

Assessment of the morphology and morphometry of the caudate lobe of the liver using computed tomography

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Abstract. – OBJECTIVE: The caudate lobe differs from the rest of the liver. This study was planned to evaluate the caudate lobe's morphology, morphometry, and vascular structures using computed tomography (CT).

PATIENTS AND METHODS: Three hundred eighty-eight cases were evaluated retrospectively in terms of caudate lobe morphology, morphometry, and vascular anatomy from patients undergoing contrast-enhanced abdominal CT for any reason between September 2018 and December 2019. After the application of exclusion criteria, 196 patients were eventually included in the study.

RESULTS: One hundred seventeen (59.7%) of the 196 patients were men. The patients' mean age was 57.88 years (ranging from 18 to 82). Morphologically, the caudate lobe was classified as rectangular, piriform, or irregular-shaped, with 117 cases being evaluated as piriform (59.7%), 51 as irregular-shaped (26%), and 28 as rectangular (14.3%). The caudate process was visible in most cases (92.9%). No papillary process was observed in the great majority of patients (87.2%).

CONCLUSIONS: Caudate lobe evaluation criteria can be obtained using CT *in vivo* based on morphological and morphometric values for the caudate lobes yielded by cadaver studies.

Key Words:

Caudate lobe, Caudate process, Papillary process, Computed tomography.

Introduction

The caudate lobe is of great clinical importance in liver diseases. Also known as the Spigelian lobe, the caudate lobe is one of the four anatomical lobes of the liver. However, it differs from the rest of the liver in that it behaves paradoxically, especially in cases of cirrhosis. The caudate lobe is bounded by the ligamentum venosum on the

left, inferiorly by the porta hepatis, and by the inferior vena cava (IVC) on the right¹. It consists of three parts - Spiegel's lobe, the caudate process and the paracaval part in front of the IVC². The caudate lobe has portal blood supply and hepatic vein drainage independent of the remainder of the liver. It is connected to the right lobe of the liver through the caudate process extending between the portal vein and the IVC. The medial inferior part of the caudate lobe sometimes passes left (and sometimes anteriorly) into the superior recess of the omental bursa. This part is known as the papillary process³.

There are currently several classifications for the functional parts of the adult liver, largely determined by vascular structures. The Glisson system divides the liver into two, based on the left and right branches of the portal vein⁴. Couinaud (1957)⁵ divided the adult liver using the distribution of the portal venous system in which the portal vein divides the liver into left and right branches. These both subdivide again, producing four major branches, each supplying a different portal sector⁶. In this classification based on portal vein branching, eight lobes are defined, starting from the IVC in a clockwise direction. The caudate lobe represents segment I and is supplied by both the right and left portal veins². The systemic arterial supply of the caudate lobe is usually provided by the caudate arteries originating from the right, left and, if present, middle hepatic arteries. Venous drainage of the liver to the IVC is provided by the three main hepatic veins – left, right and middle. However, the caudate lobe also contains several small hepatic veins that open into the IVC independently of the main hepatic veins^{7,8}. These differences in portal and arterial supply and hepatic vein drainage explains why the caudate lobe is affected differently in liver diseases. This variation also accounts for the importance of the caudate lobe⁹.

In cirrhotic livers, the caudate lobe becomes relatively enlarged, while the right lobe atrophies. Cirrhotic livers can be differentiated from non-cirrhotic livers with 84% sensitivity and 100% specificity using the ratio of the width of the caudate lobe to the width of the right lobe (the Harbin index)¹⁰.

Caudate lobectomy is increasingly performed during the laparoscopic era. Caudate lobectomy with open surgery with or without hepatectomy is performed to treat cholangiocarcinoma, hepatocellular tumors, and metastatic tumors. More recently, laparoscopic isolated caudate lobectomy became feasible and safe in selected patients. The morphology of the caudate lobe is important in terms of diagnostic imaging and minimally invasive surgical approaches^{11,12}. The purpose of this study was to evaluate the morphology, morphometry and vascular structures of the caudate lobe using CT.

Patients and Methods

Patients

Caudate lobe morphology, morphometry, and vascular anatomy were retrospectively evaluated in patients who underwent contrast-enhanced abdominal CT for any reason between September 2018 and December 2019. Ethics approval was obtained from the Faculty Clinical Research Ethics Committee (no. 83, dated 12.03.2020). Three hundred eighty-eight cases were evaluated retrospectively. In order to define the normal anatomy and morphology of the caudate lobe, our hospital database was scanned retrospectively, excluding patients with hepatosteatosis, hepatomegaly, cirrhosis, tumor, metastasis, etc. liver pathologies, a history of liver surgery or trauma, and patients under 18 years of age. Cases with non-optimal image quality (due to patient movement, artifact, or insufficient vascular contrast) were also excluded from the study. Once the exclusion criteria had been applied, 196 patients were finally enrolled in the study. Contrast-enhanced CT scans were performed using a 128-slice CT device. (Definition AS, Siemens Medical Solutions, Forchheim, Germany) as an our standard abdominal triphase contrast imaging protocol described below.

Methods

Scanning parameters were as follows: slice thickness, 5 mm; slice interval, 5 mm; reconstructed slice thickness, 1.25 mm; tube voltage, 120 kVp; tube current, 240 mA; helical pitch, 1.375. After CT non-contrast scan, 3-phase dy-

namic contrast scan was performed. Non-ionic contrast agent was injected into elbow vein with a two-headed auto-injector (Stellant, Medrad, Inianola, MS, USA) at an injection rate of 4.0 mL/S and an injection dose of 100-120 mL, followed by 30 mL saline at the same rate. After injection, the arterial phase was achieved with a delay time of 30 seconds and portal venous phase with 70 seconds. The images were evaluated on an Apple® 5120x2880 matrix, 27-inch monitor (Retina 5K / late 2014), with an Osirix-Viewer® 6.5 (Pixmeo SARL, Switzerland).

The age and gender of the patients, caudate lobe morphology and morphometric values, whether the caudate process was prominent or not, presence or absence of the papillary process were recorded. The width and length of the right liver lobe and the width, length and anterior posterior diameter of the caudate lobe were measured. Caudate lobe vascular anatomy was also evaluated. The caudate lobe was evaluated by three directions, axial, coronal, and sagittal.

Morphological Evaluation of the Caudate Lobe

The caudate lobe was classified morphologically in terms of three different shapes – rectangular, piriform or irregular¹³. In the rectangular shape, the superior and inferior pole of the caudate lobe are approximately equal in size, and are generally rectangular (Figure 1a). In the piriform shape, the superior or inferior pole of the caudate lobe is wider and the counter pole is narrower (Figure 1b). Irregular is used to refer to any caudate lobe shape other than piriform or rectangular (Figure 1c). The caudate lobe is connected to the right lobe of the liver by the caudate process extending between the portal vein and IVC (Figure 1d)¹³. The inferior medial part of the caudate lobe sometimes forms the papillary process extending toward the superior recess of the omental bursa (Figure 1e)².

Morphometric Evaluation of the Caudate Lobe

Caudate lobe morphometric measurements and morphometric evaluations were performed as in previous cadaver studies¹³⁻¹⁷. As shown in Figure 2 and 3a-c, the transverse length of the caudate lobe (CLTL), the width or the transverse length of the right lobe (RLTL), the anterior posterior diameter of the caudate lobe (CLAP), the longitudinal length of the caudate lobe (CLLL), and the longitudinal length of the right lobe (RLLL) were measured¹⁰.



Figure 1. Caudate lobe morphology in CT images. **a**, Appearance of the piriform shape of the caudate lobe on a sagittal CT image. **b**, Appearance of the rectangular shape of the caudate lobe on a sagittal CT image. **c**, Appearance of the irregular shape of the caudate lobe on a sagittal CT image. **d**, View of the caudate process connecting the caudate lobe to the right liver lobe on a sagittal CT image. **e**, View of the papillary process in the inferomedial part of the caudate lobe on an axial CT image.

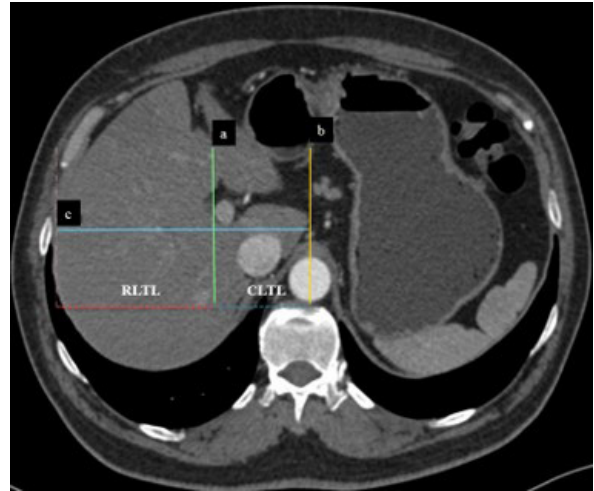


Figure 2. Morphometric evaluation of the caudate lobe on CT images. A parasagittal line “a” passing through the bifurcation level of the main portal vein was drawn from the right lateral wall of the main portal vein (green line) on an axial CT image. A second line “b” parallel to line “a” was drawn from the most medial edge of the caudate lobe (yellow line). A third line “c” perpendicular to the line “a” and “b” was drawn passing through the main portal vein and inferior vena cava extending to the lateral edge of the right lobe (blue line). Along line “c”, the distance between lines “a” and “b” consisted of the width or transverse length (CLTL) of the caudate lobe (blue dashed line). Along line “c”, the distance between the lateral edge of the right lobe of the liver and line “a” was the width or the transverse length (RLTL) of the right lobe (red dashed line).



Figure 3. Morphometric evaluation of the caudate lobe on CT Images. **a**, The widest anterior posterior diameter of the caudate lobe (CLAP) was measured (green line) where the transverse length of the caudate lobe was determined on the axial CT image. **b**, On the sagittal CT image, the longitudinal length of the caudate lobe (CLLL) was measured in the craniocaudal axis (blue line) where the inferior vena cava was located. **c**, On the coronal CT image, the longitudinal length of the right lobe (RLLL) of the liver was measured on the craniocaudal axis (red line) at the portal vein branching point.

Statistical Analysis

In order to determine the differences between the means, the Independent Simple *t*-test was used when the assumption of normality was provided for two independent groups, while the Mann-Whitney U test was used when the assumption was not met. One Way ANOVA test was used in cases where the assumptions of normality and homogeneity of variance were met for three or more independent groups, while the Kruskal-Wallis H test was used when the assumptions were not met. The statistical significance level for all analyzes was determined as $p=0.05$. Analyzes were provided with SPSS, Version 21.0 program (IBM Corp., Armonk, NY, USA).

Results

One hundred seventeen (59.7%) of the 196 patients were men. The mean age of the patients was 57.88 years (range 18 to 82 years). One hundred seventeen cases were evaluated as piriform (59.7%), 51 as irregular shape (26%), and 28 as rectangular shape (14.3%) (Table I). The caudate process was clearly visible in most cases (92.9%). Papillary processes were observed in only 25 (12.8%) of the 196 cases, with none being detected in the great majority (87.2%). The average width of the caudate lobe was 4.04 cm, ranging from 2.44 to 5.48 cm. The average ratio of caudate lobe width to right lobe width was 0.46, ranging widely from 0.26 to 0.64. The morphometric values in this study are summarized in Table II. There was no significant difference between the morpho-

metric parameters and the shape of the caudate lobe, whether the caudate process was prominent or not, and the presence or absence of the papillary process ($p>0.05$).

The portal and venous vascular anatomy of the caudate lobe was also evaluated. The blood supply of the caudate lobe was from the right portal vein in 82 cases (41.8%), the left portal vein in 13 (6.6%), the bifurcation level in 47 (24%), the main portal vein in 5 (2.6%), and from a combination of these in 38 (19.4%). Portal vascular structures could not be determined in 11 cases (5.6%). There was no significant difference between the morphometric parameters and the venous vascular anatomy of the caudate lobe ($p>0.05$).

Venous drainage of the caudate lobe was direct to the inferior vena cava in all cases by at least one major vein (100%).

Discussion

This study evaluated caudate lobe morphologic evaluation and morphometric values using CT, a diagnostic imaging modality. Cadaver studies¹³⁻¹⁷ investigating the morphological features of the caudate lobe and the information from the present study are summarized in Table III. In their study involving 36 cadaver livers, Sadanandan and Varghese¹⁴ classified the caudate lobe as rectangular, triangular, elongated, or dumb-bell-shaped, with 22 caudate lobes (61.11%) being described as rectangular, six (16.67%) as triangular, six (16.67%) as elongated, and two (5.55%) as dumb-bell-shaped. The incidence of rectangular-shape caudate lobes in cadaver studies varies between 48% and 91.66%, and this is the most common shape¹³⁻¹⁷. 117 cases were evaluated as piriform (59.7%) in the present study, 51 as irregular (26%), and 28 as rectangular (14.3%). In contrast to the previous literature, the piriform shape was the most common form in the present study at 59.7%, while only 14.3% of caudate lobes were

Table I. Shapes of the caudate lobe.

Shape	Number of Cases	Incidence
Piriform	117	59.7%
Rectangular	51	26%
Irregular	28	14.3%

Table II. Morphometric values for the caudate lobe and right lobe.

Hepatic measurements	Distance (cm)	Mean	Standard deviation (SD)
Caudate lobe A-P length	1.23- 5.52 cm	2.71 cm	0.59
Caudate lobe length	3.14-7.08 cm	4.91 cm	0.87
Caudate lobe width	2.44-5.48 cm	4.04 cm	0.59
Right lobe length	10.91-16.62 cm	14.49 cm	1.1
Right lobe width	6.29-11.7 cm	8.86 cm	1.07
Caudate lobe width / Right lobe width	0.26-0.64	0.46	0.08

Table III. Summary of previous studies of caudate lobe shapes and the findings of the present study.

Shape	Sadanandan and Varghese ¹⁴	Arora et al ¹⁵	Joshi et al ¹⁶	Sahni et al ¹³	Chavan and Wabale ¹⁹	Sarala et al ¹⁷	The present study
Rectangular	61.11%	91.66%	58%	94.5%	48.5%	48%	14.3
Triangle	16.67%	5.55%	22%	-	4%	-	59.7
Elongated	16.67%	2.77%	-	-	-	-	-
Pear	-	-	-	4.5%	26%	18%	-
Heart	-	-	-	-	-	-	-
Square	-	-	-	-	6%	-	-
Bicornuate	-	-	20%	-	-	-	-
Irregular	-	-	-	1%	-	16%	26%
Oval	-	-	-	-	14%	-	-
Dumbbell	5.55%	-	-	-	-	-	-
Caudate process	77.8%	13.8%	32%	59.5%	-	-	92.9%
Papillary process	77.8%	100%	-	33.5%	-	-	12.8%

rectangular. This may be due to the difference in the local population studied¹⁵, as well as to loss of liver vitality during *in vivo* cadaver studies¹³⁻¹⁷, and to the morphologically different behavior of the caudate lobe in a free environment. This discrepancy may also be attributed to living tissue being examined using CT, and to the behavior of the caudate lobe under intraabdominal pressure.

Sadanandan and Varghese¹⁴ observed the presence of papillary and caudate processes in most livers (77.78%). While Arora et al¹⁵ observed caudate processes in all cadaveric livers, the papillary process was present in only 13.8%. Sahni et al¹³ reported that 33.5% of livers had papillary process and 59.5% caudate process. Similarly, Joshi et al¹⁶ reported an incidence of papillary processes of 32%. Srimani and Saha¹⁸ reported that abnormalities of processes were more profound in the caudate lobe than in other lobes. In 16.4%, no caudate and papillary processes were seen. Large papillary processes (hypertrophied and elongated) were seen in 21.8%; whereas caudate lobes without papillary process were in 3.6%. In the present study, and similarly to Arora et al¹⁵, while caudate processes were observed in most cases (92.9%), papillary processes were observed in only 12.8%.

Sadanandan and Varghese¹⁴ reported an average caudate lobe length of 5.4 cm and an average width of 2.58 cm, with an average right lobe length of 11.31 cm and an average width of 7.39 cm in their study of 36 cadaver livers. Arora et al¹⁵ reported an average caudate lobe length of 5.03 cm and an average width of 2.7 cm, and an average right lobe length of 7.79 cm and an average

width of 11.43 cm. Sahni et al¹³ and Chavan and Wabale¹⁹ reported caudate lobe lengths between 4.0 cm and 9.3 cm, and 4.0 cm and 7.2 cm, and widths between 2.5 cm and 4.2 cm, and 1.8 cm and 4.1 cm, respectively. In the present study, the average width of the caudate lobe was 4.04 cm (range 2.44-5.48 cm), the average caudate lobe length was 4.91 cm (range 3.14-7.08 cm), the average right lobe width was 8.86 cm (range 6.29-11.7 cm), and the average right lobe length was 14.49 cm (range 10.91-16.62 cm). The caudate lobe length and right lobe width in the present study were similar to the measurements reported in the previous literature, while other parameters were slightly higher than the literature values. Cadaver studies^{13-17,20} have demonstrated that tissues shrink (by 10% in the liver) after fixation with formalin. This may help explain the difference between *in vivo* cadaver studies and *in vitro* CT examination evaluations.

Arora et al¹⁵ reported that when the rest of the liver is atrophied, hypertrophic changes occur in the caudate lobe, as also described in numerous studies^{19,21,22}. The ratio of the width of the caudate lobe to the width of the right lobe therefore increases, exceeding 0.65 in cirrhotic livers. In the present study, this ratio ranged between 0.26 and 0.64, with an average value of 0.46, and was slightly higher than the data in the previous literature data^{13,14,18}.

In terms of caudate lobe vascular anatomy, while differing results have been reported, left portal vein origin vascular feeding was more common^{13,18,22}. In Sadanandan and Varghese's study¹⁴, a single branch originating from the left portal

vein supplied the caudate lobe in 55.55% of livers. None of the caudate lobes in that study were supplied by the right branch of the portal vein alone¹⁴. Consistent with Sadanandad and Varghese¹⁴, both Chawan and Wabale¹⁹ and Kogure et al²³ reported that venous supply to the caudate lobe was largely through the branch originating from the left portal vein. However, in contrast to Sadanandan and Varghese¹⁴, Kogure et al²³ reported a higher rate (22.9%) of caudate lobe feeding from the right portal vein. In the present research, and in contrast to current cadaver studies¹³⁻¹⁷, the caudate lobe was predominantly supplied through the right portal vein (41.8%). Dodds et al¹ reported that venous drainage of the caudate lobe occurs through small emissary veins that pass directly from the caudate lobe to the inferior vena cava. In the present study, caudate lobe venous drainage was observed in all cases (100%), with small venous structures directly opening from the caudate lobe to the vena cava inferior.

The principal aim of the present study was to evaluate caudate lobe morphology and morphometric measurements using CT as a diagnostic imaging method in the light of recent cadaver studies^{13-17,20}. The limitations of the present study include its retrospective nature, the fact that the presence of liver disease was evaluated only by means of the hospital database, the low number of patients, and the fact that measurements were performed by a single individual. The effect of body size on the morphological and morphometric values of the caudate lobe could not be evaluated since total body mass index (BMI) was not calculated. Since the presence of papillary and caudate processes will affect the caudate lobe volume and considering that we evaluated caudate lobe data from measurements taken from a specific location, volumetric evaluations are needed for an accurate understanding of the real contribution of the caudate lobe.

Conclusions

The caudate lobe can assume different shapes. These shapes described in cadaver studies can also be visualized on CT images, and caudate lobe measurements can be taken from these. The piriform shape was more common on CT images, while the rectangular caudate lobe is more prominent in cadaver studies. Morphometric measurement values of the caudate lobe were clearer than those of cadaver studies. Caudate lobe evaluation

criteria can be obtained using CT *in vivo* based on morphological and morphometric values for the caudate lobes yielded by cadaver studies.

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Informed Consent

All subjects provided informed consent prior to participation.

Authors' Contributions

Project development, data collection, manuscript writing, data management, analysis, manuscript editing.

Ethics Approval

Ethics Committee approval was released from Suleyman Demirel University Clinical Research Ethics Committee (No. 83, dated 12.03.2020).

Conflict of Interests

The authors declare that they have no conflict of interest.

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