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MORPHOLOGICAL VARIATIONS OF THE CAUDATE LOBE OF THE LIVER: A CADAVERIC STUDY WITH SPECIAL REFERENCE TO DUPLICATION AND AN INDEPENDENT VASCULAR PEDICLE

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ABSTRACT

Background: The caudate lobe of the liver has distinctive portal venous, arterial, biliary, and venous anatomy and occupies a surgically complex location adjacent to the porta hepatis and inferior vena cava. Morphological variations of the caudate lobe may complicate radiologic interpretation and hepatobiliary procedures. Duplication of the caudate lobe associated with a separate vascular pedicle is particularly uncommon. This study evaluated morphological variations of the caudate lobe in adult human cadaveric livers, with emphasis on duplication and its potential clinical relevance.

Materials and Methods: This descriptive cross-sectional cadaveric study included 68 adult human liver specimens obtained during routine anatomical dissections. Specimens with gross pathological alteration, traumatic disruption, or deformity involving the caudate region were excluded. Each liver was systematically examined for variations in the caudate process, papillary process, fissural configuration, duplication, and the presence of a distinct vascular pedicle. Relevant findings were documented photographically. Data were summarized using frequencies and percentages. Age and biological sex of the cadavers were not available from institutional records and were therefore not included in the analysis.

Results: Conventional caudate lobe morphology was identified in 62 of 68 specimens (91.2%), whereas 6 specimens (8.8%) demonstrated morphological variation. An elongated caudate process was present in 3 specimens (4.4%), and a prominent papillary process was identified in 2 specimens (2.9%). A duplicated caudate lobe was identified in 1 specimen (1.5%). The duplicated component was separated from the principal caudate lobe by a deep fissure and demonstrated a distinct vascular pedicle containing separate portal venous and arterial branches arising from the porta hepatis.

Conclusion: Morphological variations of the caudate lobe are uncommon but clinically relevant because they may alter expected hepatic anatomy on imaging and during surgery. The identification of a duplicated caudate lobe with a separate portal and arterial supply expands the recognized spectrum of caudate morphology and has potential implications for hepatobiliary surgery, liver transplantation, and image-guided intervention. Awareness of such variants may improve preoperative vascular assessment and reduce diagnostic or intraoperative uncertainty.

KEYWORDS: caudate lobe; anatomical variation; duplicated caudate lobe; vascular pedicle; cadaveric study; hepatobiliary surgery; liver transplantation

INTRODUCTION

The caudate lobe is a morphologically and functionally distinctive component of the liver, situated on its posterior surface in close relationship to the porta hepatis, fissure for the ligamentum venosum, and inferior vena cava. Although conventionally regarded as segment I, its configuration is variable, and its anatomical relationships differ from those of the surrounding hepatic parenchyma. Morphological and morphometric evaluation of the caudate lobe has demonstrated considerable variation in its shape, dimensions, caudate process, and papillary process, with differences also reported among populations [1]. Recognition of this variability is clinically important because deviations from conventional morphology may influence radiologic interpretation and operative orientation.

Variation of the caudate lobe forms part of a broader spectrum of hepatic morphological diversity. Accessory lobes and fissures have been documented in cadaveric specimens and may alter the expected external contour of the liver [2]. Comprehensive anatomical studies have further demonstrated wide variation in hepatic surface morphology, including changes involving lobar configuration, accessory fissures, grooves, and parenchymal bridges [3]. Such findings reinforce the concept that hepatic surface anatomy is not uniform and that unusual configurations should not automatically be interpreted as pathological abnormalities.

Several cadaveric studies have emphasized the clinical relevance of these external variations. Joshi et al. described multiple surface abnormalities of the liver and highlighted their potential importance during imaging and surgery [4]. Vinnakota and Jayasree similarly demonstrated considerable variability in gross hepatic morphology and emphasized that knowledge of such patterns is essential for accurate anatomical identification [5]. More specifically, morphometric assessment of the caudate lobe has confirmed substantial variation in its size, shape, and processes, supporting the need for careful characterization of caudate anatomy in individual specimens [6].

Accessory hepatic tissue represents another important developmental variation. Accessory liver lobes may remain connected to the parent liver by broad parenchymal tissue or by a relatively narrow pedicle containing vascular and biliary structures. A cadaveric accessory hepatic lobe attached to the gallbladder has been described, illustrating the range of anomalous hepatic development that may be encountered [7]. Additional anomalous hepatic structures have also been reported and attributed to variations occurring during embryologic development of the liver [8]. Cadaveric identification of accessory lobes further supports the clinical importance of distinguishing developmental hepatic tissue from adjacent pathological masses [9].

Accessory grooves and fissures may complicate this distinction. Deep grooves on the liver surface can alter apparent lobar boundaries and, depending on their configuration, may resemble traumatic, fibrotic, or pathological clefts [10]. Accessory hepatic lobes may themselves produce diagnostic uncertainty when their hepatic origin is not immediately recognized [11]. Additional studies of accessory hepatic sulci have demonstrated that such structures can occur in otherwise normally formed livers and may have implications for radiologic interpretation and operative anatomy [12]. Detailed examination of diaphragmatic sulci and portal fissures has further shown that hepatic surface grooves may reflect complex anatomical relationships rather than disease [13]. Population-based cadaveric observations of hepatic surface grooves have likewise demonstrated substantial variability in these structures [14].

The clinical significance of caudate morphology is amplified by its distinctive surgical anatomy. The caudate lobe lies immediately anterior to the retrohepatic inferior vena cava and is closely related to the portal structures and hepatic veins. Its embryologic development and complex vascular relationships make surgical isolation technically demanding, particularly during isolated caudate lobectomy, extended hepatic resection, and procedures involving the hepatic hilum [15]. Detailed anatomical investigations have shown that the caudate lobe receives variable portal venous and biliary branches, underscoring its relative anatomical independence from neighboring hepatic segments [16].

Its arterial anatomy is similarly complex. Caudate arterial branches may arise from different components of the hepatic arterial circulation, a finding of particular importance during transarterial therapy and surgical vascular control [17]. Cadaveric investigation of the caudate vascular system has further demonstrated considerable variation in portal inflow and venous outflow, reinforcing the need for individualized anatomical assessment during hepatobiliary procedures [18]. More broadly, contemporary concepts of liver surgery are based on functional vascular territories rather than external lobar morphology alone, making accurate understanding of segmental and vascular anatomy essential for safe hepatic resection [19].

The relationship between external caudate morphology and internal vascular segmentation has been examined in detail. Portal segmentation, hepatic venous landmarks, and external caudate notches do not invariably correspond, demonstrating that surface anatomy alone may be insufficient to define the functional limits of the caudate region [20]. Identification of hepatic veins forming boundaries between the caudate lobe and adjacent liver segments has further refined the anatomical understanding of this region [21]. Three-dimensional analyses of portal supply and venous drainage have similarly demonstrated the complexity and variability of caudate vascular architecture [22].

Anatomical studies have also questioned whether the caudate lobe should be regarded simply as a homogeneous segment I. Detailed evaluation has shown that the caudate region comprises anatomically distinct components with variable relationships to surrounding hepatic segments [23]. Portal-based definitions have therefore been proposed to characterize the caudate lobe more accurately according to its vascular territories [24]. Recent work examining its cranial boundary has continued to refine these anatomical limits and illustrates that even the superior extent of the caudate region may not conform consistently to traditional descriptions [25].

Despite advances in cross-sectional imaging, cadaveric investigation remains valuable for identifying subtle morphological and vascular variants. Recent cadaveric studies have documented substantial variation in the human liver, including differences in caudate configuration, accessory fissures, and lobar morphology [26]. Similar contemporary investigations have confirmed that these variations remain clinically relevant because they may alter expected anatomy during imaging and surgical procedures [27]. Computed tomographic assessment has extended these observations to living populations by demonstrating measurable differences in caudate morphology and morphometry and by allowing evaluation of its relationship to surrounding vascular structures [28].

Broader studies of external hepatic morphology also continue to demonstrate marked anatomical diversity [29]. Recent cadaveric investigations have emphasized that such variability has implications for diagnostic imaging, hepatic surgery, and anatomical education [30]. Collectively, these studies establish that caudate morphology should be interpreted within the broader context of developmental and vascular variation of the liver.

Among the recognized variations, duplication of the caudate lobe appears to be particularly uncommon. An accessory projection or deep fissure alone does not necessarily establish true duplication because superficial lobulation can occur without corresponding vascular separation. A morphologically distinct caudate component associated with a separate vascular pedicle provides substantially stronger anatomical evidence of an organized variant. Such a configuration may be relevant to radiologists because it can alter the expected appearance of the posterior liver, to hepatobiliary and transplant surgeons because it may introduce unexpected vascular anatomy, and to interventional radiologists because a separate arterial territory may require independent recognition during selective catheter-based procedures.

The present study was therefore undertaken to characterize morphological variations of the caudate lobe in adult human cadaveric liver specimens, with particular attention to the caudate process, papillary process, fissural configuration, duplication, and vascular pedicles. The primary objective was to determine the frequency and pattern of observed caudate lobe variations and to document the anatomical characteristics of a duplicated caudate lobe associated with an independent vascular pedicle.

MATERIALS AND METHODS

Study Design and Setting

This descriptive cross-sectional cadaveric study was conducted in the Department of Anatomy using adult human liver specimens obtained during routine anatomical dissections undertaken for medical education and anatomical research. The study was designed to characterize gross morphological variations of the caudate lobe, with particular attention to the caudate process, papillary process, fissural configuration, duplication, and grossly identifiable vascular supply.

Specimen Selection

A total of 68 adult human liver specimens were examined. Specimens were eligible for inclusion when the caudate lobe, porta hepatis, and adjacent posterior hepatic anatomy were sufficiently preserved to permit reliable gross anatomical assessment. Specimens demonstrating gross pathological alteration, traumatic disruption, marked postmortem distortion, or deformity affecting the caudate lobe or hilar region were excluded. All specimens satisfying these criteria were included in the final analysis; no sampling or random selection was performed.

Information regarding donor age and biological sex was not available from the institutional records accessible for this study and was therefore not included in the analysis. No demographic characteristics were inferred from the specimens.

Gross Anatomical Examination

Each liver was examined systematically on its visceral and posterior surfaces. Anatomical orientation was established using the porta hepatis, groove for the inferior vena cava, fissure for the ligamentum venosum, gallbladder fossa, and adjoining hepatic parenchyma as reference landmarks. The caudate lobe was identified in its conventional posterior location and assessed for overall configuration, surface contour, caudate process, papillary process, fissural pattern, and the presence of any additional caudate-type hepatic component.

The caudate process was examined for its configuration, degree of projection, and continuity with the principal caudate lobe and adjacent right hepatic parenchyma. A conspicuous extension beyond the usual gross anatomical contour was categorized descriptively as an elongated caudate process. The papillary process was assessed for its configuration and projection from the principal caudate lobe; a clearly conspicuous projection was categorized as a prominent papillary process. Because the original anatomical assessment did not employ validated quantitative thresholds for either feature, no retrospective morphometric cutoff was imposed.

Assessment of Fissural Anatomy and Caudate Lobe Duplication

The caudate region was inspected for superficial grooves, accessory fissures, deep fissures, and apparent separation of hepatic tissue. A superficial cleft or lobulation without convincing macroscopic separation was not classified as duplication.

For this study, a duplicated caudate lobe was defined as a distinct additional caudate-type component that was macroscopically separated from the principal caudate lobe by a well-defined deep fissure and demonstrated a separately identifiable gross vascular supply. This operational definition was used to distinguish duplication from an accessory fissure, superficial lobulation, or localized prominence of the caudate or papillary process.

Vascular Assessment

When an anatomically separate caudate component was encountered, the hilar region and grossly visible vessels supplying the component were examined by direct anatomical dissection. Identifiable vascular structures were followed from the porta hepatis toward the additional hepatic component. A vascular pedicle was considered separate when discrete vascular branches could be traced directly from the porta hepatis to the variant component rather than reaching it through the principal caudate parenchyma.

In the specimen demonstrating caudate lobe duplication, separate portal venous and arterial branches arising from the porta hepatis were identified supplying the duplicated component. These findings established distinct gross portal and arterial inflow to the additional caudate tissue.

No vascular injection, corrosion casting, angiographic examination, microvascular dissection, histologic assessment, or three-dimensional vascular reconstruction was performed. Detailed biliary drainage and short hepatic venous outflow of the duplicated component were not assessed. Accordingly, the study did not assume complete functional independence of the duplicated component beyond the portal venous and arterial anatomy demonstrated by gross dissection.

Data Recording and Photographic Documentation

Morphological findings were recorded systematically for each specimen. The variables documented were conventional caudate lobe morphology, elongated caudate process, prominent papillary process, duplicated caudate lobe, and the presence of a separate vascular pedicle when applicable. Each liver specimen contributed once to the study denominator.

Relevant anatomical findings were photographed during examination. Particular attention was given to documenting uncommon variants and their relationships to the principal caudate lobe, intervening fissures, porta hepatis, and grossly identifiable vascular structures. The specimen demonstrating duplication was photographed to document the separate caudate component, the deep intervening fissure, and its vascular pedicle.

Study Size

The study comprised all 68 eligible adult human liver specimens accessible for examination within the study material.

Because the investigation was descriptive and exploratory and was not designed to test a prespecified association or treatment effect, no hypothesis-based sample-size or statistical power calculation was performed.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using descriptive statistics. Categorical morphological findings were summarized as absolute frequencies and percentages. The total number of examined specimens (n = 68) was used as the denominator for calculation of the frequency of each morphological category. No inferential statistical testing was performed because the study did not include comparison groups or demographic variables suitable for association testing. Missing donor age and biological sex were not imputed.

Ethical Considerations

The study used adult human cadaveric liver specimens obtained through routine anatomical teaching and research activities. No living participants were recruited, contacted, examined, or followed, and no personally identifiable donor information was collected or analyzed. The specimens were handled respectfully and in accordance with institutional requirements and accepted ethical principles governing the use of donated human bodies for medical education and anatomical research.

RESULTS

A total of 68 adult human cadaveric liver specimens met the eligibility criteria and were included in the final analysis. Conventional caudate lobe morphology was observed in 62 specimens (91.2%; 95% CI, 81.8%-96.7%), whereas 6 specimens (8.8%; 95% CI, 3.3%-18.2%) demonstrated a distinct morphological variation. No specimens included in the final analysis had missing data for the morphological variables assessed. The distribution of the observed caudate lobe configurations is summarized in Table 1.

An elongated caudate process was the most frequently observed variant and was identified in 3 specimens (4.4%; 95% CI, 0.9%-12.4%). In these specimens, the caudate process demonstrated conspicuous extension beyond the usual gross anatomical contour while remaining continuous with the principal caudate lobe and adjacent right hepatic parenchyma.

A prominent papillary process was identified in 2 specimens (2.9%; 95% CI, 0.4%-10.2%). In both specimens, the papillary process formed a distinct projection from the principal caudate lobe and was readily distinguishable from the usual caudate contour on gross examination.

Duplication of the caudate lobe was identified in 1 specimen (1.5%; 95% CI, 0.04%-7.9%). The additional caudate component was macroscopically distinct from the principal caudate lobe and was separated from it by a well-defined deep fissure. Its configuration differed from a superficial lobulation or an elongated caudate or papillary process because the additional component demonstrated both clear morphological separation and a separately identifiable vascular supply. Gross examination of the hilar region demonstrated a distinct vascular pedicle extending from the porta hepatis to the duplicated component. Within this pedicle, separate portal venous and arterial branches were identified and could be traced directly toward the duplicated lobe. These vessels were anatomically distinct from the vascular structures supplying the principal caudate lobe. The duplicated component, the intervening deep fissure, and the associated vascular pedicle were documented photographically (Figure 1).

No additional duplicated caudate components were identified among the remaining 67 specimens. Detailed biliary drainage and short hepatic venous outflow of the duplicated component were not assessed and therefore are not reported as anatomical outcomes.

Donor age and biological sex were unavailable from institutional records for all 68 specimens; consequently, demographic subgroup analyses could not be performed. Because the study was descriptive and did not include prespecified comparison groups, no hypothesis testing, multivariable analysis, subgroup analysis, or sensitivity analysis was undertaken.

Table 1. Distribution of Caudate Lobe Morphology in 68 Cadaveric Liver Specimens

Morphological finding	n	%	95% CI
Conventional morphology	62	91.2	81.8-96.7
Elongated caudate process	3	4.4	0.9-12.4
Prominent papillary process	2	2.9	0.4-10.2
Duplicated caudate lobe with an independent vascular pedicle	1	1.5	0.04-7.9
Total	68	100.0	—

DISCUSSION

The present study demonstrates that the caudate lobe is morphologically conventional in most adult cadaveric livers but may exhibit clinically relevant variations in its processes, fissural configuration, and vascular organization. Among the 68 specimens examined, morphological variation was identified in 6 (8.8%), comprising an elongated caudate process in 3 specimens, a prominent papillary process in 2, and a duplicated caudate lobe in 1. The most distinctive observation was the duplicated caudate component, which was separated from the principal caudate lobe by a deep fissure and supplied through a separate grossly identifiable vascular pedicle containing portal venous and arterial branches arising from the porta hepatis. This finding is important because the combination of morphological separation and distinct vascular inflow provides stronger anatomical evidence for duplication than surface configuration alone.

Variability of the caudate lobe has been documented in morphometric studies, although the reported patterns differ across populations and study designs. Sagoo et al. demonstrated substantial variation in caudate lobe morphology and dimensions and reported population-related differences in several morphometric parameters [1]. These observations support the concept that the caudate lobe should not be considered morphologically uniform. The findings of the present study are consistent with this broader anatomical variability, although direct numerical comparison is limited because different investigators have used different definitions and measurement criteria for individual caudate variants.
Morphological variation of the caudate lobe should also be considered within the wider spectrum of hepatic variation. Accessory lobes and fissures have been described in cadaveric livers and may substantially alter the external configuration of the organ [2]. Ragavan et al. further demonstrated the diversity of hepatic morphology, including variations involving lobes, fissures, and surface contours [3]. These studies illustrate an important methodological distinction: frequencies reported in investigations of the entire liver are generally higher than those observed in studies restricted to a specific anatomical region. The 8.8% frequency identified in the present series therefore should not be compared directly with studies in which multiple variations across the entire liver were counted independently.
Joshi et al. described several unusual hepatic surface configurations and emphasized their potential clinical significance [4], while Vinnakota and Jayasree similarly documented marked variability in gross liver morphology [5]. Such observations are relevant to the present findings because changes in surface anatomy can alter conventional anatomical landmarks without necessarily representing disease. This distinction becomes particularly important in the posterior liver, where a localized projection or fissure may modify the expected appearance of the caudate region.
The elongated caudate process was the most frequently encountered variant in this series. Previous cadaveric work focusing on caudate morphology has demonstrated substantial variation in both the dimensions and configuration of this process [6]. Comparison of reported frequencies across studies is difficult because there is no universally accepted quantitative threshold for defining an elongated caudate process. In the present investigation, classification was based on gross anatomical prominence rather than an arbitrary retrospective measurement cutoff. This approach is appropriate for a descriptive study but should be recognized when comparing the findings with morphometric investigations.
Accessory hepatic tissue provides an additional framework for interpreting unusual lobar configurations. Sirasanagandla et al. described an accessory hepatic lobe attached to the gallbladder, demonstrating that anatomically discrete hepatic tissue can occur in atypical locations [7]. Choy et al. also reported anomalous hepatic structures and related them to developmental variation [8]. Similar cadaveric observations of accessory lobes have emphasized that these structures may have their own vascular connections and therefore may be clinically relevant despite their small size [9]. These reports are important when considering the duplicated caudate component identified in the present study; however, an accessory hepatic lobe and a duplicated caudate lobe should not be regarded as synonymous entities.
The distinction between fissural variation and true duplication deserves particular emphasis. Accessory grooves may be prominent and may alter the appearance of hepatic surfaces without creating separate functional territories. Nayak et al. documented accessory diaphragmatic grooves and highlighted their potential to simulate pathological clefts [10]. Similarly, accessory hepatic tissue has been reported as a diagnostic dilemma when its hepatic origin is not readily recognized [11]. Accessory sulci described by Othman et al. [12], diaphragmatic and portal fissures analyzed by Macchi et al. [13], and hepatic surface grooves reported by Gardner et al. [14] collectively demonstrate that deep surface divisions can occur without establishing true lobar duplication.
Accordingly, the deep fissure observed in the present specimen would not, by itself, be sufficient evidence of duplication. The more compelling feature was the presence of a distinct vascular pedicle containing separate portal venous and arterial branches supplying the additional component. This combined morphological and vascular pattern distinguishes the finding from a simple accessory fissure or superficial lobulation.
The surgical importance of this distinction becomes apparent when the anatomical position of the caudate lobe is considered. Abdalla et al. emphasized the unique embryological and operative anatomy of the caudate region, particularly its relationship to the retrohepatic inferior vena cava, portal structures, and hepatic veins [15]. Caudate resection can therefore be technically demanding even when the anatomy is conventional. An additional caudate component supplied through a separate pedicle could introduce an unexpected structure during hilar or posterior hepatic dissection and may require modification of the operative approach.
Portal venous and biliary anatomy further contribute to the relative autonomy of the caudate region. Kumon demonstrated considerable variability in portal venous and biliary branches supplying different portions of the caudate lobe [16]. These findings are relevant to the present specimen because they provide a recognized anatomical basis for separate portal inflow to caudate tissue. Nevertheless, the present study demonstrated only gross portal and arterial branches to the duplicated component. Biliary drainage was not mapped; therefore, the finding should not be interpreted as evidence of complete functional independence.
The arterial supply of the caudate lobe is similarly variable. Miyayama demonstrated that caudate arteries may arise from multiple hepatic arterial territories, a feature that has particular relevance to transarterial treatment of tumors in this location [17]. In the present study, identification of a separate arterial branch entering the duplicated component adds to the evidence that the structure represents an organized anatomical variant rather than a superficial morphological irregularity. From an interventional standpoint, such a branch could also become relevant if focal pathology were to arise within the duplicated tissue.
Cadaveric vascular studies further illustrate the complexity of this region. Mao et al. demonstrated variable portal inflow and venous outflow of the caudate lobe and emphasized the close anatomical relationship between caudate parenchyma and the retrohepatic inferior vena cava [18]. These observations have practical implications for hepatic surgery because vascular structures in the caudate region may be small, variable, and difficult to control after inadvertentdivision.
Modern liver surgery relies increasingly on functional vascular territories rather than external lobar landmarks alone.

Abdel-Misih and Bloomston emphasized the importance of portal pedicles and hepatic venous anatomy in contemporary hepatic resection [19]. From this perspective, the separate portal branch identified in the duplicated component may be more anatomically informative than the deep surface fissure itself. External morphology indicates separation, whereas portal inflow provides evidence of an internally organized vascular territory.

Studies correlating caudate morphology with portal segmentation have similarly demonstrated that external boundaries do not always correspond precisely to internal vascular territories. Kogure et al. showed relationships among portal segmentation, hepatic venous anatomy, and external caudate landmarks [20]. Subsequent investigation of hepatic veins forming boundaries between the caudate lobe and adjacent segments further refined understanding of this region [21]. These studies reinforce the principle that surface morphology and vascular architecture should be interpreted together. Three-dimensional assessment of portal inflow and venous drainage has provided additional evidence of the complex organization of the caudate region [22]. Anatomical analyses have also suggested that the conventional description of the caudate lobe as a homogeneous segment I may oversimplify its internal organization [23]. Portal-based definitions proposed by Kumon et al. emphasize the Spiegel lobe, paracaval portion, and caudate process as components with distinct vascular relationships [24]. More recent work examining the cranial boundary of the caudate lobe has further demonstrated that even its superior anatomical extent may be difficult to define using surface landmarks alone [25]. These observations provide an important context for interpreting the duplicated component in the present study. The finding should not be considered evidence that the conventional caudate lobe is invariably duplicated into two equivalent segments. Rather, it represents an uncommon anatomical configuration in which an additional caudate-type component demonstrates both macroscopic separation and distinct portal and arterial inflow. Because complete biliary and hepatic venous anatomy was not established, a more extensive claim regarding functional segmentation would not bejustified. Contemporary cadaveric studies continue to demonstrate the value of direct anatomical observation. Sambhav et al. documented substantial variability in hepatic morphology, including variations in caudate configuration and accessory fissures [26]. Chauhan et al. similarly described clinically relevant morphological variants in cadaveric livers [27]. Although modern imaging can depict many of these abnormalities, dissection remains particularly valuable for confirming small vascular branches and directly assessing the relationship between fissures and hepatic tissue. Computed tomography provides the complementary advantage of evaluating caudate morphology in living individuals. Imaging-based morphometric studies have demonstrated that the size and configuration of the caudate lobe can be assessed using computed tomography [28]. Recognition of a duplicated caudate component in clinical practice would depend on identifying hepatic parenchymal characteristics, evaluating continuity or separation from the principal lobe, and carefully tracing its vascular connections on multiplanar and multiphasic imaging.

The radiologic implications are therefore clinically relevant. A prominent papillary process or unusual caudate projection may resemble lymphadenopathy, an exophytic hepatic lesion, or another upper abdominal mass when viewed in isolation. A deep fissure may simulate a pathological cleft or alter the apparent contour of the posterior liver. Awareness of the broader spectrum of external hepatic morphology described in cadaveric studies [29] can reduce such interpretive errors. When an unusual tissue component demonstrates attenuation, signal characteristics, and enhancement identical to hepatic parenchyma, careful review of its portal and arterial connections may help establish itshepaticorigin. Recent studies emphasizing the clinical implications of morphometric and morphological variability further support the need to recognize these variants before intervention [30]. The relevance extends beyond diagnostic imaging. During hepatic resection, transplantation, or hilar dissection, an unrecognized vascular pedicle may create an unexpected source of bleeding or result in ischemia if divided inadvertently. During donor evaluation, preoperative vascular mapping may reveal additional branches that could influence operative planning. In image-guided therapy, separate arterial supply may require selective identification if a lesion develops within the variant tissue.

The principal contribution of the present study lies in the combination of morphological and vascular observations rather than in the estimated frequency of duplication. The duplicated caudate lobe occurred in only one of 68 specimens, yielding an observed frequency of 1.5%. Because this estimate is based on a single event in a relatively modest sample, it should not be interpreted as a reliable population prevalence. The finding is primarily anatomical and descriptive. A substantially larger, preferably multicenter series would be required to estimate the prevalence of this variantwithreasonableprecision.

Several limitations should be considered. First, donor age and biological sex were unavailable, preventing assessment of demographic variation. Second, the study was based on gross cadaveric examination and did not incorporate quantitative morphometry for defining elongation of the caudate process or prominence of the papillary process. Third, the vascular assessment was limited to grossly identifiable portal venous and arterial branches. Vascular injection, corrosion casting, microvascular dissection, angiographic correlation, and three-dimensional reconstruction were not performed. Fourth, biliary drainage and short hepatic venous outflow of the duplicated component were not mapped. Consequently, although separate portal and arterial inflow was demonstrated, complete functional independence cannot be established. Finally, the descriptive design and modest sample size limit generalization of the observed frequencies. The study nevertheless has several strengths. All specimens were assessed systematically using the same anatomical domains, and uncommon findings were documented photographically. The duplicated component was not classified solely on the basis of an unusual external contour; its separation by a deep fissure was accompanied by a distinct gross vascular pedicle containing both portal venous and arterial branches. This combination provides a stronger anatomical basisforclassificationthansurfacemorphologyalone.

Future studies should integrate cadaveric dissection with detailed morphometry, vascular casting, cholangiographic assessment, and three-dimensional imaging. Such investigations could determine whether duplicated caudate morphology follows reproducible portal, arterial, venous, and biliary patterns. Large imaging-based studies could additionally establish whether the variant can be recognized prospectively in living populations and define its practical

relevance to hepatic surgery, transplantation, and image-guided intervention.
Overall, the present observations expand the recognized spectrum of caudate lobe morphology and emphasize the importance of interpreting unusual posterior hepatic anatomy in conjunction with its vascular organization. The rare duplicated caudate component documented in this series demonstrates that morphological separation may coexist with distinct portal and arterial inflow. Recognition of this configuration may improve anatomical interpretation and preprocedural planning while reducing the likelihood that an uncommon but organized hepatic variant is mistaken for pathology or encountered unexpectedly during intervention.

CONCLUSION

This cadaveric study demonstrates that morphological variation of the caudate lobe includes elongation of the caudate process, prominence of the papillary process, and, rarely, duplication. The duplicated caudate component identified in this series was separated from the principal caudate lobe by a deep fissure and demonstrated a distinct vascular pedicle containing separate portal venous and arterial branches arising from the porta hepatis.
The combination of morphological separation and independent gross portal and arterial inflow supports classification of this finding as a duplicated caudate lobe with a separate vascular pedicle. Because biliary drainage and hepatic venous outflow were not evaluated, complete functional independence cannot be established.
Recognition of this variant is relevant to radiologic interpretation, hepatobiliary surgery, liver transplantation, and image-guided intervention, where unexpected posterior hepatic anatomy may influence diagnosis, vascular planning, and operative strategy. Larger anatomical and imaging-based studies are required to define the prevalence and complete vascular and biliary architecture of this uncommon variant.

Author Contributions

All authors contributed substantially to the work and meet the criteria for authorship. Shilpi Shrivastava, Harshika Khatri, Kashi Nath Sarkar, Prakriti Mishra, Amrita Bharti, and Rachna Rohatgi contributed to the conception and design of the study, interpretation of the findings, and critical revision of the manuscript for important intellectual content. The authors involved in the anatomical examination contributed to specimen assessment, acquisition of anatomical data, and photographic documentation. All authors reviewed and approved the final version of the manuscript and agree to be accountable for the accuracy and integrity of the work.

Ethical Considerations

This study was conducted using adult human cadaveric liver specimens obtained through routine anatomical teaching and research activities. No living human participants were recruited or studied, and no personally identifiable donor information was collected, accessed, or analyzed. All cadaveric specimens were handled in accordance with institutional requirements and accepted ethical principles governing the respectful use of donated human bodies for medical education and anatomical research.

Informed Consent

Informed consent from living participants was not applicable because this study did not involve living human subjects. The study used adult human cadaveric liver specimens obtained through institutional anatomical teaching and research activities. No personally identifiable donor information was collected or analyzed.

Conflict of Interest

The authors declare that they have no financial, commercial, professional, or personal conflicts of interest that could have influenced the conduct, interpretation, or reporting of this study.

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Data Availability

All data generated and analyzed during this study are presented within the manuscript. The study did not generate an individual-level clinical dataset. Photographic documentation of the anatomical findings was obtained during gross examination and is represented in the accompanying figure material. Additional study-related information may be made available by the authors in accordance with institutional policies governing cadaveric specimens and anatomical research documentation.

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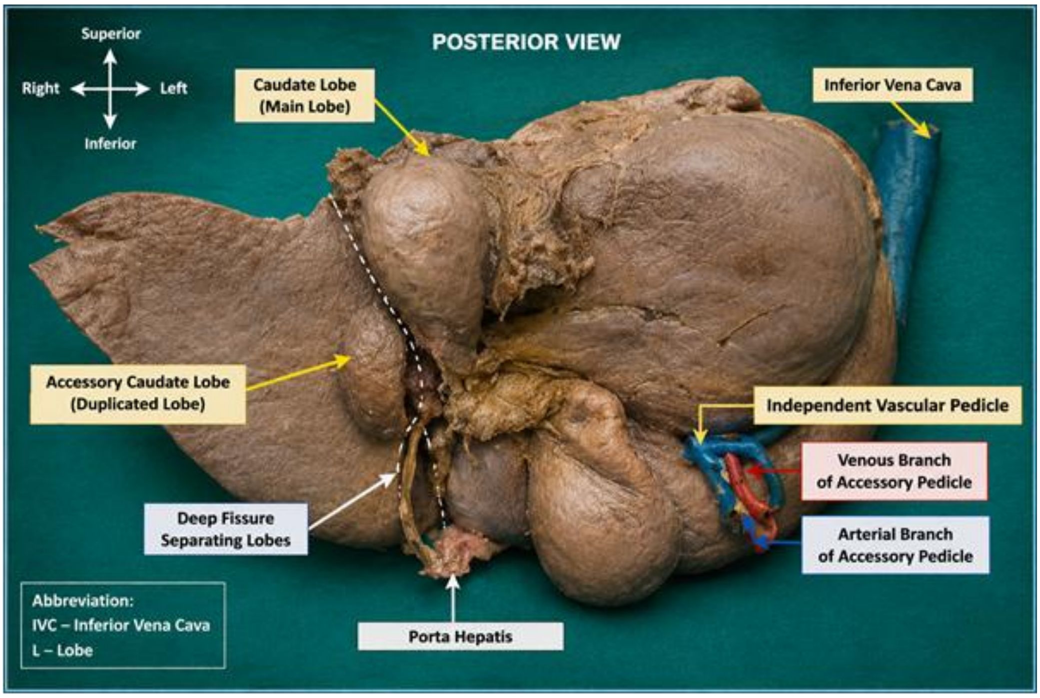

Figure 1. Duplicated caudate lobe with a separate vascular pedicle. Gross anatomical specimen demonstrating a distinct duplicated caudate component separated from the principal caudate lobe by a well-defined deep fissure. A separate vascular pedicle extending from the porta hepatis to the duplicated component contains identifiable portal venous and arterial branches.

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