

# Anatomical variations of hepatic and pancreatic vascularization: A comprehensive review

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## ABSTRACT

This review analyzes and deepens our understanding of the anatomical variations of the hepatopancreatic region, a crucial area in many medical fields. Precision and surgical efficiency largely rely on a thorough understanding of anatomical nuances and variations. In recent years, significant emphasis has been placed on exploring anatomical variations, particularly in the context of hepatopancreatic surgery. This review collects key information on the types of lesions within the major vessels of the liver and pancreas and presents their incidence. The cited material is based on a review of studies and observations, textbooks, and other review articles. The collected data highlight the importance of hepatic and pancreatic vascular variability, which should be considered an anatomical feature rather than an exception. Further exploration of the occurrence of such features is crucial. This understanding of anatomy is particularly crucial in hepatobiliary and pancreatic surgery, where anatomical complexity directly impacts procedural planning and surgical strategy.

**KEY WORDS:** hepatic vessels, pancreatic vessels, anatomical variation, vascular anatomy

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## INTRODUCTION

The anatomy of the hepatopancreas region is crucial in many medical fields, encompassing not only basic structures but also complex variations that make each patient unique [1]. As emphasized by the principles of safe surgery, a surgeon's proficiency in hepatopancreatic procedures relies largely on a comprehensive understanding of anatomical nuances and their variations [2]. Navigating the delicate areas of the liver and pancreas requires not only theoretical knowledge but, equally importantly, practical knowledge of the relevant surgical anatomy [3]. In recent years, considerable emphasis has been placed on understanding and appreciating anatomical variations in the context of hepatopancreatic surgery.

## AIM

In this publication, we aim to discuss and deepen our understanding of the anatomical variations of the hepatopancreas region, maintaining their importance in the discussion of normal anatomy.

## MATERIALS AND METHODS

PubMed and Google Scholar databases were searched in English and Polish. Search keywords: hepatic vascular anatomy variations, pancreatic vascular anatomy variations, hepatic and pancreatic vascularization, anatomical variations of hepatic and pancreatic vessels. Over 40 sources were analyzed.

## REVIEW

### LIVER

The liver, stituting approximately 2% to 3% of the average body weight, stands as the largest organ. Situated beneath the right hemidiaphragm in the right upper quadrant of the abdominal cavity [4, 5]. The most used anatomical division in surgery and radiology is the one proposed in 1957 by Couinaud, distinguishing eight segments within its parenchyma [6]. These segments are independent in terms of blood supply and biliary drainage, formed by branches of the portal vein and the right, middle, and left hepatic veins. The hepatic veins divide the liver parenchyma into 4 sectors, each receiving its own portal branch. These sectors are the right posterior (postero-lateral), including segments 6 and 7, the right anterior (antero-lateral) including segments 5 and 8, the left medial (anterior), which constitutes segment 4 (a - upper and b - lower according to Bismuth's classification), and the left lateral (posterior), composed of segments 2 and 3. Segments 5, 6, 7, and 8 constitute the right lobe, and 2, 3, and 4 constitute the left lobe. Segment 1, anatomically corresponding to the caudate lobe, has a direct venous outflow to the inferior vena cava, receiving blood supply from the right and left branches of the hepatic artery and the portal vein [7].

### VASCULAR LANDSCAPE OF THE LIVER

The liver, a vital organ for sustaining life, boasts a robust circulatory system. Approximately 20%–25% of the cardiac output, equivalent to 1–2 liters per minute, traverses through the liver. Notably, the liver receives a distinctive dual blood supply, comprising oxygen-rich arterial blood from the hepatic artery (HA) and nutrient-laden blood from the portal vein (PV). Within the sinusoids enveloping hepatocytes organized in cord-like structures, arterial and portal venous blood blends seamlessly. Subsequently, this mixed blood flows into the central veins, ultimately draining through the hepatic veins (HV) into the inferior vena cava (IVC). At any given moment, approximately 40% of the liver's blood volume resides in the substantial vessels, while the remaining 60% occupies the sinusoids [8, 9]. Understanding the vascular anatomy of the liver is crucial, as variations in hepatic vascular structure may necessitate adjustments or alternative strategies during medical procedures and surgeries. Proficiency in this knowledge is imperative to navigate potential complexities arising from anatomical differences [8, 10].

### PROPER PORTAL VEIN AND ITS ANATOMICAL DIFFERENCES

The portal vein, supplying the liver with about 3/4 of its blood volume, has tributaries in the form of the splenic

and superior mesenteric veins. The division into right and left branches occurs in the liver hilum. Branches also arise for segment 1, usually three, but their number can vary from 1 to 6. The right portal branch supplies segments 5 and 8 (anterior branch) and segments 6 and 7 (posterior branch) after division. Both branches supply blood to segment 1. The left portal branch supplies segment 2 with upper posterior branches, segment 3 with left branches, and segment 4 with right branches (ascending 4a and descending 4b) [11].

Anomalies in the anatomy of the portal vein (PV) are infrequent, and among these, the prepancreatic postduodenal portal vein (PPPV) is exceptionally rare. In this anomaly, the portal vein is positioned in front of the pancreas and behind the duodenum, contrary to its typical placement behind both the pancreas and duodenum. While the PPPV is uncommon, the knowledge of this condition plays a pivotal role in preventing catastrophic complications that may arise from unintended PV injury, leading to severe consequences such as massive hemorrhage or ischemic complications affecting the liver or bowel [12].

In the realm of laparoscopic cholecystectomy, surgeons must have a thorough understanding to ensure the safe execution of laparoscopic cholecystectomy. One of the rare but very important anatomical variations of the portal vein is Preduodenal portal vein. PDPV usually presents in the pediatric population as it is the associated congenital anomalies that draw attention to its presence. Out of the identified cases, thirty-four instances (83%) were linked with additional multiple congenital malformations. Among these cases, intestinal malrotation was connected to 80%, situs inversus to 40%, pancreatic malformations to 33%, and biliary atresia, duodenal stenosis, or atresia to 13%. In most of these cases, the primary rationale for operative intervention was the presence of associated malformations rather than the prepancreatic postduodenal portal vein (PDPV) itself [13].

### PROPER HEPATIC VEINS AND THEIR ANATOMICAL DIFFERENCES

Unlike portal vessels, hepatic veins do not have a visible wall in imaging studies. The hepatic veins originate in liver lobules, which, by connecting, form increasingly larger trunks, eventually creating the right, middle, and left hepatic veins, emptying into the inferior vena cava. The right hepatic vein receives blood from segments 6, 7, and 8, and partially from segment 5; the middle hepatic vein receives blood from segments 4, 5, and 8, and the left hepatic vein from segments 2, 3, and partially 4 [11].

Traditional anatomical descriptions outline a single superior right hepatic vein (SRHV) that discharges into the inferior vena cava (IVC). Any supplementary vessels originating from the right liver and draining into the IVC are categorized as accessory RHVs. Three recognized variants include an inferior RHV draining segment VI, which directly empties into the IVC just above the liver's inferior border, positioned more than 2 cm away from the hepatocaval junction (HCJ). Additionally, the middle RHV drains segment VII and directly flows into the IVC within a proximity of 1-2 cm from the HCJ. In the population from the eastern Caribbean, only 39% exhibited the typical venous drainage patterns from the right hemi-liver. Various RHV variants were prevalent, including proximal venous confluence (61%), accessory RHVs (49.2%) and inferior RHVs (45%). Interventional radiologists and hepatobiliary surgeons catering to patients from the Caribbean diaspora need to be aware of these distinctions to reduce the risk of complications during invasive procedures and minimize morbidity [14].

## PROPER HEPATIC ARTERY AND ITS ANATOMICAL DIFFERENCES

The proper hepatic artery is a branch of the common hepatic artery. Its division usually occurs in the liver hilum or the hepatoduodenal ligament. The right hepatic artery supplies the right liver segments (5, 6, 7, and 8), and the left artery supplies the left segments: 4, 2, and 3. Segment 1 receives arterial blood from both the right and left branches.

The most encountered type of blood supply is the common hepatic artery branching off from the celiac trunk and then, after giving off the gastroduodenal artery, running as the proper hepatic artery towards the liver hilum, where it divides into the right and left hepatic arteries. Based on available data, the percentage of patients with vascular variations can range from about 13% [11] to 22.8% [15], and according to some authors, even up to 50% of patients [16]. According to these publications, the most common variations are the right hepatic artery originating from the upper mesenteric artery and the left hepatic artery originating from the left gastric artery, as well as additional hepatic arteries. Preoperative assessment of liver blood supply should be carried out with particular care. It is of great importance, especially for a surgeon planning surgical treatment, as it allows for proper procedure planning and avoids intraoperative complications [10, 11].

## PANCREAS

The pancreas constitutes a crucial role in the human body. It is located transversely in the retroperitoneal

space, in the upper abdominal cavity in front of the spine at the level of the 1st and 2nd lumbar vertebrae. It produces digestive enzymes and hormones which regulate the blood sugar level. The pancreas is situated near various anatomical structures in the human body. This proximity increases the likelihood of pancreatic cancer spreading to adjacent organs [17]. The pancreas (70-100g, 12-20cm) consists of four parts: the head, neck, body and tail. The pancreas is closely associated with several structures in its upper region. It shares proximity with the starting point of the coeliac trunk, the common hepatic artery and the splenic artery [18].

Anteriorly, you'll find the stomach, lesser sac (omental bursa), and transverse mesocolon. Positioned at the rear are the aorta, inferior vena cava, and portal vein. The head of the pancreas is disc-shaped and is enveloped by the inner curve formed by the initial three segments of the duodenum. It is connected to the duodenum through connective tissue. Positioned to the right of the superior mesenteric artery (SMA) and the superior mesenteric vein (SMV), the head's lower part extends as the uncinate process, resembling a hooked continuation of the inferomedial part of the head. This part is situated within the bend of the fourth part of the duodenum, and the SMV, and occasionally the SMA, run down on its front surface. The common bile duct is situated on the right side of the gastroduodenal artery, along the posterior wall of the initial segment of the duodenum. Often, the gastroduodenal artery passes either in front of or behind the upper part of the common bile duct [17]. The pancreas neck measures 1.5 to 2.0 cm in length. It is partially covered at the front by the pylorus and extends to the right until it reaches the point where the anterosuperior pancreaticoduodenal artery branches off from the gastroduodenal artery.

Behind the neck, the portal vein is formed by the merging of the superior mesenteric and splenic veins. Typically, there are no veins from the pancreas crossing in front of these vessels, but occasionally a few short veins may be present. It might be necessary to carefully lift the neck and tie off such veins if they exist to prevent bleeding, which could complicate the assessment of structures beneath the neck. The pancreatic body is situated on the left side of the superior mesenteric vessels. The front surface of the body is covered by peritoneum, contributing to the formation of the back portion of the lesser sac.

Positioned in front of the aorta, the body extends upwards towards the spleen. The splenic artery traces along the path of the body, forming a groove on its posterior and upper surface. As for the tail, it is closely located near the splenic hilum and is enclosed within the splenorenal ligament [18].

## PROPER VASCULARIZATION OF THE PANCREAS

The blood supply to the pancreatic head and uncinate process comes from two sources: the superior pancreaticoduodenal artery (SPDA) and the inferior pancreaticoduodenal artery (IPDA). These arteries contribute to the formation of the anterior and posterior pancreaticoduodenal arcades [18]. The SPDA branches off from the gastroduodenal artery, which originates from the common hepatic artery (CHA), a branch of the coeliac trunk. On the other hand, the IPDA arises from the superior mesenteric artery (SMA). The body and tail of the pancreas are supplied by various branches of the splenic artery [19]. The neck acts as a transitional area between these two vascular systems, and venous drainage occurs through the portal system. The head and neck are predominantly drained by branches of the superior mesenteric vein (SMV) into the portal vein (PV). The rest of the pancreas is drained by delicate branches of the splenic vein. The splenic vein courses behind the body, eventually joining the SMV to form the PV behind the neck [18].

## ANATOMICAL VARIANTS

Circumportal pancreas refers to a condition where pancreatic tissue surrounds the portal vein (PV) or superior mesenteric vein (SMV). This occurrence is observed in approximately

1.1–2.5% of individuals and is believed to stem from the abnormal merging of the dorsal and ventral pancreatic buds during development. While patients with this condition typically do not experience noticeable symptoms when planning surgical procedures, as it may elevate the likelihood of specific complications such as postoperative pancreatic fistula [18].

## VARIATIONS OF PANCREATIC ARTERIAL VASCULARIZATION

The pancreas has a complex arterial supply, making it essential to pay special attention during arterial interventions for patients with conditions like acute pancreatitis and pancreatic carcinomas. Understanding the anatomy of pancreatic arteries and their territories is crucial for both surgical procedures and interpreting pancreatic angiography and cross-sectional imaging [20].

## VARIATION OF THE MAJOR ARTERIES

Out of 162 celiac arteriograms, there were 15 cases where the right hepatic artery was replaced, 3 cases

with a replaced common hepatic artery (CHA), and one case with a shared trunk of the celiac artery and superior mesenteric artery (SMA). In one instance, the gastroduodenal artery (GDA) originated from the left hepatic artery, while in another case, the gastroepiploic artery originated from the superior mesenteric artery [20].

## VARIATION OF THE SUPERIOR PANCREATICODUODENAL ARTERIES

In all cases examined, the anterior superior pancreaticoduodenal artery (ASPD) consistently arose from the gastroduodenal artery (GDA). Additionally, in 14.2% of cases, a connecting branch was identified, forming an anastomosis between the ASPD and the dorsal pancreatic artery (DPA). Regarding the posterior superior pancreaticoduodenal artery (PSPD), in 96.1% of cases, it originated from the GDA, with some cases showing the presence of two PSPDA branches emerging from the GDA. However, alternative origins of PSPDA were observed, including cases where it arose from the common hepatic artery (CHA), both the GDA and CHA, or the proper hepatic artery. In rare instances, when the PSPDA was not visible in the celiac arteriogram, it was found to arise from the replaced right hepatic artery. An anastomotic branch connecting the PSPDA to the DPA was observed in 11.7% of cases. This study also found that the gastroduodenal artery (GDA), anterior superior pancreaticoduodenal (ASPD), and anterior inferior pancreaticoduodenal (AIPD) artery were present in all cases, while the posterior superior pancreaticoduodenal (PSPD) and posterior inferior pancreaticoduodenal (PIPD) artery were present in 93.34% of cases. Variations in the origin of PSPD, AIPD, and PIPD artery were observed, with anatomical and numerical variations noted in both anterior and posterior arches, with the posterior arch being absent in 20% of cases [20, 21]

## VARIATION OF THE INFERIOR PANCREATICODUODENAL ARTERIES

The study of the inferior pancreaticoduodenal artery (IPDA) revealed its presence in 77.5% of cases, with various origins observed. Predominantly, the IPDA originated from the SMA, either independently or in conjunction with the 1st jejunal artery. Alternative sources included a shared trunk with the 1st jejunal artery, a replaced right hepatic artery, or a common trunk with the dorsal pancreatic artery (DP) from the SMA. In IPDA-absent cases, the anterior inferior pancreaticoduodenal artery (AIPDA) typically arose from the SMA or the 1st jejunal artery. Conversely, the posterior inferior pancreaticoduodenal artery (PIPDA) had diverse origins,

including the SMA, 1st jejunal artery, dorsal pancreatic artery, or replaced right hepatic artery. Understanding these variations is crucial for accurate preoperative planning and surgical management [20, 22].

### SMALL PANCREATIC BRANCHES SUPPLYING PANCREATIC HEAD

The small branches that provide blood to the pancreatic head were observed in 19.8% of 226 cases. These branches originated from different arteries, including 19 cases from the gastroduodenal artery (GDA), 5 cases from the common hepatic artery (CHA), 2 cases from the right hepatic artery, 2 cases from the splenic artery (SPA), 1 case from both GDA and CHA, 1 case from a replaced right hepatic artery, 1 case from the superior mesenteric artery (SMA), and 1 case from both GDA and a replaced right hepatic artery [20].

### VARIATION OF THE DORSAL PANCREATIC ARTERIES

The dorsal pancreatic artery is regarded as the largest vessel branching off from the splenic artery, occasionally reaching a size equivalent to one-third of the splenic artery. Its diameter varies significantly, spanning from 1 millimeter to almost 1 centimeter, with an average measurement typically falling between 1 and 3 millimeters [20, 23]. In set of angiograms, Bertelli E. observed the dorsal pancreatic artery as a relatively sizable vessel in numerous instances, irrespective of its source, occasionally reaching dimensions of up to 1 centimeter [23]. Other research show, that the dorsal pancreatic artery (DPA) was present in 79.6% of cases. Among these cases, 51.2% showed the DPA originating from the splenic artery (SPA). Other sources of the DPA included the common hepatic artery (CHA) in 22.2% of cases, the celiac artery in 5 cases, the gastroduodenal artery (GDA) in 2 cases, and the right inferior phrenic artery in 1 case. There was a unique case where two DPAs were identified, one arising from the SPA and another from the CHA [20]. Regarding numerical variations, identifying double dorsal pancreatic arteries with certainty proved challenging; we encountered this occurrence only once and never observed instances of triple or quadruple dorsal pancreatic arteries [23].

### TRANSVERSE PANCREATIC ARTERIES

The transverse pancreatic artery (TPA), also referred to as the horizontal pancreatic artery, described by Popova, could be identified in angiographic studies of the celiac artery, particularly when combined with those of the superior mesenteric artery. However, due to the overlapping of

vessels in the gastric and colic areas, the identification of this artery was often uncertain. To estimate its incidence, selective angiographies of the splenic artery, which were less numerous, were relied upon [24]. Under these conditions, the horizontal pancreatic artery could be identified in 25.93% of cases. This artery displayed variability in development and importance, with its diameter ranging from that of a very thin vessel to about one-third the caliber of the splenic artery. While it consistently originated directly from the splenic artery, in rare instances (3% of cases), a vessel resembling the horizontal pancreatic artery appeared as an early branch of the dorsal pancreatic artery [20,24]. This vessel seemed to function more as an anastomotic channel between pancreatic branches descending from the splenic artery than as an independent artery. It shared a longitudinal course close to the superior border of the pancreas with the horizontal pancreatic artery. However, when a regular pancreatica magna artery was identified in these cases, it was considered a second transverse pancreatic artery [24]. The horizontal pancreatic artery supplied variable portions of the distal pancreas, sometimes restricted to the tail of the pancreas or extending to part of the body. In most cases (70.6%), it coexisted with the inferior pancreatic artery and often joined it through several fine descending branches. Occasionally (17.6% of cases), it ended by anastomosing with the caudal pancreatic artery. In rare instances (11.7% of cases), it was the sole artery supplying the distal pancreas with descending branches that did not connect with visible inferior pancreatic arteries. In nearly all cases (88.23%), the horizontal pancreatic artery divided in a comb-like fashion, giving off several descending branches that distributed to the pancreas and/or ended by anastomosing with the inferior pancreatic artery [20, 24].

Anatomy and variations of pancreatic venous vascularization

### PANCREATICODUODENAL VEINS

The blood outflow from the duodenum and pancreas can be conceptually split into two regions, ventral and dorsal. Each of these regions has two primary veins responsible for this drainage. For the ventral aspect: the anterior superior pancreaticoduodenal vein (ASPD) and the anterior inferior pancreaticoduodenal vein (AIPD), while the dorsal: posterior superior pancreaticoduodenal vein (PSPD) and the posterior inferior pancreaticoduodenal vein (PIPD) handle the back region [25].

### ANTERIOR SUPERIOR PANCREATICODUODENAL VEIN

Was observed in all of the studied cases. It was single in 51% of cases, represented by two branches in 18%

of cases, and by multiple branches in 31% of cases. In most samples, it drained into the gastro-colic venous trunk (82%) and less frequently into the right gastro-epiploic vein (11%), the superior mesenteric vein (4%), or the portal-mesenteric junction (2%). We can distinguish two types: Type I veins (44%), are responsible for the venous drainage of the upper part of the duodenum, the superior duodenal angle, the proximal two-thirds of the descending part of the duodenum, and the adjacent pancreas. They connect at the middle of an arcade with the AIPD and primarily drain into the gastro-colic venous trunk (70%), but also into the right gastro-epiploic vein (20%), the superior mesenteric vein (5%), or the portal-mesenteric confluence (5%). Type II veins (56%), drain the same area as the Type I veins, but they also cover the entire descending duodenum, the inferior duodenal angle, and the proximal third of the horizontal part of the duodenum [25, 26].

#### ANTERIOR INFERIOR PANCREATICODUODENAL VEIN

This vein is responsible for the venous drainage of inferior ventral part of the right pancreas. Its unique characteristic is its bipolar ending, meaning it connects to the superior mesenteric vein either directly or through one of the jejunal veins. It was found in only 62% of cases. It anastomoses in some cases with the ASPD vein to form a ventral arch. It terminated in the superior mesenteric vein (35.7%), the gastro-colic venous trunk (35.7%), the first jejunal vein (17.9%), the second jejunal v. (3.6%), the right gastro-epiploic vein (3.6%) or the superior right colic vein (3.6%) [25,27].

#### POSTERIOR SUPERIOR PANCREATICDUODENAL VEIN

In almost all the cases studied (98%), the PSPD was present. The most consistent observations were related to the posterior superior pancreaticoduodenal vein, which was seen to drain into the portal vein. It is typically formed by the merging of three main tributaries. The anterosuperior tributary is responsible for draining the upper portion of the right pancreas's dorsal surface. In 80% of cases, this tributary was found to receive a vein that originated from the prepancreas and wrapped around the right anterior edge of the portal vein. The posterolateral tributary follows the pars descendens of the duodenum to create the superior crus of the dorsal venous arcade (when present). The posteromedial tributary traverses diagonally across the dorsal surface of the right pancreas. In certain instances, it participated in the drainage of the retrovenous pancreas (draining the uncinate process

in 14% of cases, the retromesenteric pancreas in 34% of cases, and the retroportal pancreas in 24% of cases). In some specimens (18% of cases), the PSPD consisted of two distinct veins with different termination points. In these instances, the vein that ended higher on the portal trunk was responsible for draining the prepancreas [27,28].

#### POSTERIOR INFERIOR PANCREATICDUODENAL VEIN

It was identified in 60% of cases. It originated in the duodenopancreatic sulcus beneath the common bile duct and was responsible for draining blood from the lower portion of the gland's head and the adjacent part of the duodenum. Its path was either within the sulcus or over the surface of the gland. It moved towards the medial edge of the uncinate process, around which it coiled to reach its endpoint. It terminated in the first jejunal tributary, occasionally in conjunction with the anterior inferior pancreaticoduodenal vein. In one instance, the vein terminated in the right limb and connected with a colic vein as it emerged from the mesocolon [29].

### DISCUSSION

The vascular anatomy of the liver and pancreas is characterized by considerable variability. This reflects their complex embryological development and topography within the upper abdominal cavity. This review discusses the diversity of the arterial and venous systems supplying these organs.

In the liver, alterations in the portal vein, hepatic veins, and hepatic arteries are common. The branching morphology of the portal vein, such as early segmental division and the presence of additional or replaced hepatic arteries, is associated with the dynamic remodeling of the vitelloabdominal venous network during embryogenesis. Similarly, the hepatic venous system is characterized by a wide spectrum of configurations, ranging from additional inferior hepatic veins to variable vascularization patterns in the posterior segments of the right liver [30, 31].

The pancreas has a more complex vascular architecture, characterized by dense arterial arcades and highly variable venous outflow. The arterial vascularization is dominated by numerous anastomoses connecting the celiac trunk to the superior mesenteric artery, resulting in a greater diversity of pancreaticoduodenal and dorsal pancreatic artery arcades [32]. The venous system reflects this complexity, with numerous drainage patterns to the portal and superior mesenteric veins and frequent connections between the anterior and posterior pancreaticoduodenal veins [33, 34].

The literature reviews analyzed revealed a lack of a universal classification system for variants of pancreatic vascularization, in contrast to well-described patterns of hepatic arterial anatomy. Although the reported prevalence rates vary significantly among available studies, the review considered the most frequently recurring findings. However, this reflects differences in methodology, imaging techniques, population characteristics, and sample size. While cadaveric studies, angiographic series, and modern cross-sectional imaging provide complementary perspectives, each approach carries its own limitations.

## CONCLUSIONS

The collected data emphasize that the variability of hepatic and pancreatic vessels should be considered an anatomical feature, not an exception. Further work on standardized nomenclature, large-scale imaging studies, and comprehensive anatomical atlases are essential to deepen our understanding of hepatopancreatic vascular anatomy. A thorough understanding of these vascular anatomy is fundamental in many medical disciplines, particularly in hepatobiliary and pancreatic surgery, where anatomical complexity directly impacts procedural planning and surgical strategy.

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## CONFLICT OF INTEREST

The Authors declare no conflict of interest

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