Review Article

The retroperitoneal interfascial planes: current overview and future perspectives

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Recently, the concept of interfascial planes has become the prevalent theory among radiologists for understanding the retroperitoneal anatomy, having replaced the classic tricompartmental theory. However, it is a little known fact that the concept remains incomplete and includes embryological errors, which have been revised on the basis of our microscopic study. We believe that the concept not only provides a much clearer understanding of the retroperitoneal anatomy, but it also allows further development for diagnosis and treatment of retroperitoneal injuries and diseases, should it become an accomplished theory. We explain the history and outline of the concept of interfascial planes, correct common misunderstandings about the concept, explain the unconsciously applied therapeutic procedures based on the concept, and present future perspectives of the concept using our published and unpublished data. This knowledge could be essential to acute care physicians and surgeons sometime soon.

Key words: Embryology, interfascial planes, retroperitoneum, sepsis/multiple organ failure, trauma

I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.
Sir Isaac Newton

INTRODUCTION

SURPRISINGLY, THE STRUCTURE of the retroperitoneum has not been entirely clarified.[1] Even the famous tricompartmental theory for retroperitoneal structures advocated by Meyers *et al.*[2,3] has failed to explain the dynamic changes of retroperitoneal pathologies. Instead, the radiological concept of interfascial planes, which considers the retroperitoneal fasciae as potential spaces,[4–7] is being widely accepted to explain the extension of retroperitoneal pathologies.[8–12] Recently, the concept has become requisite knowledge for radiologists,[12] and furthermore, it has appeared in a popular anatomy textbook for medical students.[13] However, the concept remains incomplete and has been fundamentally misunderstood in terms of embryological development.[1] We have been studying the interfascial planes since 2001 in the belief that having a definitive understanding of the planes not only will completely clarify the retroperitoneal anatomy but also will revolutionize the understanding of the pathology of retroperitoneal injuries and diseases, which are often difficult to diagnose and treat, and might bring a breakthrough in the treatment for such trauma and diseases.[1,8–11] Therefore, for physicians focusing on acute medicine and surgery, we review the concept of interfascial planes, present its future perspectives, and introduce our unpublished data and the latest studies.

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BASIC KNOWLEDGE

Conventional understanding of the retroperitoneum

RETROPERITONEAL FASCIAE WERE found by legendary anatomists, such as Cooper, Treitz, and Toldt, in the 19th century.[14] Until then, the retroperitoneum was believed to be homogeneous fatty tissues acting as a mere cushion.[15] Major progress in the knowledge of the retroperitoneal fasciae was achieved by the discovery of the posterior renal fascia by Zuckerkandl and of the anterior renal fascia by Gerota.[15] Particularly, the exquisite color illustrations by Gerota remain a basis for the study of the retroperitoneal anatomy even now, while both Zuckerkandl and Gerota seemed to consider the fasciae as apparatuses to anchor the kidneys to prevent their floating.[14,15] On the basis of the above anatomical studies, Meyers *et al.*[2,3] established the reputable tricompartmental theory (Fig. 1), although the idea that the retroperitoneum can be divided into several compartments by the retroperitoneal fasciae seemed to exist earlier than Meyers, as is found in the paper by Mitchell.[16] The point of the theory was that the retroperitoneal space comprises only three compartments: the anterior pararenal space, the perirenal space, and the posterior pararenal space, which are demarcated by three well-defined fasciae (Fig. 1A), and that retroperitoneal lesions are confined to the one compartment in which they originate. The theory rapidly spread worldwide because it seemed to coincide with images visualized by computed tomography (CT) scanning that had just been developed.[17] However, as we previously described in detail,[8,9] the "tricompartmental theory" failed to explain the dynamic changes in the pathological spread of fluid beyond the original compartment,[18] such as the spread of renal lesions into the contralateral perirenal space or into the pelvic retroperitoneum. Additionally, the retroperitoneal anatomy below the "discontinued" renal fasciae (Fig. 1C), as illustrated by Gerota,[15] remained ambiguous[8,9] according to the theory.

Birth of the concept of interfascial planes

The idea that pathologic fluid spreads in the potential space within the retroperitoneal fasciae was, to our knowledge, initially proposed by Feldberg in 1983.[19] Additionally, Marks *et al.*[20] and Raptopoulos *et al.*[21] showed that the lateroconal fascia, which has long been thought to comprise the union of the anterior and posterior renal fasciae,[2,3,14,16,22–24] is distinct from the renal fasciae by macroscopic dissection in cadavers and by histological study. They concluded that the posteromedial part of the lateroconal fascia runs close to the posterior renal fascia, and this combination appears as a single-layered fascia. Regrettably, they considered the potential space between the proper lateroconal fascia and the posterior renal fascia as the anterior pararenal space,[25] but they generated the idea that pathologies spread by dissecting the fascia. Sato *et al.*, Japanese anatomists, advocated the "interfascial spaces", a similar concept to the interfascial planes, in the early 1980s.[26] (Figs. S1, S2) It is no exaggeration to say that the concept of interfascial planes was conceived in the 1980s.

In 1996, the concept of interfascial planes was debuted by Molmenti *et al.*[4] They demonstrated the existence of potential spaces within the retroperitoneal fasciae by injection of colored latex and contrast medium in cadavers and coined the terms "retromesenteric plane" and "retrorenal plane". This concept considers the fasciae not only as barriers dividing the retroperitoneum but also as pathways through which retroperitoneal lesions can spread beyond the original compartment by dissecting the fasciae[4,6] (Fig. 1B, D).

Aizenstein *et al.*[5] completed the original form of the concept by combining the interfascial planes with perinephric bridging septa[27] (Figs. 1E, 2A), potential spaces in the perirenal space. Consequently, this concept has settled controversies over the patency of the medial or inferior part of the perirenal space and over the pathways whereby retroperitoneal pathologies extend into the other compartments.[5–10] They explained that renal lesions extend into the contralateral perirenal space not directly but by way of bridging septa and the retromesenteric plane (Figs. 1E, 2) and into the pelvic retroperitoneum not by direct spread from the narrow patent part of the perirenal space (Fig. 1C) but by spreading within the combined interfascial plane after traveling within the retromesenteric or retrorenal plane by way of perinephric bridging septa (Figs. 1D, 3).[5–11]

The concept was further applied to the clinical stratification of the retroperitoneal diseases after we revised the relationship between the posterior pararenal space and the retrorenal plane around the psoas muscle and found another retroperitoneal potential space named the "subfascial plane" (Fig. 1F).[10,11] Results from a search on Google Scholar show a dramatic increase in published works written in English on the interfascial planes after 2008.

CLINICAL APPLICATION

Traumatic retroperitoneal hematoma

MORBIDITY AND MORTALITY rates associated with traumatic retroperitoneal hematoma (TRH) remain high despite improvements in prehospital care.[10,28] Additionally, decision-making in the treatment of TRH is often controversial even after CT scanning. In the early 1980s, Kudsk and Sheldon[28] introduced a famous treatment principle founded on a location-based classification of TRH as central-medial (Zone I) TRH, flank or perirenal (Zone II) TRH, and pelvic (Zone III) TRH. This principle has been used as a bible for the treatment of TRH;[29,30] nevertheless, the strategy remains controversial. For example, many patients with Zone I TRH do not undergo surgical management,[10] although exploration of a Zone I TRH with emergent laparotomy is recommended.[28–30] Additionally, it is often impossible to classify every TRH into one of the three zones because TRH can extend beyond a single zone.[10] Therefore, we proposed a new classification of TRH according to the concept of interfascial planes by analyzing CT images.[10]

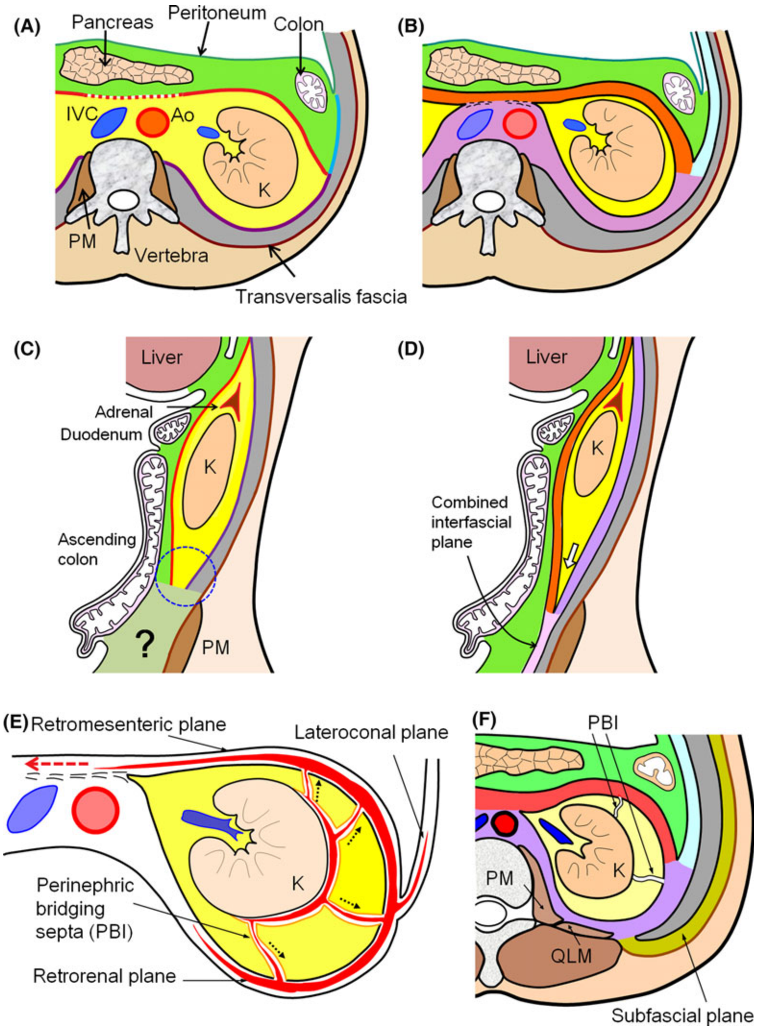

Fig. 1. Diagrams of retroperitoneal anatomy. A, Cross-sectional diagram of the median and left parts of the retroperitoneum according to the tricompartmental theory.[3] The retroperitoneum is divided into the anterior pararenal space (green area), perirenal space (yellow area), and posterior pararenal space (gray area) by the anterior renal fascia (red line), posterior renal fascia (purple line), and lateroconal fascia (blue line). Ao, aorta; IVC, inferior vena cava; K, kidney, PM, psoas muscle. B, Cross-sectional diagram of the same area in panel A, according to the concept of interfascial planes.[5] This diagram depicts the interfascial planes as potential spaces among the three compartments: the retromesenteric plane (red area) corresponds to the anterior renal fascia; the retrorenal plane (purple area) corresponds to the posterior renal fascia; and the lateroconal plane (sky-blue area) corresponds to the lateroconal fascia. Note that the perirenal space is closed medially. C, Longitudinal diagram of the retroperitoneum according to the tricompartmental theory.[3] As shown within the dotted circle, the bottom of the perirenal space is patent, and the retroperitoneum below the discontinued renal fasciae (olive area) is ambiguous. D, Longitudinal diagram of the retroperitoneum according to the concept of interfascial planes. The perirenal space is closed inferiorly (open arrow). The combined interfascial plane (pink area) is formed by the inferior blending of the retromesenteric and retrorenal planes and continues into the pelvis. Renal lesions can reach interfascial planes through the perinephric bridging septa (described below) and spread within the combined interfascial plane into the pelvis. E, Aizenstein's advanced diagram of the planes.[5] A renal lesion (red area) spreads within the perinephric bridging septa (dotted arrows) and intrudes into the interfascial planes. The lesion can extend contralaterally (red dashed arrow) by way of the retromesenteric plane. F, Our modification of the concept.[10,11] We pointed out that the retrorenal plane, not the posterior pararenal space, lies immediately adjacent to the psoas muscle and quadratus lumborum muscle (QLM) and that the inner border of the posterior pararenal space is limited to the lateral edge of the QLM.[10] In addition, we advocated another potential space communicating with the retrorenal plane, which exists behind the posterior pararenal space, and named this the subfascial plane (gold area).[10,11] Panels in this figure are reprinted with permission from the copyright owners (panels A, C: Springer Science+Business Media;[3] panels B, E: American Roentgen Ray Society[5]; panel F: Elsevier[11]; panel D: Nagai Shoten Co.[8,9] and Wolters Kluwer Health, Inc.[10]; illustrated by Ishikawa, according to the description by Aizenstein *et al.*[5]).

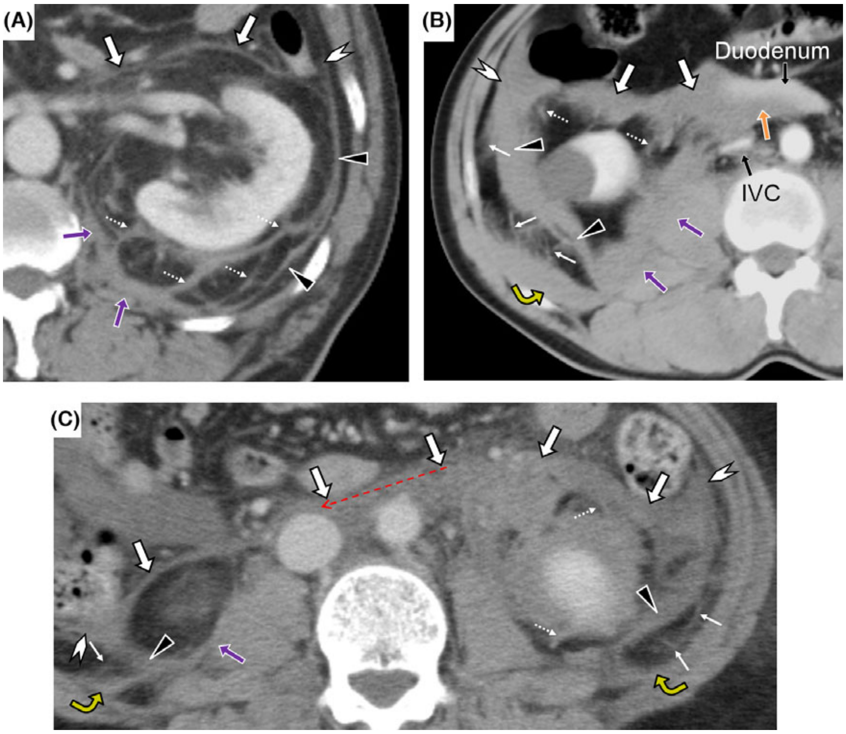

Fig. 2. Traumatic retroperitoneal hematoma. A, A 74-year-old man with left renal injury. Computed tomography (CT) image on admission shows hematoma sequentially spreading from perinephric bridging septa (thin dotted white arrows) in the perirenal space (Type II) to the retromesenteric (white thick arrows), retrorenal (black triangles), and lateroconal (white arrowhead) planes. Note that the psoas muscle and quadratus lumborum muscle are located close to the hematoma within the medial part of the retrorenal plane (purple arrows) as well as in panels B and C. B, A 62-year-old man with lumbar spine injury. CT image on admission shows massive retroperitoneal hematoma spreading from the medial part of retrorenal plane (purple arrows) (Type IV), resulting from lumbar fracture and lumbar arteries, into the retromesenteric (white thick arrows), lateroconal (white arrowhead), and lateral part of the retrorenal (black triangles) planes and into the subfascial plane, showing the checkmark sign (gold curved arrow). He died from uncontrollable hemorrhage. Note that the hematoma in the retromesenteric plane is closely located to and elevates the duodenum (shown with orange arrow), and that many strands are detected within the posterior pararenal space (thin white arrows) as well as thickened perinephric bridging septa (thin dotted white arrows). C, A 44-year-old man with left renal injury. CT image 3 days after injury shows massive retroperitoneal hematoma travelling into the undamaged right retroperitoneum (red dotted arrow) through the retromesenteric plane (white thick arrows) from the perinephric bridging septa (thin dotted white arrows) in the perirenal space (Type II). Hematoma also extends to the retrorenal (black triangles and purple arrow) and lateroconal (white arrowheads) planes. Note bilateral checkmark signs (gold curved arrows) and strands (thin white arrows) in the posterior pararenal space.

As shown in Table 1, we classified TRH into four types by its origin, to which it is traceable (Figs. S3-1, S3-2), according to the principle that TRH extends within the interfascial planes, regardless of the etiology or bleeding source, and presented a therapeutic strategy for each type of TRH.[10] For Type IV TRH (Fig. 2B), with the worst prognosis, interventional radiology is sometimes effective, but offhand surgical treatment with exploration of the retroperitoneum, which is sometimes inevitable, might induce a poor outcome. Treatment for Type IV TRH is still challenging and requires further investigation. Among all four types, the mortality rate was much higher in patients with the checkmark sign[10] (Fig. 2B), representing an extension of hematoma into the subfascial plane, than in others.

Our previous study[10] recognized the subfascial plane as a part of the posterior pararenal space. Therefore, the data must be corrected; that is, TRH was identified in the interfascial and subfascial planes in more cases (91.7%, and not 88.8% as originally reported), and the partial volume of TRH within the interfascial planes accounted for 83.2%, and not 78.1%, of the total volume. Traumatic retroperitoneal hematoma encompassing all potential spaces, including the perinephric bridging septa, would result in larger values than those above. Additionally, we noticed that the checkmark

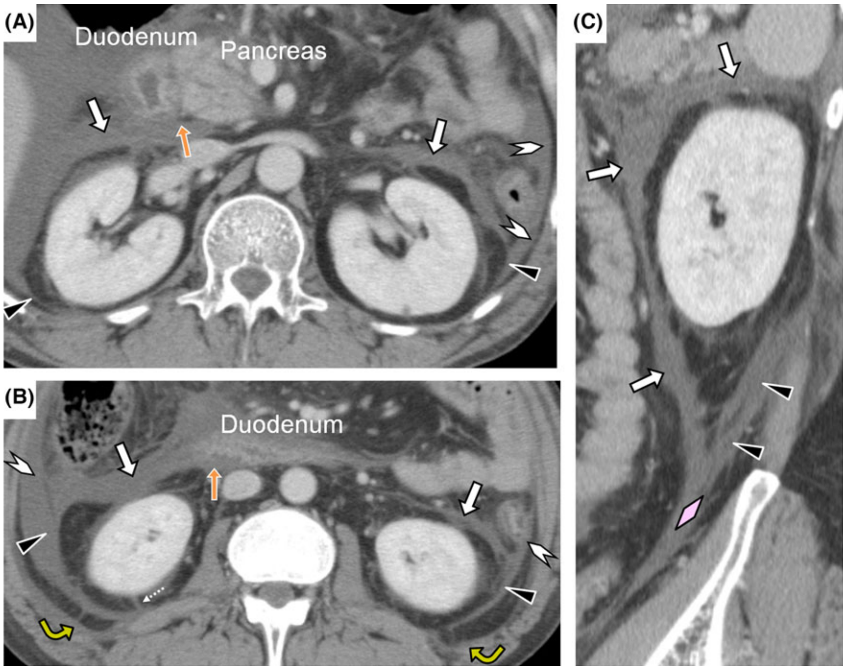

Fig. 3. Acute pancreatitis. A, B, Transverse computed tomography images of a 76-year-old man with severe acute pancreatitis. The pancreas head and the duodenum are swollen and fluid collection spreads within the retromesenteric (white thick arrows), lateroconal (white arrowheads), and retrorenal (black triangles) planes and forms checkmark signs (gold curved arrows) (grade IV). Fluid collection in the retromesenteric plane elevates the duodenum (orange arrows). C, Reconstructed sagittal computed tomography image in the same patient. Note that the retromesenteric (white thick arrows) and retrorenal (black arrows) planes unite to form the combined interfascial plane (pink rhombus). He recovered 15 days after admission with intensive care.

sign is only useful when the sign is depicted on CT within several hours after injury because TRH can spread gradually into the subfascial plane (Fig. 2C). (Presented at the 41st annual meeting of the Japanese Association of Acute Medicine [JAAM] in 2013.)

Acute pancreatitis

Early and accurate prediction of the severity of acute pancreatitis is critical to its treatment but is often difficult. Balthazar *et al.*[31,32] established the CT severity index, which combines assessment of the degree of pancreatic or extrapancreatic inflammation with the degree of pancreatic necrosis. However, the CT severity index is not sufficient to accurately represent the location of retroperitoneal lesions because it is based on the tricompartmental theory.[2,3] Therefore, we clarified the principle of retroperitoneal extension of fluid collection resulting from acute pancreatitis, which had been misunderstood until then,[3,8,9] and provided a system to classify the severity of acute pancreatitis, according to the concept of interfascial and subfascial planes.[8,9,11] The retroperitoneal extension of acute fluid collection was classified into five grades (Table 2, Fig. 3). Our classification system has been cited in many published reports[33] because it is in accord with the natural progression of the disease and both identifies and predicts disease severity without the necessity of contrast medium-enhanced CT. Additionally, we found that fluid collection confined to the interfascial planes, corresponding to Grade I, II, or III pancreatitis, resolved spontaneously in all cases, whereas fluid collection in some patients with Grade IV disease and in all patients with Grade V disease did not resolve spontaneously. We suspect that the persistent fluid collection present in Grade V disease can easily progress to infectious abscess requiring drainage.[11]

Other retroperitoneal diseases

Diseases of the retroperitoneal organs can easily reach the interfascial planes and spread within the planes.[4–9,12] In our critical care center, thickened retroperitoneal fasciae were often observed in septic patients with diseases of the

Table 1. Classification of traumatic retroperitoneal hematoma according to the concept of interfascial planes (partially revised from the classification in our previous paper[10])

Type	Origin of the hematoma	Injured organ or vessel	Therapeutic strategy
I	Anterior pararenal space Retromesenteric plane	Pancreas, duodenum, colon, etc.	Emergent retroperitoneal exploration, surgical hemostasis Subsequent control of contamination
II	Perirenal space Posterior pararenal space Laterоconal plane Lateral part of the retrorenal plane	Kidney, adrenals, etc.	Conservative therapy, IVR Surgical hemostasis if renal pedicle injury is complicated
III	Pelvic retroperitoneum	Pelvic fracture	IVR, C-clamp, or external fixation No laparotomy
IV	Combined interfascial plane Medial part of the retrorenal plane	Great vessels, psoas muscle, lumbar artery, lumbar vertebral fracture, etc.	IVR, emergent exploration of the retroperitoneum (Strategy is not fully established. Offhand laparotomy sometimes induces poor outcome.)

Checkmark sign,[10] representing hematoma intruding into the subfascial plane, predicts a poor outcome in every type. IVR, interventional radiology.

Table 2. Grade of retroperitoneal extension of acute pancreatitis according to the concept of interfascial planes

Grade	Retroperitoneal extension
I	Fluid confined to the anterior pararenal space or the retromesenteric plane
II	Fluid spreading into the lateroconal or retrorenal plane
II	Fluid spreading into the combined interfascial plane
IV	Fluid spreading into the subfascial plane beyond the interfascial planes
V	Fluid clearly intruding into the posterior pararenal space

Please refer to our previous paper[11] for detailed information.

retroperitoneal digestive tract (27%) (Fig. 4A, B) and with urogenital diseases (39%) (Fig. 4C). It is important to notice that thickened retroperitoneal fasciae indicate the presence of disease in the retroperitoneal organs and that the early appearance of the checkmark sign (Fig. 4B) often indicates a serious disease condition. (Presented at the 34th annual meeting of JAAM in 2006.)

Pneumoretroperitoneum spreads within the interfascial planes (Fig. 4D) regardless of the etiology, such as colon perforation or extension of pneumomediastinum.[5–9] Retroperitoneal abscess (Fig. 4E) or non-traumatic retroperitoneal hematoma (Fig. 4F) also spreads in the same manner.[4–9,12]

UNSOLVED PROBLEMS

Embryology

THE CONCEPT OF interfascial planes had a serious defect in that there was no embryological evidence to support their existence. The advocators[4–7] of the concept considered the retromesenteric plane as the potential space within fusion fascia of Toldt and that of Treitz, according to the paper by Dodds *et al.*,[18] but they explained the origin of neither retrorenal nor combined interfascial plane. Their consideration has been accepted and taught worldwide without any verification.[12] If it is valid, however, the interfascial planes must escape from the retroperitoneum into the peritoneal cavity (Fig. S4). Moreover, such consideration is incompatible with the formation process of fusion fascia embryologically explained as follows: after fusion of the opposed peritoneum, mesothelial cells immediately disappear and the two young connective tissues, subserosal layers of the peritoneum, fuse intimately, producing a single inseparable layer.[14,34] According to the theory, a potential space in the fusion fascia is highly improbable, and, at least, an "interfascial" structure never forms because of the bilaterally vanished peritoneum. Therefore, we re-examined the embryological development of the retroperitoneal fasciae in light of the interfascial planes.[1]

In our observations,[1] just as in the classical anatomical researches,[14,22–24] the retroperitoneal organs were embedded in the homogeneous loose mesenchymal tissues in the embryonic stage, and around the 12th week of fetal life,

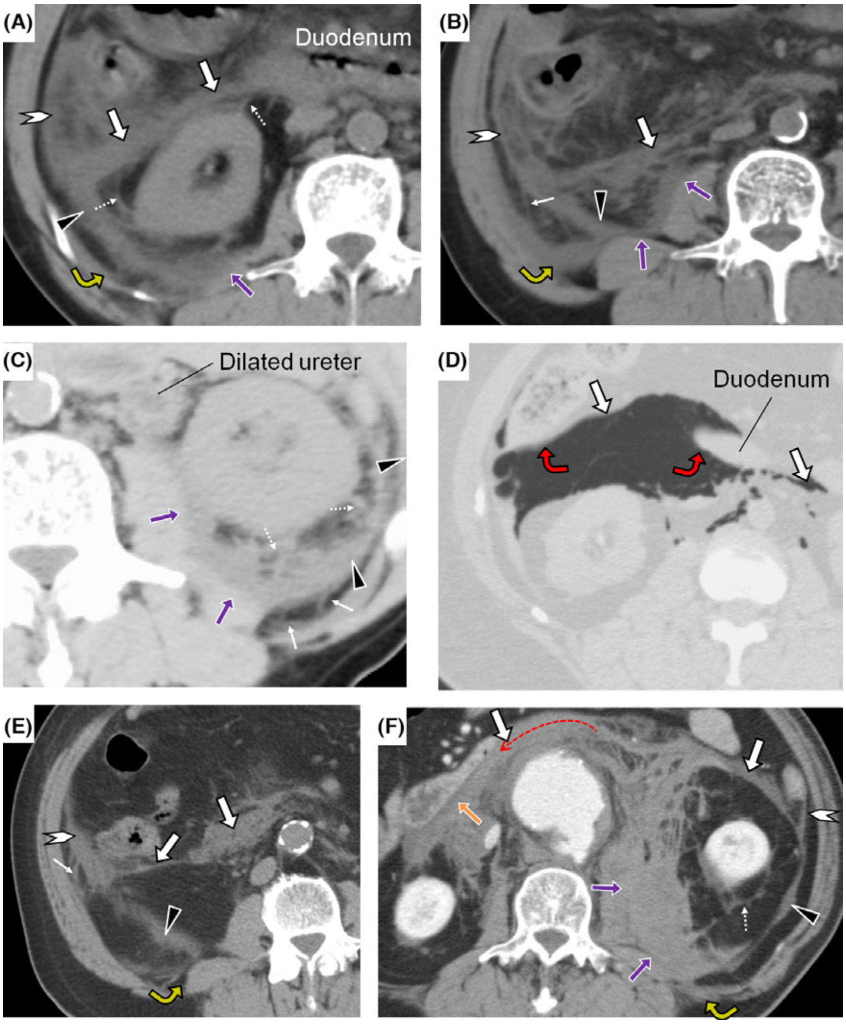

Fig. 4. Other retroperitoneal diseases. A, B, A 54-year-old man with infectious colitis probably from *Aeromonas hydrophila*. Note the marked fluid collection in the retromesenteric (white thick arrows), lateroconal (white arrowheads), and retrorenal (black triangles) planes and clear checkmark signs (gold curved arrows). Additionally, note that fluid collection within the medial part of the retrorenal plane is located close to the psoas muscle and quadratus lumborum muscle as well as in panels C and F (purple arrows). He died 10 h after admission despite emergent right colostomy and intensive care. C, A 75-year-old man with obstructive acute pyelonephritis. Note the fluid collection within the retrorenal plane (black triangles and purple arrows) with the thickened perinephric bridging septa (thin dotted white arrows) and strands (thin white arrows) in the posterior pararenal space. D, A 36-year-old woman with barotraumas due to transtracheal jet ventilation. Massive pneumoretroperitoneum spreads in the retromesenteric plane (white thick arrows) and appears as mobilizing colon and duodenum by Cattell–Braasch maneuver (curved red arrows). E, A 65-year-old man with retroperitoneal abscess accumulated within the retromesenteric (white thick arrows), lateroconal (white arrowhead), retrorenal (black triangle), and subfascial (gold curved arrow) planes, speculated to be a hematogenously disseminated abscess after sepsis. Note the strands (thin white arrow) in the posterior pararenal space. F, A 69-year-old man with ruptured abdominal aortic aneurysm. Retroperitoneal hematoma in the retromesenteric plane (thick white arrows) spreads beyond the midline (red dotted arrow) and elevates the duodenum (orange arrow). Note the retroperitoneal hematoma within the retrorenal (black triangle and purple arrows), lateroconal (white arrowhead), and subfascial (gold curved arrow) planes and the perinephric bridging septa (thin dotted white arrow).

fibrous structures, considered as the primordial renal or transversalis fascia, were identified in the homogeneous connective tissue. Then, around the 25th week, both the renal and transversalis fasciae became clearly identifiable, and primitive adipose tissue developed. Additionally, we noticed that another fascia-like structure, considered as the latero-

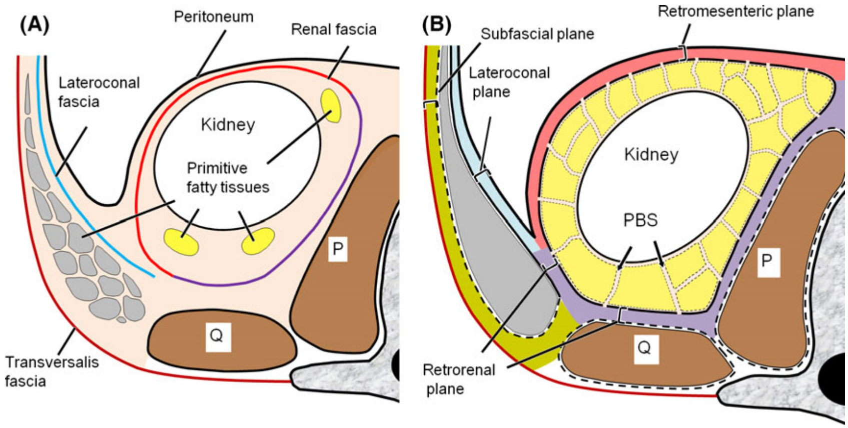

Fig. 5. Our concept for the development of interfascial planes. A, Our findings. The clear renal and transversalis fasciae and the developing lateroconal fascia are located in the loose connective tissues (flesh-colored area). Immature adipose tissues can be detected in the connective tissues between the lateroconal fascia and the transversalis fascia and in those within the perirenal space. B, Our concept. The pre-existing loose connective tissues are narrowed by developing fatty tissue and organs and destined to be the interfascial planes: the retromesenteric (red), retrorenal (purple), and lateroconal (sky-blue) planes. Additionally, the loose connective tissues within the perirenal space are also narrowed by adipose tissues and presumed to be the perinephric bridging septa (flesh-colored area). The loose connective tissue lateral to the flank pad is also destined to be the subfascial plane (gold area). Dotted lines are not confirmable in our study but are presumed to be formed as migration fasciae. P, psoas muscle; PBS, perinephric bridging septa; Q, quadratus lumborum muscle. Figures are reprinted from our previous paper[1] with permission from the copyright owners (Springer Science+Business Media).

conal fascia, appeared between the renal fascia and the primitive adipose tissues of the flank pad (Fig. 5A), and the pre-existing homogeneous loose connective tissue was conversely compressed and narrowed between the opposing fasciae or peritoneum.[1]

We conclude that the interfascial planes are remnants of the primitive loose mesenchymal tissues (Fig. 5B).[1] As paradoxical as it may seem, the true retroperitoneum consists of the interfascial planes, not the adipose tissues, which occupy a great part of the retroperitoneum in the adult but develop later than the primitive fasciae as noted in our predecessors' researches.[23,35,36] Next, it must be noted that the lateroconal fascia is a "migration fascia".[37] Although the term migration fascia is unfamiliar, Hayes[14] stated that it was conceptualized by His in 1874 as follows: The continuous migration and growth of organs gradually brings further pressure on the loose connective tissues to produce a linear orientation of the loose connective tissue fibers that results in fascia. The renal fascia, formed by compression resulting from ascent and growth of the kidney, is considered as the representative migration fascia.[14,23] Matsubara *et al.*[37] concluded that the lateroconal fascia is formed by compression due to growth of the flank pad as shown in Figure 5A. We consider the loose connective tissue between the peritoneum and anterior renal fascia as the retromesenteric plane, that between the peritoneum and lateroconal fascia as the lateroconal plane, and that between the posterior renal fascia and lateroconal fascia or fasciae of the psoas muscle and quadratus lumborum muscle as the retrorenal plane (Fig. 5B). We show a fetal specimen vindicating our hypothesis in Figure S5. Needless to say, our idea is not completely verified, but we believe that this simple idea that potential spaces are the remnant of primitive loose connective tissues should solve the mysteries of retroperitoneal structure and of other potential spaces ubiquitous in the body.

Detailed structure

Despite our study, the structure of the retroperitoneum has not yet been completely clarified. First, another compartment around the aorta and inferior vena cava, the perivascular central space,[25] might exist. From the view of our embryological study, this compartment might develop as adipose tissues around the vessels and the migration fascia, which might resolve the vague structure of the median part (Fig. 1B) in the interfascial planes, around the tissues. Next, the relationship between the interfascial planes and the anterior pararenal space remains unclear. We believe that the lateroconal plane and the subfascial plane communicate with the posterior pararenal space through thin pathways (Figs. 2B, C, 4B, C, E) similar to perinephric bridging septa, as Raptopoulos *et al.*[25] suggested, because the flank pad develops as clusters of adipose tissue (Fig. 5A),[1,23,35-37] We are now examining the communication between the anterior pararenal space and the retromesenteric plane. The problems mentioned above are summarized in Figure S6. Finally, as the biggest unsolved problem, the structure of the interfascial planes in the pelvic retroperitoneum, which is essential to establish scientific principles for the treatment of severe pelvic fracture, remains to be clarified. We created a prototype of the anatomy by analyzing the CT images of patients with pelvic disease and pelvic fracture (data not shown), but it requires verification by microscopic studies of fetal development.

Unconsciously applied surgical techniques

Skilled surgeons experientially know the appropriate surgical planes along which bloodless dissection is possible.[38] These planes are called surgical anatomical planes or surgical planes of dissection. It is speculated that the interfascial planes might correspond to the planes.[13] In damage control surgeries, the Kocher maneuver, Cattell–Braasch maneuver, and Mattox maneuver are frequently used.[39,40] By analysis of CT images, we concluded that the former two correspond to dissection of the retromesenteric plane and the latter is that of the retrorenal plane (presented at the 35th annual meeting of JAAM in 2007) because fluid collection in the retromesenteric plane (Figs. 2B, C, 3A, B, 4A, F) or that in the retrorenal plane (Figs. 2A, B, 4B, C, F) corresponds to the mobilization route,[39,40] and fluid, pneumoretroperitoneum, or hematoma developing in the retromesenteric plane is located closely to the duodenum and pancreas and elevates them (Figs. 2B, 3A, B, 4D, F), which corresponds to the Kocher maneuver. At the least, the Kocher maneuver is never dissection of the fusion fasciae because recent research[41] revealed that the fusion fascia of Treitz spontaneously disappears around the 11th week of fetal life and reappears as a migration fascia after the 20th week. We assume that the migration fascia might be a constitutive part of the retromesenteric plane.[42] Following the application of retroperitoneoscopy to urological surgeries,[43] gasless, single-port urological surgery using an endoscope was recently established by Kihara *et al.*[44,45] They state clearly that dissection was carried out along the surgical anatomical planes. Consequently, complete clarification of the interfascial planes should systematize the surgical maneuvers and contribute to their improvement.

Future treatment for retroperitoneal diseases

We believe that the interfascial planes can also serve as therapeutic routes for drainage or drug administration because retroperitoneal pathologies are communicated by way of these planes.[4–12] In fact, descending necrotizing mediastinitis, which spreads within the cervical fascial planes, can be already treated with percutaneous tube drainage into the planes rather than with radical thoracotomy.[46] Recently, the effectiveness of the i.v. administration of hemostatic nanoparticles was reported in animal models.[47] Retroperitoneal bleeding would be a good indication for such treatment because local hemostasis by the nanoparticles and the tamponade effect caused by the opposed fasciae would act synergistically. Further, we envisage a treatment strategy that contains the retroperitoneal hematoma within the interfascial planes like that for renal injury.[10] We are researching a method to enhance the binding strength of the interfascial planes to realize "containment therapy" for uncontrollable retroperitoneal hemorrhage under the present strategy.[10]

CONCLUSIONS

WE REVIEWED THE radiological concept of the interfascial planes and elevated the concept to a higher level by presenting anatomical and embryological evidence. The concept has the potential to bring unprecedented treatment to retroperitoneal diseases and injuries. We strongly hope that the readers of this review will help to fully clarify the structure of interfascial planes, including other potential spaces outside the retroperitoneum, and develop revolutionary therapeutic methods for retroperitoneal injuries and diseases.

CONFLICT OF INTEREST

NONE.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Fig. S1. "Interfascial spaces" advocated by Sato.

Fig. S2. Our previous interpretation of the interfascial planes based on the "interfascial spaces".

Fig. S3-1. Dynamic spread of a traumatic retroperitoneal hematoma of Type II (Fig. 2A).

Fig. S3-2. Dynamic spread of a traumatic retroperitoneal hematoma of Type IV (Fig. 2B).

Fig. S4. If the interfascial planes were the potential spaces within the fusion fascia.

Fig. S5. Microscopic observation of the retroperitoneal structure in the early-stage fetus.

Fig. S6. Our tentative model of the retroperitoneal anatomy.