to see the craft of surgery made much more perfect than it is today. We are at the end of a chapter.

Berkeley George Moynihan, Leeds University Medical School, 1930

The great era of scientific discovery is over. . . .Further research may yield no more great revelations or revolutions, but only incremental, diminishing returns.

John Horgan, science journalist, 1996[3]

Reality shows that such statements border on farce.

A shift in paradigm occurs after new discoveries, new facts, new problems concerning the facts cannot be explained within the existing framework. This shift comes only after a reevaluation of traditional procedures indicates the inadequacy of underlying concepts leading to an altering of perception and the introduction of a new paradigm. It is the initiation of inquiry into the reigning paradigm that is the most difficult

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part in the transformation process. The difficulty lies in recognizing that a problem exists and in noting precisely the point or points to direct the inquiry.

In many fields – most notably in physics – advances during the twentieth century have been made by discarding mechanistic principles of what came to be known as the scientific method and adopting a new concept. The world could no longer be viewed and understood as a multitude of individual objects but rather as one indivisible dynamic whole, whose parts are interrelated and understood as integrated parts of the whole.

The fields of biology and psychology have also raised serious questions about the scientific method. Inductive reasoning comes into question with views on perception according to the reporting individual and actual objects. Experiences are subjective with the brain formulating the images we perceive. The processes of perception themselves are unconscious and involve a whole range of presuppositions. How we grasp an image is very much dependent upon multiple factors: our presuppositions, expectations, experiences. This has been demonstrated by psychologists by a series of drawings with subtle progressive differences until the last panel depicts an illustration radically different from the first (Fig. 1–1). The recognizable point of transition where the image shifts in the viewer's perception is different depending whether the viewer traces the series from left to right or backward. This illustrates that pre-conditioning – in other words, the concepts of expectation, prior knowledge, and experience – determines in large measure visual perception.

In abdominal radiology, the traditional concept divides the abdomen and pelvis into component parts. This proved useful in the broad classification of disease processes, but with the technological developments and widespread applications of axial imaging the traditional concepts failed to explain all observations.

Axial imaging provides the exciting capability to visualize portions of the abdomen and pelvis not imaged previously. It has become apparent that the traditional analysis of compartmentalization does not fully explain certain manifestations of the spread of disease. Significantly, spread between intraperitoneal organs, spread between intraperitoneal and extraperitoneal sites, spread within the extraperitoneal compartments, and spread within areas not previously described, e.g., root of mesenteries, all demanded a new paradigm. Our perception of images of the abdomen needs a new abstraction and a new conceptual model to provide the fullest understanding of the spread and localization of disease processes.

There is always a reluctance to change paradigms, especially one that has served us for years. However, inquiry toward a new solution starts when something is unsatisfactory and traditional methods provide an inadequate solution. The critical step is to realize the problem and initiate inquiry.

Seeing is in the realm of cognition. The psychology behind this thinking derives in large part from Gestalt theory. Artists, of course, have been aware of this for years. A fresh look at reality is needed as most phenomena of nature cannot be described adequately if analyzed part by part. This realization is that the whole is greater than the sum of its parts or the whole has properties that do not reside in the parts at all. The complexity of organization and the relationships formed by interconnections play as much a part in the conception of the whole as does the naming of its parts.

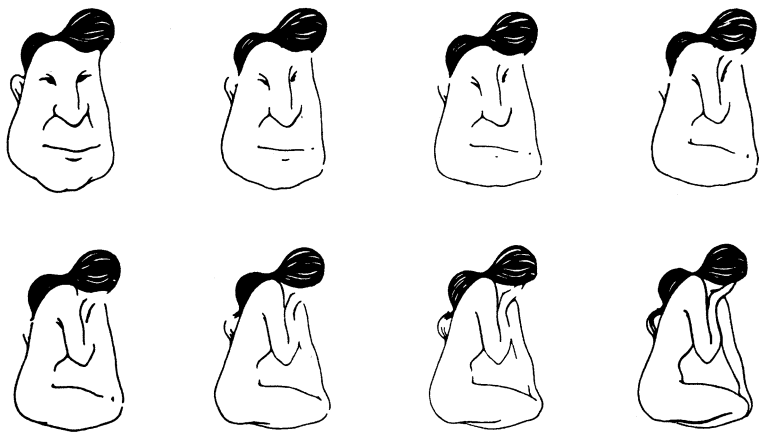

Fig. 1–1. A drawing of a man's face subtly changes to the outline of a young female.
The transition point is dependent not only on subjective variations but also on the sequence followed.

Illustrative of this phenomenon are poet John Godfrey Saxe's six blind men (from his poem "The Blind Men and the Elephant") observing different parts of an elephant and coming to a very different but equally erroneous conclusions about it. The first fell against the elephant's side and concluded that it was a wall. The second felt the smooth, sharp tusk and mistook it for a spear. The third held the squirming trunk and knew it was a snake. The fourth took the knee to be a tree. The fifth touched the ear and declared it a fan. And the sixth seized the tail and thought he had a rope. One of the poem's lessons: "Each was partly in the right, and all were in the wrong!"[4]

The relevance of these views on cognition becomes evident in the art and science of imaging. We can view an image and yet perceive it in different ways. Figure 1–2 illustrates that the image first seen is determined by the relationship between individual features. Both images are present in the one drawing. The viewer sees either an old woman or a young lady. The perception of both images is determined by their relationships. Interestingly, one sees the young lady or the old woman, but not both at once.

Using the same perceived images but with different concepts reveals different pictures. Salvador Dali's *Voltaire in the Marketplace* is an example (Fig. 1–3). The images seen as individual parts appear as people within the marketplace. Seen as a whole, however, the image appears as a bust of Voltaire. Each is seen individually, and each is true, only the concept behind the perception has changed.

In the same manner perceived axial images can be conceived differently. The images seen as parts correspond with the traditional concept, the abdomen and pelvis. If, however, we use a holistic concept the perceived images are seen as one space greater than its sum. The image is the sum of its parts plus the interconnections between the parts.

Fig. 1–2. W.E. Hill's "My Wife and My Mother-in-Law." Both images are present in the drawing. The viewer first sees either an old woman or a young lady. The old woman's prominent nose in profile is the young woman's chin. This drawing illustrates that perception is determined by the relationships.

Origami serves here as a useful visual metaphor to illuminate the anatomic continuity of the plane deep to the peritoneum throughout the abdomen and pelvis. Starting with a flat piece of paper, the craft of origami applies a series of creative foldings to finally yield an identifiable figure (Fig. 1–4). The essential point is this: all the planes of the folded figure distinctly remain in continuity. Despite the creases,

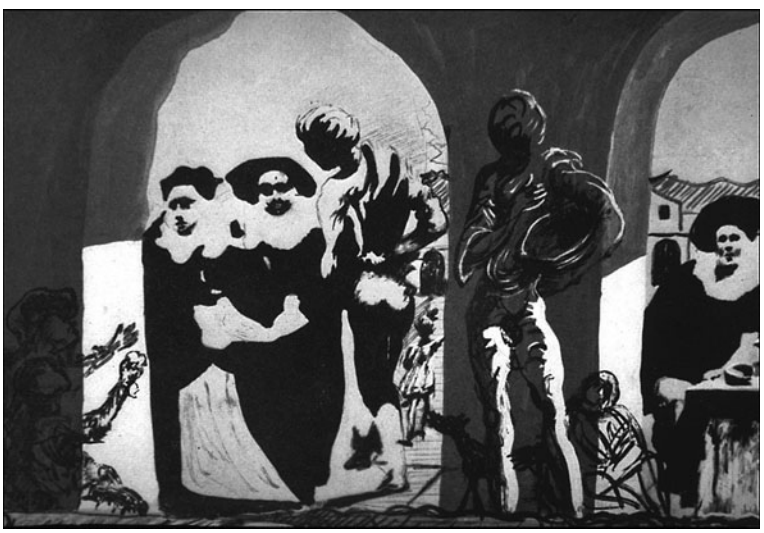

Fig. 1–3. ***The Slave Market with Disappearing Bust of Voltaire*** **by Salvatore Dali.** Both the marketplace and the bust are in the same picture. The marketplace is seen as individuals, and the bust is seen as the sum of the parts.

Fig. 1–4. ***Origami Monkey.***
(Courtesy of Annemarie Johnson.)

bends, overlaps, and projections, the surface of the original flat paper is uninterrupted.

Similarly, as detailed in the following chapters on the embryology of the abdomen and pelvis, the plane deep to the peritoneum is continuous throughout. To recognize this is to vastly extend the clinical contributions of abdominal imaging. In the planes formed by the subperitoneal space course connective tissue, blood vessels, nerves, and lymphatics.[5] It thus becomes evident that the roots of the mesenteries – transverse mesocolon, small bowel mesentery, sigmoid mesocolon, broad ligament – provide avenues of anatomic continuity (Figs. 1–5 and 1–6).

This holistic concept underscores the viewing of the fundamental structures of the abdomen and pelvis as one space – the subperitoneal space. This space includes the extraperitoneal space, and the ligaments and mesenteries of the abdomen and pelvis. The abdomen and pelvis conceived within this holistic paradigm readily explain the interconnections between all the organs, mesenteries, roots of mesenteries, and extraperitoneum in any conceivable combination.

A curved line, viewed from one side, is convex, but viewed from the other side, is concave. Two concepts applied to the same perceived image yield two pictures. Put another way, inherent in the grouping of lines and shadows in the illustrated drawings are two individual perceptions, co-existing and reflective of each other. Conceiving the images as individual parts is most useful in explaining confinement of a disease process and differential diagnosis based on location. However, conceiving the image as a holistic anatomic concept illuminates a new revolutionary paradigm. The abdomen and pelvis are constituted by one interconnected space. This is of critical use in explaining the pathways of spread of disease.

The introduction and acceptance of a new paradigm is made more difficult if vocabulary from a previous paradigm continues to be used. This is due to the potentially misleading implications the term carries from its use in the previous paradigm. While it is best to use new terms, this is not always possible. A clear set of definitions of how a word or words are used in the holistic concept is useful:

Subperitoneal Space: Extraperitoneal space and the ligaments/mesenteries of the abdomen and pelvis.

Extraperitoneal: The circumferential space around the abdomen and pelvis lying beneath the parietal peritoneum, stratified in the abdomen by renal fascia and in the pelvis by umbilicovesical fascia.

Retroperitoneum: Posterior portion of the extraperitoneum in the abdomen.

Ligaments/mesenteries: Formed by two peritoneal layers (visceral peritoneum) in continuity with the parietal peritoneum. The structures enclosed – connective tissue, blood vessels, nerves, and lymphatics – are in continuity with the extraperitoneum.

A major purpose of *Meyers' Dynamic Radiology of the Abdomen* is in explaining the pathways of disease spread. The subperitoneal space provides the avenues for spread interconnecting all the organs. The peritoneal cavity provides the potential pathways for intraperitoneal spread. The benefits of this cognitive framework are multiple. When the primary site of disease – whether infectious, traumatic, or neoplastic in nature – is known, precise identification can be made of the expected sites of spread and localization. On the other hand, when a patient presents with a remote lesion, the primary site – which may be clinically occult – can be inferred. Furthermore, such basic understanding facilitates identification of the expected site of recurrent disease or the pattern of progression after treatment.

By developing focused search patterns, the radiologist serves in a critical position to direct the course of investigation, to evaluate the extent of disease, to indicate the prognosis, and to determine the appropriate management.

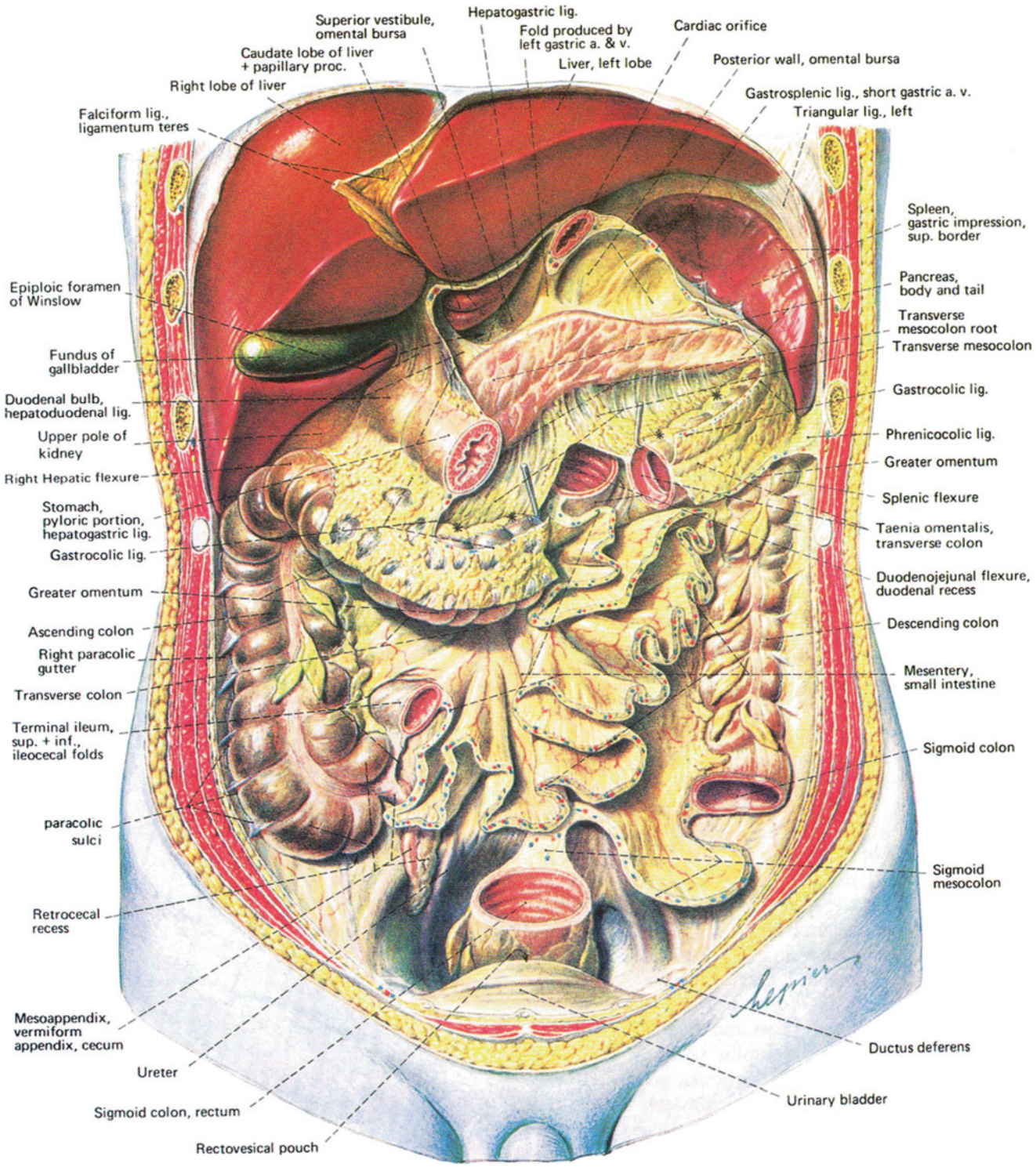

Fig. 1–5. Abdominal viscera.
The stomach has been removed from the cardia to the pylorus, revealing the lesser sac (omental bursa) and structures on the posterior wall.
(Reproduced with permission from Putz.[6] Copyright Elsevier [Churchill Livingstone Imprint].)

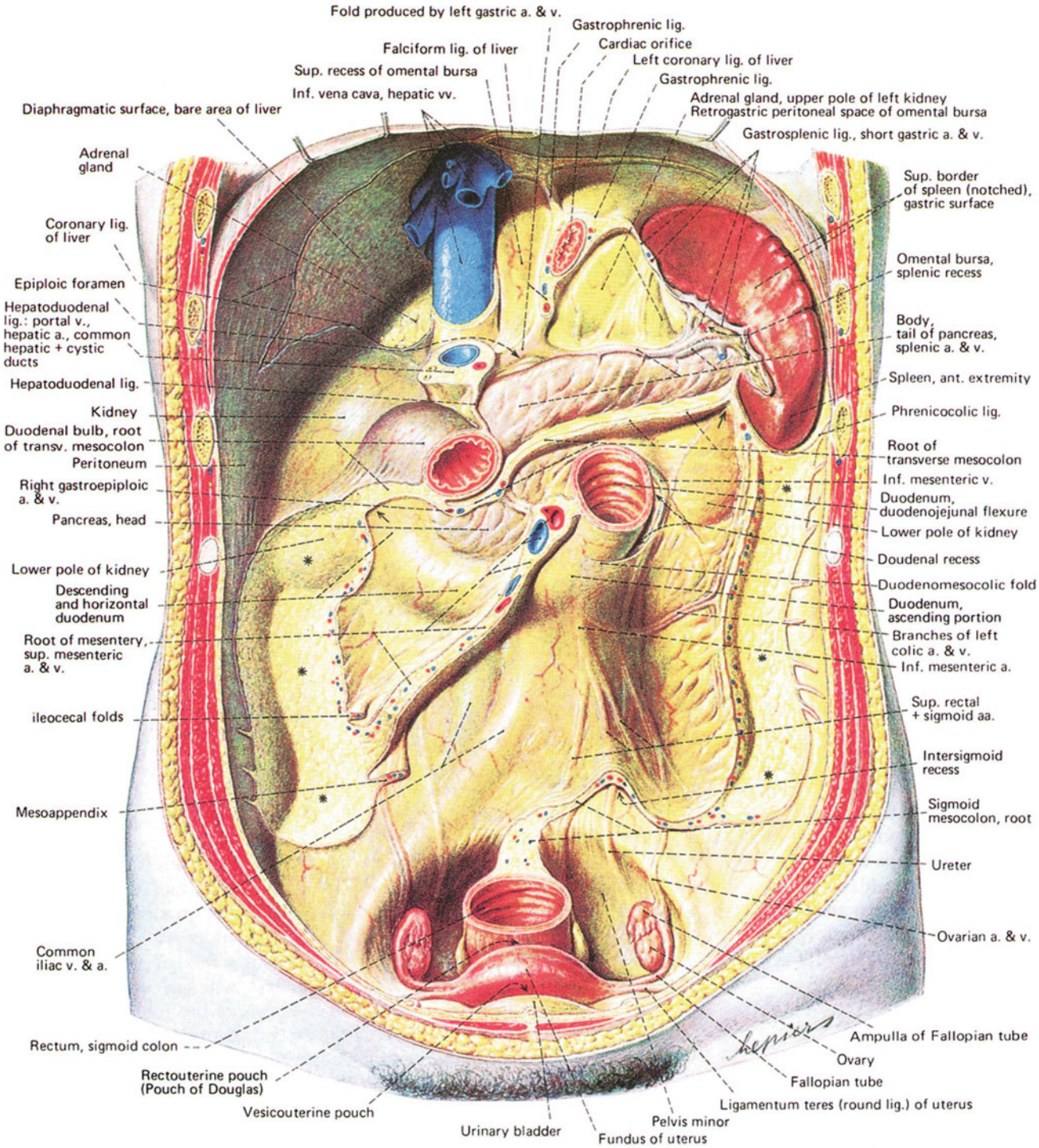

Fig. 1–6. Retroperitoneum of an adult female.
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Clinical Embryology of the Abdomen

2

Introduction

Conventional distinction between intraperitoneal and extraperitoneal sites is often helpful in differential diagnostic considerations.[1] Yet it should be understood that the abdomen and pelvis constitute an anatomic continuum that is punctuated by the mesenteries, ligaments, and fasciae, which may either confine pathology or actually provide avenues for disease spread. It is essential to recognize the anatomic continuity of subserous connective tissue with its vessels and lymphatics as an extension of the extraperitoneal space that underlies the holistic concept of the subperitoneal space. A scaffold with precise anatomic planes is provided for spread of disease not only between intraperitoneal structures but also between extraperitoneal and intraperitoneal sites.[2] This unifying concept is the basis for understanding the dissemination of intraabdominal disease, including malignancies and inflammatory and traumatic processes, both focally and at areas distant from the site of origin.

The subperitoneal space's continuity with the thorax provides access for the bidirectional spread of disease involving these regions.[3–7] It is the continuity between and within the abdomen and thorax that provides the rationale for understanding the paradoxical clinical appearance of disease at a distance from its site of origin. The graphic display of the anatomy with modern imaging modalities coupled with current knowledge of the morphology of the subperitoneal space provide a comprehensive clinical delineation of disease processes and an improved understanding of the pathogenesis of direct spread of disease.

The knowledge of the development of the subperitoneal space is a prerequisite to recognizing pathologic conditions and understanding the pathogenesis of disease spread.[8–11] The conceptualization of the abdomen and pelvis as one space, the subperitoneal space, and its continuity with the thorax requires the reexamination of standard embryology from a holistic perspective.

Early Embryonic Development

After fertilization, the zygote rapidly develops into a trilaminar sphere with three distinct layers: entoderm, mesoderm, and ectoderm. Various body parts are then derived by progressive differentiation and divergent specialization. The entoderm becomes the lining of the gastrointestinal tract, the liver, and pancreatic glandular tissue. The ectoderm becomes the nervous system and epidermis. The mesoderm develops into the remaining tissue including the visceral and parietal peritoneum, visceral and parietal pleura, as well as the ligaments and the mesenteries of the abdomen.

The lateral portion of the mesodermal layer of the embryo divides by the 4th week (Fig. 2–1). The lateral margins move ventrally and medially and encompass the yolk sac (Fig. 2–2). This incorporates the intraembryonic coelom, forming a tube within a tube. The outer tube is the body cavity, and the inner tube is

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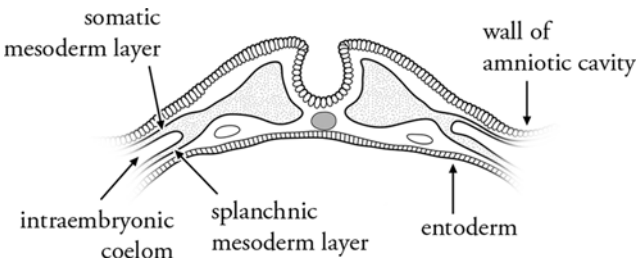

Fig. 2–1. Diagrammatic drawing of a transverse section through an embryo at the end of the 3rd week of gestation.
The somatic mesoderm and the splanchnic mesoderm result from the division of the lateral plate. The serous membrane is formed from the tissue lining the intraembryonic coelom.

the primitive gastrointestinal tract. The inner tube is suspended from the outer tube by the primitive mesentery. The inner tube (primitive gastrointestinal tract) maintains a dorsal attachment to the outer tube (body wall) throughout its length via a dorsal mesentery. The ventral attachment involutes except at the level of the distal foregut where it persists as the ventral mesentery.[11]

Thus, by the 4th week the continuity of the body wall (extraperitoneal space) with the suspended gastrointestinal tract is established by the connecting primitive mesentery. This interconnection persists throughout development and into the adult form as the subperitoneal space. Subserous continuity is also preserved between the abdomen and the thorax.

Thoracoabdominal Continuum

The traditional description of the development of the separate body cavities emphasizing principally the cavities has tended to obscure the critical subserous continuity. Instead, focusing on the subserous membrane and the subjacent structures allows for appreciation of the unbroken subserous space.

There are three partitions that subdivide the body cavity. The first partition occurs at 5 weeks when the septum transversum forms from the ventral wall and divides the coelom into the eventual thoracic and

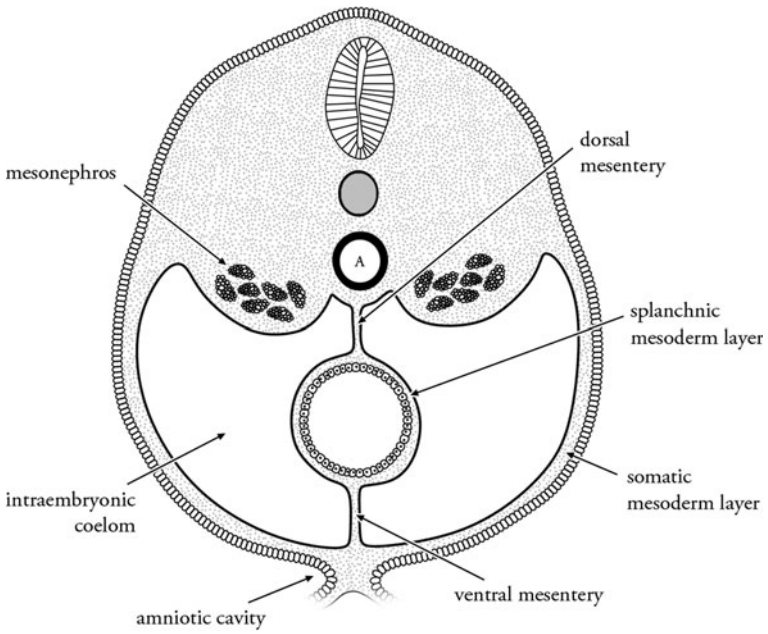

Fig. 2–2. Diagrammatic transverse section through an embryo at the end of 4 weeks of gestation.
The somatic mesoderm and the splanchnic mesoderm result from the division of the lateral plate. The serous membrane is formed from the tissue lining the intraembryonic coelom. The splanchnic mesoderm, the black line outlining the intraembryonic coelom, has enfolded from the midline and formed a serous membrane containing an extension of the subserous space (*stippled area*) and suspending the primitive gut. The gut is contained within and divides the primitive mesentery into the dorsal mesentery and ventral mesentery. Note the continuity of the subserous space into the primitive mesentery. A = aorta.

abdominal cavities. The persistent openings on each side of the coelomic cavity are called the pericardioperitoneal canals. These are potential spaces defined by the subserous lining. The developing organs are subjacent to this lining and project into the potential space of the coelomic cavity. The lung buds form in the thorax from the primitive gut and grow laterally. The lungs project into the pericardioperitoneal canals enclosed by the serous membrane (Fig. 2–3).

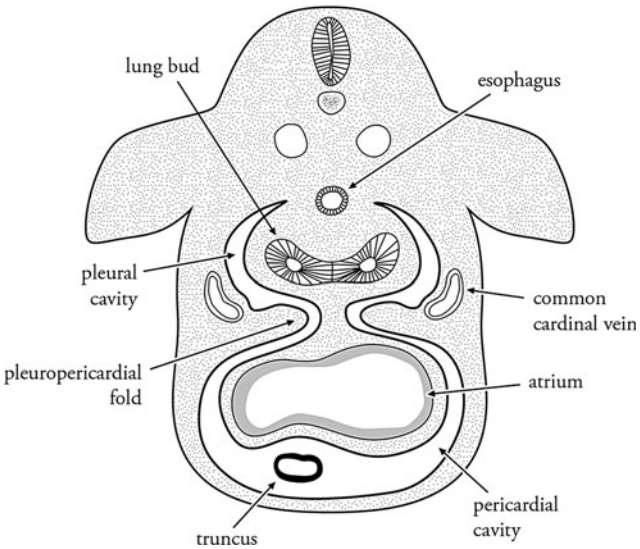

Fig. 2–3. Diagrammatic drawing transverse section through a 4-week embryo in which the pleural and pericardial regions are forming.
The lung buds are growing into the pericardioperitoneal folds, and the heart is forming. The continuous serous membrane lines that portion of the coelomic that will become the pleural cavity and pericardial cavity. The subserous space is the stippled area subjacent to the serous membrane.

Dorsal to the septum transversum, the heart is confluent with the gut and liver. The gut and liver are enclosed by the serous membrane and suspended on their mesenteries. A portion of the liver develops within the caudal side of the septum transversum. This forms a barrier preventing the developing lung from expanding into the abdomen. The lungs develop covered by the serous membranes (parietal and visceral pleura) and project laterally forming the pleural cavities. As the lungs and pleura develop, a second partition is formed: the pleuropericardial folds (Fig. 2–4). The portion of the serous membrane between the lung and heart grows medially and fuses at the midline separating the pericardial cavity. The pleural cavities remain connected dorsally with the peritoneal cavity due to the incomplete development of the diaphragm.

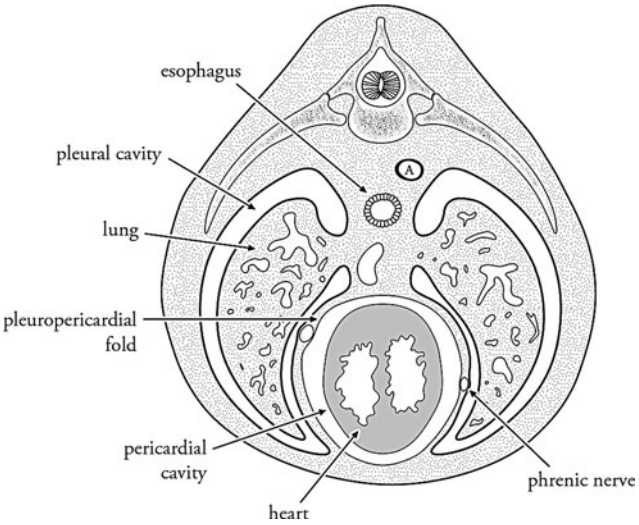

Fig. 2–4. Diagrammatic drawing of transverse section through a 5-week embryo in which the pleural and pericardial regions of the coelom become separated.
Complexity of the serous membrane results as it fuses ventrally forming the pericardial cavity. The pleuropericardial folds fuse bilaterally at the root of the lungs. The serous membrane lines the pleural cavities as the visceral and parietal pleura. The subserous space is subjacent to this lining. *A* = aorta.

The isolation of the pleura and peritoneal cavities occurs by 7 weeks as the diaphragm is completed by the third partition – the pleuroperitoneal folds. These fuse with the esophageal mesentery, dividing the pleural and peritoneal cavities (Fig. 2–5).

The diaphragm is covered by the serous membrane: the thoracic side by the pleura and the abdominal side by the peritoneum. The diaphragm, although separating the body cavities, allows continuity of the subserous space mainly through the esophageal and aortic hiatuses.[12]

The esophageal hiatus is ventral and cranial to the aortic hiatus. The esophageal hiatus contains areolar tissue and the esophagus, vagus nerves, esophageal vessels and lymphatics as they course between the thorax and abdomen. The aortic hiatus is an osseoaponeurotic opening between the diaphragm and vertebral column. The aorta, azygous vein, thoracic duct, and lymphatics course through this aperture. Thus, the esophageal hiatus and the aortic hiatus allow continuity of the subserous space of thorax and abdomen. The vena cava foramen is the most ventral of the three main diaphragmatic apertures and transmits only the inferior vena cava. The caval wall is adherent to the margins of the foramen and interrupts continuity of the subserous space. Small apertures reside ventrally between the sternum and the costal cartilage and allow the superior

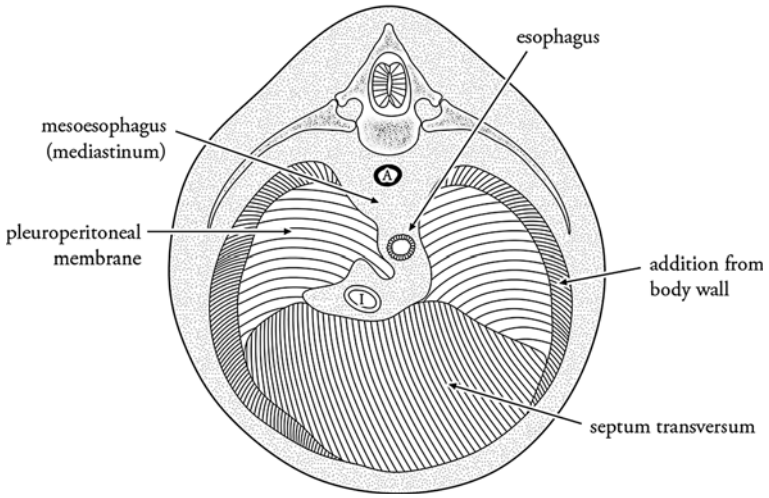

Fig. 2–5. Diagrammatic drawing of transverse section illustrating the hiatuses of the respiratory diaphragm at the 4th month of gestation.
The pleuroperitoneal membrane fuses with the septum transversum and the esophageal mesentery forming the respiratory diaphragm. Esophageal mesentery encloses that portion of the subserous space that encases the esophagus and the inferior vena cava (I). *Stippled area* = subserous space. The serous membrane lines the diaphragm and invaginates dorsomedially, encasing the subserous space. A = aorta.

epigastric branch of the internal mammary artery and lymphatics to course between the abdomen and the thorax.

The function of the cavities is unique. Developmentally, the cavities permit the visceral organs to grow and shift each in their distinctive cavity. The subserous space contains the organs and their blood, nerves, lymphatic supply, and establishes continuity.

This concept of continuity is important to keep in mind as the abdominal mesenteries are described. The essential point is that, regardless of the complexity of development from a single primitive mesentery to the adult form, the continuity of the subperitoneal space is preserved as is continuity of the subperitoneal space of the abdomen and the subserous space of the thorax.

Subperitoneal Space

The abdominal cavity, formed by the 7th week, provides the space within which the viscera grow, shift position, and move without hindrance. To achieve this goal, the developing abdominal organs are suspended by two opposing splanchnic mesodermal layers that form a double-layered mesentery at 3½ weeks – the primitive mesentery.

The gut arises by the enfolding of entoderm at 3 weeks to form a tube. The splanchnic mesoderm contains the gut and extends as a double layer from the dorsal to the ventral wall of the coelomic cavity. The gastrointestinal tract at 3 weeks is a straight tube and divides the primitive mesentery into the dorsal mesentery and the ventral mesentery (Fig. 2–2). At this time, the liver appears, partially enclosed within the ventral mesentery.

The primitive mesentery contains a layer of connective tissue beneath its serous lining. The development of the vascular system is heralded by the appearance of numerous islands that form plexiform networks throughout this mesenchyme. These plexuses fuse and give rise to the ventral (splanchnic) vessels (Fig. 2–6). At the end of 4 weeks, the aorta has formed and has developed three prominent ventral branches: the celiac artery in the stomach and pancreas region, the superior mesenteric artery in the small intestine region, and the inferior mesenteric artery in the large intestine region. These three vessels course from within the body wall via the mesenteries to the gastrointestinal system (Fig. 2–7).[12] Thus, the blood supply and the eventual lymphatic and nerve supply to the gastrointestinal organs are established, coursing within the mesenteries as they extend from the extraperitoneal tissue to the suspended organs.

The ventral and dorsal mesenteries undergo specialization as the abdominal and pelvic organs develop.

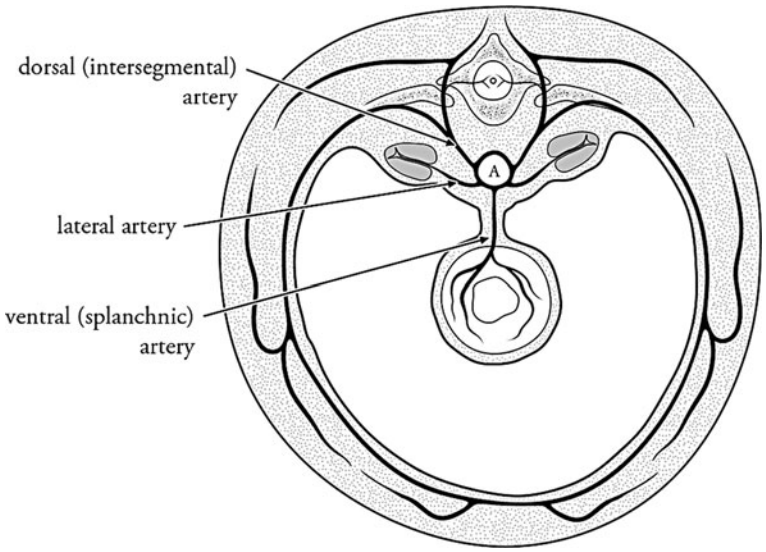

Fig. 2–6. Diagrammatic drawing of transverse section through an embryo at the end of 4 weeks of gestation. The ventral (splanchnic) artery has formed and supplies the primitive gut. The ventral artery extends within the mesentery from the aorta (*A*) to the suspended gut. Note continuity of subperitoneal space (*stippled area*) within the mesentery as well as continuity from right to left and dorsal to ventral.

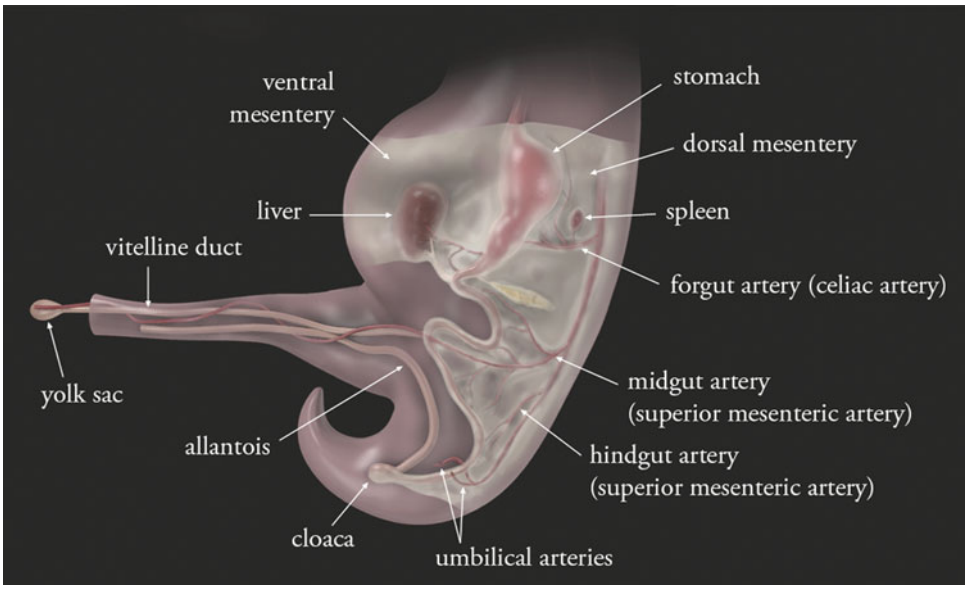

Fig. 2–7. Three-dimensional drawing of a 5-week embryo. The entire gut as well as the liver, pancreas, and spleen are encased within the mesentery. The organs of the foregut are within the ventral and dorsal mesentery; the organs of the midgut and hindgut are within the dorsal mesentery. All the organs are supplied by the aorta and its three ventral arteries (celiac, superior mesenteric, inferior mesenteric arteries) as they extend within the mesentery to the suspended organs.

Ventral Mesentery Specialization

The ventral mesentery that initially attaches the entire length of the primitive gut to the ventral abdominal wall regresses except in the region of the lower esophagus, stomach, upper duodenum, and liver. The liver appears at 3–4 weeks and rapidly enlarges as it projects from the septum transversum into the ventral mesentery. The liver splits the ventral mesentery into anterior and posterior portions, *the falciform ligament* and *gastrohepatic ligament* (lesser omentum), respectively (Fig. 2–8a, b). The free margin of the falciform ligament contains the left umbilical vein, forming the *ligamentum teres*. The free margin of the gastrohepatic ligament contains the common bile duct, portal vein, and hepatic artery and is termed the *hepatoduodenal ligament*

The liver capsule, formed by the visceral peritoneum, is continuous with the peritoneum, except where the liver is embedded within the septum transversum, known as the "bare area." The peritoneal lining reflects from this area as the *coronary ligament* and attaches to the lateral abdominal wall as the *triangular ligaments*. The liver ligaments are in continuity with the falciform ligament and the gastrohepatic ligament as derivates of the ventral mesentery (ventral mesogastrium) (Fig. 2–9).

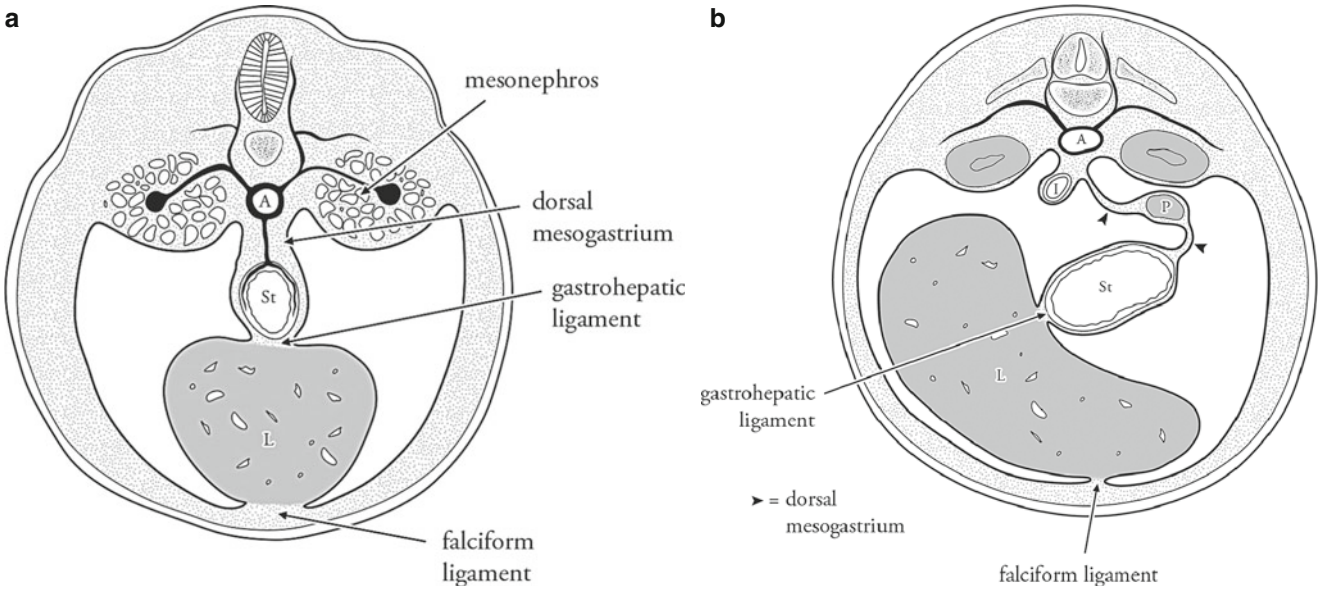

Fig. 2–8. (a) Diagrammatic transverse section through an embryo at 5 weeks.
The liver has appeared within the ventral mesentery forming the falciform ligament and gastrohepatic ligament. *L* = liver; *St* = stomach; *A* = aorta. Note continuity of subperitoneal space (*stippled area*).
(b) Diagrammatic transverse section with further growth of the liver and appearance of the pancreas.
The liver (*L*) has grown, causing rotation of the stomach (*St*) and further development of the ventral mesogastrium (falciform ligament and gastrohepatic ligament). Note appearance of the pancreas (*P*) within the dorsal mesogastrium. *A* = aorta; *I* = inferior vena cava. *Arrowheads* = dorsal mesogastrium.

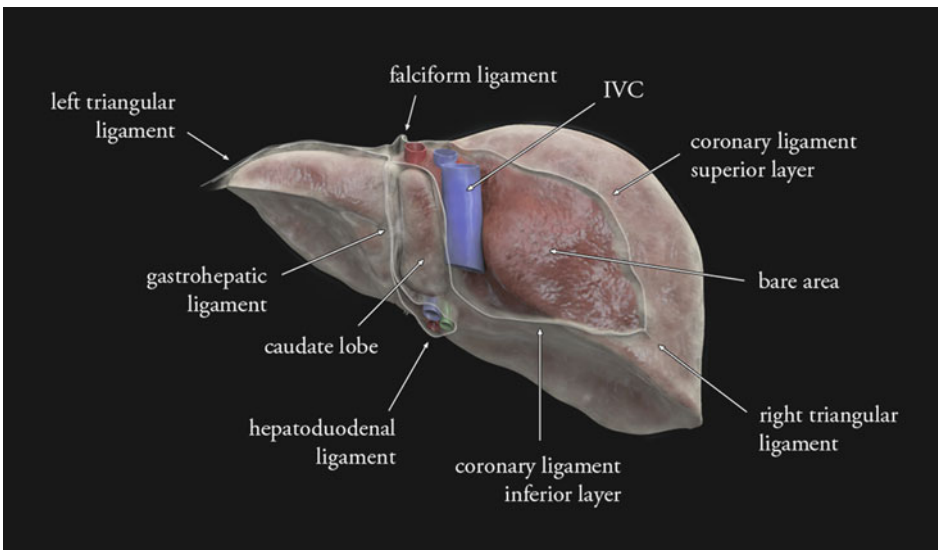

Fig. 2–9. Three-dimensional drawing of the liver (posterior view).
The ligaments of the liver formed from the ventral mesogastrium and are shown in continuity. Note the gastrohepatic ligament as its free margin forms the hepatoduodenal ligament. The ligaments attach to the abdominal wall ventrally (falciform ligament) and laterally (triangular ligaments).

Dorsal Mesentery Specialization

The dorsal mesentery extends from the lower end of the esophagus to the rectum. Throughout its length, it serves as a pathway for blood vessels, lymphatics, and nerves to the gastrointestinal tract. It is a continuous mesentery suspending the gut, and its subsegments take their names from the regions served, i.e., region of the stomach, the dorsal mesogastrium; region of the duodenum, the dorsal mesoduodenum; region of the colon, the dorsal mesocolon; and the region of the jejunum and ileum, the mesentery proper or small intestine mesentery.

The spleen appears between the folds of the dorsal mesogastrium at the 5th week and, as it grows, bulges into the left upper portion of the coelomic cavity. The dorsal mesogastrium connecting the spleen and stomach is the *gastrosplenic ligament*. The dorsal mesogastrium of the pancreas fuses posteriorly (Fig. 2–10a, b). The dorsal mesogastrium between the spleen and the dorsal midline fuses with the posterior abdominal wall, whereas the remaining part connects the spleen and left kidney and is designated the *splenorenal ligament* (Fig. 2–11a–c).

The head and body of the pancreas grow within the dorsal mesoduodenum and extend into the dorsal mesogastrium. As the pancreas grows, the stomach rotates to the left and the duodenum moves from the midline to the right. After the bowel rotation, the dorsal mesoduodenum fuses onto the posterior parietal serous membrane and forms the pancreaticoduodenal compartment of the anterior pararenal space (Fig. 2–12). This compartment contains the duodenum (except for the proximal duodenum, which retains the unfused portion of mesoduodenum) and

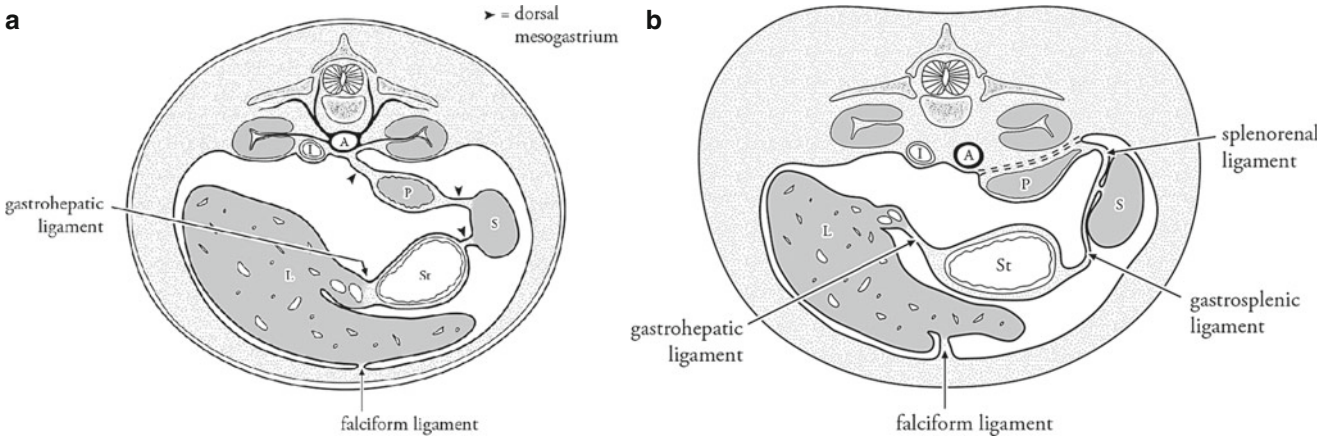

Fig. 2–10. (a) Diagrammatic drawing of transverse section through a 5–6-week embryo.
The pancreas (*P*) and spleen (*S*) have formed within and are suspended by the dorsal mesogastrium (*arrowheads*). *St* = stomach; *A* = aorta; *I* = inferior vena cava.
(b) Diagrammatic drawing of transverse section through a 6-week embryo.
The portion of the dorsal mesogastrium connecting the body wall and pancreas fuses (*dashed lines*). Persistent ligaments of the dorsal mesogastrium are the splenorenal ligament and gastrosplenic ligament.

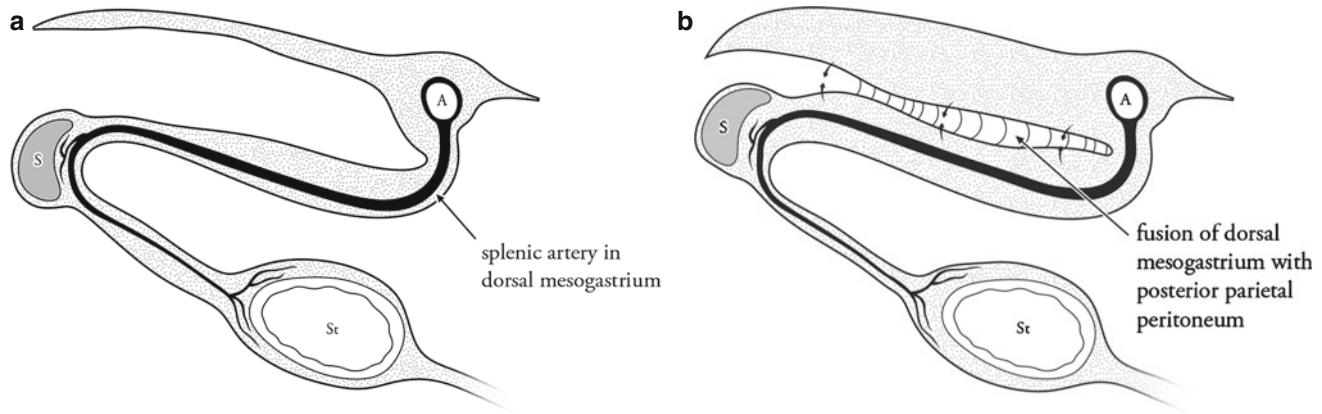

Fig. 2–11. Schematic drawing of transverse sections showing fusion of the dorsal mesogastrium in the region of the splenorenal ligament.
(**a**) The spleen (*S*) is encased and suspended in the dorsal mesogastrium between the stomach (*St*) and posterior body wall. *A* = aorta. *Stippled area* = subperitoneal space. Note continuity of dorsal mesogastrium.
(**b**) Fusion of the dorsal mesogastrium with the body wall (posterior parietal peritoneum). *Arrows* = region of fusion.

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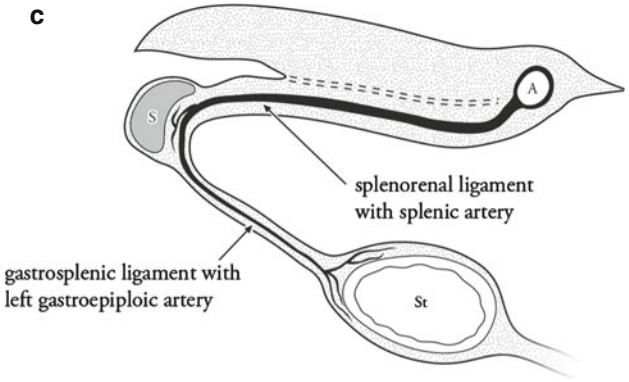

Fig. 2–11. Schematic drawing of transverse sections showing fusion of the dorsal mesogastrium in the region of the splenorenal ligament. (Continued)
(**c**) Adult form with fusion of the dorsal mesogastrium and persistence of the splenorenal ligament and the gastrosplenic ligament (both portions of the dorsal mesogastrium). Note the splenic artery and the left gastroepiploic artery as they course within the mesenteries of the dorsal mesogastrium.

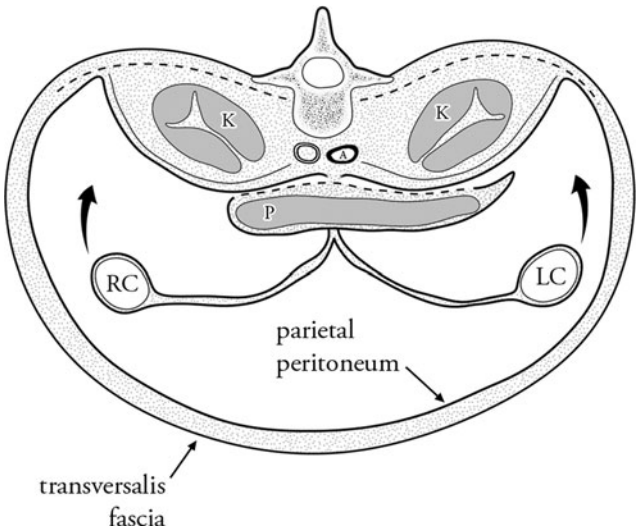

Fig. 2–12. Schematic drawing of a transverse section through an embryo after the reentry of the gut to the coelomic cavity.
The dorsal mesentery of the pancreas is shown as it fuses with posterior parietal peritoneum, indicated by dashed line posterior to pancreas (*P*). This forms the pancreaticoduodenal compartment of the anterior pararenal space. The ascending and descending mesocolons will fuse with the posterior wall of the abdomen (*curved arrows*) forming the colonic compartment of the anterior pararenal space. *RC* = right colon; *LC* = left colon; *K* = kidney. Note the subperitoneal space defined by the stippled area subjacent to the parietal peritoneum is in continuity circumferentially, within the compartments of the anterior pararenal space and the mesenteries.

pancreas. The fused fascia dorsal to these organs is the retroduodenal pancreatic fascia of Treitz. It is important to emphasize that the pancreas, while positioned beneath the posterior peritoneum, remains connected by the mesenteries of the subperitoneal space to the other abdominal organs.

The dorsal mesocolon undergoes extensive fusion. After the ascending and descending portions of the colon come to lie in their lateral positions, their mesocolons fuse with the posterior abdominal wall (Fig. 2–13a, b). These fused fascia are named the right and left retromesenteric fascia of Toldt. This forms the colonic compartment of the anterior pararenal space. It is important to note that although the ascending and descending mesocolons have fused they remain in continuity with the other organs. The appendix and cecum retain their mesenteries.

The dorsal mesogastrium continues to grow after the stomach completes its rotation. This ongoing growth forms a duplication of the dorsal mesogastrium folding upon itself anterior to the transverse colon and small intestine. Later, the four leaves fuse and are suspended from the greater curvature of the stomach as the *greater omentum*.

A fusion also occurs as the dorsal mesogastrium courses over the transverse colon and continues posterior to the posterior abdominal wall. The region of dorsal mesogastrium between the stomach and the transverse colon is the *gastrocolic ligament*. The portion from the transverse colon to the posterior abdominal wall fuses with the *transverse mesocolon* (Fig. 2–14a, b).

The right portion of transverse mesocolon fuses and covers the duodenum forming the *duodenocolic ligament*. At the anatomic splenic flexure (the junction of the transverse colon and descending colon), the transverse mesocolon extends laterally to attach to the lateral abdominal wall, forming the *phrenicocolic ligament*. *The sigmoid mesocolon*