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VARIATIONS IN PORTAL VEIN BRANCHING: A CT-BASED EVALUATION AND ITS CLINICAL SIGNIFICANCE

Dr. G. Manikanta Sahish*	Junior Resident, Department of Radio-diagnosis, Rajarajeswari Medical College and Hospital, Bengaluru. *Corresponding Author
Dr. Gautam M	Professor and HOD, Department of Radio-diagnosis, Rajarajeswari Medical College and Hospital, Bengaluru.

ABSTRACT The portal vein (PV) system exhibits frequent anatomical variations that hold substantial clinical implications for hepatobiliary surgery, liver transplantation, and interventional radiology procedures. Precise preoperative identification of these variations is crucial for minimizing intraoperative complications and optimizing patient outcomes. This study aimed to comprehensively evaluate the spectrum and prevalence of portal vein branching variations using multidetector computed tomography (MDCT) and to assess their clinical significance in surgical and interventional planning. A retrospective observational study was conducted involving 210 patients who underwent contrast-enhanced abdominal CT with portal venous phase imaging over a 24-month period. Portal vein branching patterns were meticulously analyzed using axial, multiplanar reconstruction (MPR), and three-dimensional (3D) volume-rendered images. Variations were systematically classified based on established anatomical patterns. Statistical analysis was performed to determine the prevalence of each variant and to explore their clinical associations. The classical bifurcation pattern (Type I) was identified in 78% of the cases. Trifurcation (Type II) was observed in 12%, while early right posterior branching (Type III) accounted for 6.2%. Other accessory or rare variants constituted 3.8% of the cohort. The presence of variant anatomy was found to significantly influence surgical planning, particularly in patients undergoing hepatic resection and liver transplantation evaluations. Portal vein branching variations are commonly encountered during routine CT imaging. Implementing routine preoperative vascular mapping using MDCT is indispensable for preventing surgical complications, guiding interventional procedures, and ultimately enhancing patient safety and therapeutic efficacy.

KEYWORDS : Portal Vein, CT Angiography, Anatomical Variation, Liver Transplantation, Hepatic Surgery

INTRODUCTION

Multidetector computed tomography (MDCT) with advanced angiographic reconstruction techniques has emerged as the gold standard for detailed preoperative vascular mapping of the portal system (Koç et al., 2007). The portal vein (PV), formed by the confluence of the superior mesenteric vein and splenic vein, is a critical component of the hepatic circulatory system, supplying approximately 75% of the liver's blood flow (Lee et al., 2011). Traditionally, the main portal vein bifurcates into right and left portal veins at the hepatic hilum. However, a wide array of anatomical variations in its branching patterns has been extensively documented in medical literature (Covey et al., 2004; Hiatt et al., 1994).

Accurate knowledge of these variations is paramount for various clinical disciplines, including liver transplantation, hepatic resections, portal vein embolization, transjugular intrahepatic portosystemic shunt (TIPS) procedures, and oncologic surgery (Schmidt et al., 2008). Unrecognized variations can lead to significant intraoperative complications, such as vascular injury, segmental ischemia, or inadequate surgical margins, thereby compromising patient safety and treatment efficacy (Iqbal & Khan, 2017). This study aims to characterize the prevalence and types of portal vein branching variations observed on MDCT scans and to elucidate their clinical implications in the context of modern hepatobiliary and interventional procedures.

MATERIALS AND METHODS

Study Design and Population: This retrospective cross-sectional observational study was conducted at a tertiary care center over a 24-month period. The study population comprised 210 patients who underwent contrast-enhanced abdominal computed tomography (CT) with adequate portal venous phase imaging. Patients with portal vein thrombosis, a history of prior hepatic surgery, or distorted vascular anatomy were excluded from the study to ensure accurate assessment of native portal vein branching patterns.

CT Protocol: All CT examinations were performed using a 128-slice multidetector CT scanner. Intravenous contrast material was administered at a dose of 1.5 mL/kg. Portal venous phase imaging was acquired approximately 60–70 seconds after contrast injection. Thin-slice acquisition (0.6–1 mm) was utilized, and images were subsequently processed using multiplanar reconstruction (MPR) and three-dimensional (3D) volume-rendered techniques for comprehensive anatomical evaluation.

Image Analysis: Radiological evaluation focused on several key aspects: the level of portal vein bifurcation, the presence of trifurcation, early branching patterns, and the identification of accessory segmental branches. Portal vein variations were systematically classified into four main types based on established anatomical descriptions (Covey et al., 2004; Lee et al., 2011):

Type I (Classical Bifurcation): The main portal vein divides into distinct right and left portal veins at the hepatic hilum. The right portal vein subsequently divides into anterior and posterior branches. This is considered the standard anatomical configuration.

Type II (Trifurcation): The main portal vein simultaneously gives rise to the right anterior, right posterior, and left portal branches.

Type III (Early Right Posterior Branching): The right posterior branch originates directly from the main portal vein before its conventional bifurcation.

Type IV (Other Rare/Accessory Patterns): This category encompasses less common variations, including accessory branches supplying specific segments (e.g., segment IV) or other atypical branching configurations.

Statistical Analysis: Descriptive statistics were employed to summarize demographic data and the prevalence of different portal vein branching patterns. Prevalence percentages were reported for each identified type of variation.

RESULTS

Demographic Data: The study cohort consisted of 210 patients with a mean age of 49 ± 13 years. The gender distribution showed 134 males (64%) and 76 females (36%).

Portal Vein Branching Patterns: The analysis of MDCT images revealed a diverse spectrum of portal vein branching patterns within the study population. The classical bifurcation (Type I) was the most frequently observed pattern, accounting for 78% (n = 164) of cases. Variant anatomy was identified in approximately 22% of the individuals. The distribution of variant types is summarized in Table 1.

Table 1: Prevalence of Portal Vein Branching Patterns

Type	Pattern	Number (n=210)	Percentage
I	Classical bifurcation	164	78%
II	Trifurcation	25	12%
III	Early right posterior branch	13	6.2%
IV	Accessory/rare variants	8	3.8%

DISCUSSION

Our findings indicate that portal vein variations are present in approximately 22% of individuals, a prevalence consistent with previous anatomical and imaging studies (Atasoy & Akyildiz, 2006;

Covey et al., 2004; Sharma et al., 2017). This highlights the importance of routine preoperative assessment for these variations. The observed prevalence of classical anatomy (78%) aligns closely with reported ranges in the literature, typically between 65% and 80% (Covey et al., 2004; Liu et al., 2024). Trifurcation (Type II) and early right posterior branching (Type III) were identified as the most common variant patterns, echoing findings from other studies (Rajapriyan et al., 2022; Ullah et al., 2020).

Clinical Implications: The accurate identification of portal vein branching variations carries significant clinical implications across several surgical and interventional specialties:

Liver Transplantation: In living donor liver transplantation, variant portal vein anatomy can substantially increase technical complexity during vascular reconstruction. Unrecognized variations may lead to anastomotic complications, graft dysfunction, or even graft loss (Cheng et al., 2006).

Hepatic Resections: For oncological resections, particularly extended hepatectomies, precise knowledge of portal vein anatomy is crucial to avoid inadvertent injury to segmental branches, which could result in postoperative segmental ischemia, liver failure, or biliary complications (Gunasekaran et al., 2017; Schmidt et al., 2008). For instance, an accessory segment IV branch (a Type IV variant) is critical to recognize in extended right hepatectomy to prevent ischemia of the remaining liver segments (Lee et al., 2011).

Portal Vein Embolization (PVE): PVE is a common procedure performed prior to major hepatectomy to induce hypertrophy of the future remnant liver. Variant branching patterns can affect the approach and success of embolization, necessitating careful planning to ensure complete embolization of the target segments while preserving flow to the future remnant (Neumann et al., 2006).

Radiological Implications: The widespread use of MDCT with 3D reconstruction capabilities has revolutionized the preoperative assessment of portal vein anatomy. Radiologists play a pivotal role in the systematic evaluation and detailed description of portal vein branching patterns in imaging reports. Providing comprehensive structured reports that highlight any identified variations and generating 3D reconstructions offer surgeons and interventionalists a clear, intuitive understanding of complex vascular anatomy, thereby facilitating surgical planning and reducing intraoperative risks.

CONCLUSION

Portal vein branching variations are frequently encountered and possess considerable clinical significance in the context of hepatobiliary surgery, liver transplantation, and interventional radiology. Multidetector CT with advanced 3D reconstruction techniques is an indispensable tool for accurate preoperative vascular mapping. Routine and systematic reporting of portal vein anatomy should be an integral part of preoperative assessment to mitigate surgical morbidity, optimize procedural outcomes, and enhance patient safety.

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