Hepatocellular Carcinoma in the Caudate Lobe of the Liver: Angiographic Analysis of Tumor-feeding Arteries According to Subsegmental Location

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PURPOSE: To investigate the tumor-feeding arteries in hepatocellular carcinoma (HCC) arising in the caudate lobe of the liver.

MATERIALS AND METHODS: From January 1998 to March 2004, 140 patients with 146 caudate HCCs underwent chemoembolization. Subsegmental location of the caudate HCC and the origin of the tumor-feeding arteries was determined with computed tomography and hepatic arteriography. On follow-up angiography at 6–96 months (mean, 24 months), changes in the tumor-feeding arteries were recorded.

RESULTS: A total of 175 tumor-feeding arteries were identified. The tumors in the Spiegel lobe were supplied by tumor-feeding arteries derived from the right hepatic artery (RHA; n = 45), left hepatic artery (LHA; n = 30), and proper hepatic artery (PHA) or common hepatic artery (CHA; n = 6; P = .083, right vs left). In tumors in the paracaval portion (n = 42), the tumor-feeding arteries were derived more frequently from the RHA (n = 46) than the LHA (n = 3) or PHA/CHA (n = 2; P < .001). All the feeding arteries (n = 43) of the caudate process tumors (n = 32) were derived from the RHA (P < .001). During the follow-up period, there were replacements of the tumor-feeding arteries in 16 patients with recurrent tumors. An extrahepatic collateral supply for the recurrent tumors developed in 10 patients.

CONCLUSIONS: The distribution of the origin of tumor-feeding arteries supplying caudate HCC is different according to tumors’ subsegmental locations. When treating recurrent caudate HCC, it is important to identify replacement of tumor-feeding arteries and extrahepatic collateral supply.


Abbreviations: CHA = common hepatic artery, HCC = hepatocellular carcinoma, LHA = left hepatic artery, PHA = proper hepatic artery, RHA = right hepatic artery

DESPITE recent advances in treatment of hepatocellular carcinoma (HCC), the prognosis of HCC arising in the caudate lobe (ie, caudate HCC) has been reported to be poor (1–4). Surgical resection has been considered to be the most effective treatment for caudate HCC, but isolated resection of the caudate lobe is a difficult, time-consuming procedure that is related to a great deal of blood loss and a high degree of operative risk (4). Moreover, surgical resection of HCC in the caudate lobe is associated with a high rate of early recurrence (1). Percutaneous ablation therapies such as radiofrequency ablation, ethanol injection, and microwave coagulation can be viable alternative treatments (5–8). However,
because of the deep location of these tumors and the adjacent large vessels, these procedures might be technically difficult and, in some cases, even impossible to perform. Therefore, chemoembolization has been the main treatment for most patients with caudate HCC, especially in patients with multiple tumors involving not only the caudate lobe but also the other hepatic lobes.

To perform effective and safe chemoembolization, the segmental or subsegmental tumor-feeding arteries should be precisely recognized on angiography and selectively embolized. However, the arterial anatomy of the caudate lobe is complex and variable, which makes it difficult to identify tumor-feeding arteries on angiography (3). To our knowledge, there have been few studies about the angiographic anatomy of the caudate HCCs demonstrated on angiography, with an emphasis on their anatomic variations according to the specific subsegmental locations of the tumors.

MATERIALS AND METHODS

This retrospective study was approved by our institutional review board, and informed consent was waived.

Patients

From January 1998 to March 2004, a total of 3,443 patients with HCC underwent chemoembolization at our institution. Of these patients, 163 patients had HCCs in the caudate lobe. The diagnosis of HCC was made by means of the characteristic features of HCC on imaging studies (liver computed tomography [CT] and digital subtraction angiography) or laboratory testing (high serum level of α-fetoprotein and viral markers). We excluded 23 patients on the basis of the following criteria: (i) caudate HCC larger than 5 cm that could not be localized to a specific subsegmental location (n = 19), (ii) indistinct tumor feeding vessel on selective right and left hepatic angiograms (n = 2), (iii) lack of selective right and left hepatic angiography (n = 1), and (iv) obliteration of hepatic arteries by repeated chemoembolization (n = 1). Consequently, a total of 140 patients with caudate HCC were included in this study. The patients consisted of 111 men and 29 women who ranged in age from 41 to 81 years (mean, 58 y). All patients had liver cirrhosis related to viral hepatitis B (n = 108) or C (n = 32). Ninety-two patients had Child class A disease, 39 patients had class B disease, and nine had class C disease. Before the identification of the caudate HCCs, 74 patients had been treated for HCC in the other hepatic segments (chemoembolization [n = 56], percutaneous ethanol injection [n = 30], and/or surgical resection [n = 18]).

CT Protocol

In all patients, a triple-phase liver CT examination (ie, unenhanced, arterial, and portal venous phases) was performed within 1 month before chemoembolization. Single-detector (Somatom Plus; Siemens, Erlangen, Germany) or multidetector CT equipment (MX8000; Marconi Medical Systems, Cleveland, Ohio; or LightSpeed; GE Medical Systems, Milwaukee, Wisconsin) was used. The scanning parameters for the single-detector CT scanner were 5-mm slice thickness and reconstruction interval, table feed of 7 mm/rotation, rotation time of 1 second, 165 mA, and 120 kVp. The respective scanning parameters used for the four- and eight-detector scanners were detector configurations of 4 × 2.5 mm and 8 × 1.25 mm; slice thicknesses of 3.2 and 2.5 mm; reconstruction intervals of 3 and 2.5 mm; table speeds of 12.5 and 13.5 mm/rotation; 150 and 250 effective mA with rotation times of 0.5 and 0.8 seconds; 120 kVp; and a matrix of 512 × 512. At first, a baseline unenhanced scan was obtained of the entire liver. After the systemic administration of 120 mL of nonionic contrast material (Ultravist; Schering Korea, Seoul, Korea) was infused until stasis of arterial flow was achieved. An emulsion of 1.0–7.0 mL of iodized oil (Lipiodol Ultrafluid; Laboratoire Andre Guerbet, Aulnay-sous-Bois, France) and doxorubicin hydrochloride (Adriamycin RDF; Ildong Pharmaceutical, Seoul, Korea) was infused according to the tumor size. In patients with HCC involving other liver segments, we infused a chemotherapeutic agent (maximum of 12 mL of iodized oil and 60 mg of doxorubicin hydrochloride) through the hepatic artery and all the extrahepatic collateral arteries in the same session.

A liver CT examination was performed within 1 month after chemoembolization, and iodized oil accumulation in the entire tumor nodule without a defect was confirmed to exclude a missed tumor-feeding artery. Follow-up CT was performed at 2–3-month intervals thereafter. When a recurrent tumor was identified on CT, hepatic angiography and chemoembolization were repeated in the same manner described earlier. All the che-
moebolization procedures were performed by one of two radiologists.

Data Analysis

CT scans and angiograms of 140 patients were retrospectively reviewed in consensus by two radiologists. On the initial CT (obtained before chemoembolization), the subsegmental location of the caudate HCC was determined according to the classification of Kumon (10), including the Spiegel lobe, the paracaval portion, and the caudate process (Fig 1). If a tumor occupied two or more subsegments, the location of the tumor was assigned to the dominant subsegment. Tumor size was defined as the largest tumor diameter on transverse CT scans. Analysis of variance was used to determine differences in tumor size among three subsegmental locations.

On hepatic angiograms obtained during the initial chemoembolization procedure, the origins of the tumor-feeding arteries for caudate HCC were identified. They were classified into the (i) anterior, (ii) posterior, and (iii) main right hepatic artery (RHA); (iv) left hepatic artery (LHA); and (v) proper hepatic artery (PHA) or common hepatic artery (CHA). We compared the frequencies of the origin of the tumor-feeding arteries (RHA vs LHA) among three subsegmental tumor locations with use of the $\chi^2$ test. Differences at a $P$ value less than .05 were considered statistically significant. On follow-up hepatic angiograms obtained during repeated chemoembolization procedures, the origins of tumor-feeding arteries were identified and classified by the methods described earlier. After the follow-up angiograms were compared with the initial angiograms, changes in tumor-feeding arteries were recorded.

RESULTS

CT Findings of Caudate HCC

On the initial CT scans, a total of 146 HCCs were identified in 140 patients. Four patients had multiple caudate HCCs (two in four patients, three in one patient). Forty patients had isolated caudate HCC, and 100 patients had multiple tumors in the right lobe ($n = 57$), left lobe ($n = 16$), or both lobes ($n = 27$) as well as in the caudate lobe. The subsegmental locations of the caudate HCC were as follows: 72 tumors in the Spiegel lobe, 42 in the paracaval portion, and 32 in the caudate process. The size of the tumors ranged from 0.5 cm to 4.0 cm (mean, 2.6 cm). The size of the tumors was not significantly different among the three subsegmental locations ($P = .07$).

Origins of Tumor-feeding Arteries

During the initial chemoembolization procedures, a total of 175 feeding arteries of 146 tumors were identified (Table). Twenty-three tumors (15.8%) had multiple tumor-feeding arteries. All feeding arteries arose from the proximal hepatic arteries including the CHA, PHA, main RHA, LHA, and proximal segment of segmental hepatic arteries.

In patients with tumors in the Spiegel lobe, a total of 81 tumor-feeding arteries were identified. They were derived from the RHA (45 arteries; 55.5%), LHA (30 arteries; 37.0%), and PHA/CHA (six arteries; 7.4%). The frequencies of right- and left-sided origin were not significantly different ($P = .083$). In the case of right hepatic origins, the tumor-feeding arteries were derived from the anterior RHA (22.2%), main RHA (21.0%), and posterior RHA (12.3%; $P = .282$; Fig 2). Eight tumors in the Spiegel lobe (11.1%) were supplied by multiple tumor-feeding arteries (two arteries for seven tumors, three arteries for one tumor). Among these eight tumors, four had feeding arteries derived from the RHA and LHA (Fig 3). One Spiegel lobe tumor had an extrahepatic collateral supply through the right inferior phrenic artery as well as intrahepatic tumor-feeding arteries.

The 42 tumors in the paracaval portion were supplied by a total of 51 feeding arteries. Most derived from the RHA ($n = 46; 90.2$%). Only five tumor-feeding arteries originated from the LHA ($n = 3$) and PHA/CHA ($n = 2$). Right-sided origin was significantly more frequent than left-sided origin ($P < .001$). Among the RHA origins, the tumor-feeding arteries were derived from anterior RHA ($n = 15; 29.4$%), posterior RHA ($n = 15; 29.4$%), and main RHA ($n = 16; 31.4$%; $P = .978$). Nine tumors (21.4%) were supplied by two tumor-feeding arteries. Among these, one tumor had feeding arteries derived from the RHA and LHA.

The 32 tumors in the caudate process were supplied by tumor-feeding arteries from the RHA in all cases. The most common origin of the feeding artery was the posterior RHA (58.1%; $P = .002$). Six tumors (18.8%) had two ($n = 3$), three ($n = 2$), or four ($n = 1$) feeding arteries. One caudate process tumor was...
partly supplied by the adrenal artery derived from the proximal part of the right inferior phrenic artery, as well as by intrahepatic feeding arteries. Right-sided origin of the tumor-feeding arteries was significantly more frequent in tumors in the paracaval portion and caudate process than in tumors located in the Spiegel lobe ($P < .001$).

### Changes in Tumor-feeding Arteries

After the initial chemoembolization procedure, follow-up of more than 6 months was achieved in 89 patients (range, 6–96 months; mean, 24 months). During the follow-up period, 34 locally recurrent HCCs were identified on periodic CT scans (interval of 1–3 months) in 33 patients; the tumors were treated with repeated chemoembolization (1–12 times; mean, 3.9). On follow-up hepatic angiograms obtained during repeated chemoembolization procedures, the recurrent tumors were supplied by the same tumor-feeding arteries as those on the initial angiograms in 17 patients. In 15 patients (16 tumors), the tumor-feeding arteries on the initial angiograms were not opacified on follow-up angiograms and the caudate HCCs were supplied by newly developed tumor-feeding arteries. In 10 tumors in which the initial tumor-feeding arteries derived from the RHA ($n = 8$) or LHA ($n = 2$), newly developed tumor-feeding arteries were derived from the same-sided hepatic arteries (Fig 4). In six tumors, the origin of the tumor-feeding arteries changed from the RHA to the LHA ($n = 5$) or from the LHA to the RHA ($n = 1$). On follow-up angiograms, 10 recurrent tumors were supplied by extrahepatic collateral arteries as well as by intrahepatic tumor-feeding arteries. The subsegmental locations of these tumors were Spiegel lobe ($n = 5$), caudate process ($n = 4$), and paracaval portion ($n = 1$). The extrahepatic collateral arteries of the Spiegel lobe tumors were the right inferior phrenic artery ($n = 3$), pancreatic artery ($n = 1$), and left gastric artery ($n = 1$; Fig 5). The caudate process tumors were supplied by the adrenal artery derived from the proximal part of the right inferior phrenic artery ($n = 2$) and gastroduodenal artery ($n = 2$). The paracaval portion tumor was supplied by the right inferior phrenic artery ($n = 1$).

### DISCUSSION

It is difficult to achieve complete necrosis of caudate HCC with chemoembolization. Takayasu et al (11) performed conventional chemoembolization (from lobar hepatic arteries) in five patients with caudate HCC and

<table>
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<tr>
<th>Origin of Feeding Arteries at Initial Presentation</th>
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<tr>
<td><strong>Subsegment of Caudate Lobe</strong></td>
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<tr>
<td><strong>Anterior</strong></td>
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<td>Paracaval portion</td>
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<td><strong>Total</strong></td>
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Note.—Values in parentheses are percentages.
reported poor clinical responses (mean survival period of 5.5 months). According to a more recent report by Terayama et al (3), subsegmental chemoembolization (from the caudate artery or more distal branch) was tried in 13 patients with caudate HCC but showed a relatively low technical success rate (71%) and high local recurrence rate (75% within 6 months). The researchers observed that it was difficult to achieve complete embolization because the caudate arteries are frequently multiple and their origins are variable (3). Moreover, because the caudate lobe is centrally located in the liver, the caudate arteries usually overlap with the other hepatic arteries on hepatic angiograms, which makes it difficult to identify the origin of the tumor-feeding arteries. Therefore, knowledge of the angiographic anatomy of the caudate artery is important to perform effective chemoembolization of caudate HCC.

A cadaver dissection study by Michels (12) reported that the caudate artery derived from the RHA in 35% of the patients studied, from the LHA in 12%, and from the RHA and LHA in 53%. There were multiple caudate arteries in 75% of the patients (12). The frequencies of multiplicity and left-sided origin of the caudate artery seem to be much higher than those in an angiographic study by Miyayama et al (9) in which the caudate artery derived from the RHA in 50% of patients and the LHA in 7.5% of patients. Multiple caudate arteries were seen in 14.2% of patients. To explain this discrepancy, the authors stated that angiographic identification of the caudate artery derived from the LHA is difficult because the left hepatic lobe is short in depth (3). Similar to previous angiographic studies, our results showed a strong right-sided predominance of the origin of the tumor-feeding arteries, with 76.6% (n = 134) of tumor-feeding arteries derived from the RHA and 18.9% (n = 33) derived from the LHA. Our study is different from previous studies in that all the patients had caudate HCC. When HCCs occurs in the caudate lobe, the tumor-feeding arteries are usually engorged, and the other caudate arteries might be obscured on hepatic angiograms. Therefore, our angiograms did not demonstrate all the caudate arteries, only the tumor-feeding arteries. We think our results are more relevant to clinical practice than those of previous studies because angiographic identification of all the caudate arteries is actually impossible and frequently impractical, and exact identification of the tumor-feeding artery is more important.

The caudate lobe is anatomically subdivided into three parts according to portal vein ramification: Spiegel lobe, paracaval portion, and caudate process (9). The Spiegel lobe is defined as the portion under the lesser omentum and the left-sided portion of the intrahepatic inferior vena cava. The paracaval portion is defined as the front portion of the intrahepatic inferior vena cava extending just right of the Spiegel lobe from the caudate process to the area between the roots of the right and middle hepatic veins. The caudate process is a tongue-like projection between the vena cava and adjacent portal vein (13).

Terayama et al (3) suggested that the origin of tumor-feeding arteries might be different among the three subsegmental locations of the caudate HCC. In this study, we confirmed their observation in a larger population; HCC in the caudate process and paracaval portion were almost exclu-

**Figure 3.** Images of a 60-year-old man with a small HCC in the Spiegel lobe supplied by multiple feeding vessels from the RHA and LHA. (a) Transverse CT image obtained 2 weeks before chemoembolization shows a hypervascular tumor at the Spiegel lobe of the caudate lobe (arrow). There was another hypervascular tumor at right anterior section of the liver (arrowhead). (b) On a selective arteriogram, the tumor-feeding caudate artery is derived from the posterior RHA (arrow). Note there is a defect in tumor stain (arrowhead), which suggests the presence of the other tumor-feeding artery. Selective embolization of the tumor-feeding artery derived from the posterior RHA was performed. (c) Posteroanterior arteriogram of the segment IV hepatic artery shows another tumor-feeding caudate artery (arrow), which supplies the defect of the tumor stain in b. (d) Transverse CT image obtained 2 weeks after chemoembolization shows dense accumulation of iodized oil in the tumor without defect (arrow).
seriously fed by caudate arteries derived from the RHA. To the contrary, HCCs in the Spiegel lobe were fed by the RHA (55.5%) and LHA (37%). A notable result of our study is that tumor-feeding arteries are more likely to be derived from the RHA than from the LHA, even in Spiegel lobe HCC.

Therefore, in chemoembolization of caudate HCC, the right hepatic arteriogram should be meticulously reviewed, and at least two different projection views should be obtained. When the HCC is located in the Spiegel lobe, the right and left hepatic arteriograms should be obtained separately without overlapping each other. However, because digital subtraction angiography provides only two-dimensional information, it is occasionally difficult to comprehend the complex vascular anatomy. In these cases, intraarterial cone-beam CT might be useful to identify the tumor-feeding artery or to recognize the presence of multiple feeding arteries (14).

Seventeen recurrent caudate HCCs in our study showed replacements of tumor-feeding arteries on follow-up angiograms. When a tumor-feeding artery is embolized by chemoembolization, adjacent arterial branches can be recruited by recurrent tumors. Therefore, these new tumor-feeding arteries might be one of the caudate branches supplying the other subsegments of the caudate lobe, which was indistinct on initial angiograms. Another possibility is that new tumor-feeding arteries were derived from the intrahepatic communicating artery. Tohma et al (15) demonstrated a "communicating arcade" between the RHA and LHA on CT and angiography during temporary balloon occlusion of the RHA or LHA. They showed that the communicating arcade plays an important role not only in the interlobar arterial collateral system but also in the blood supplies to the caudate lobe. Therefore, the communicating arcade might be a source of replacement of tumor-feeding arteries.

It is well known that HCC can be supplied by various extrahepatic collateral routes, especially when hepatic arteries are attenuated as a result of repeated chemoembolization (16–20). In our study, 12 extrahepatic collateral arteries supplying caudate HCCs were identified during initial (n = 2) and repeated chemoembolization (n = 10). Among these, the inferior phrenic artery was the most frequent collateral route. Takeuchi et al (21) performed CT arteriography via the right inferior phrenic artery during temporary balloon occlusion of the PHA. Their results (21) demonstrated that the right inferior phrenic artery potentially communicates with arterial branches supplying the posterior segment of the right lobe and caudate lobe of the liver. When blood flow through the hepatic artery decreases, just as in chemoembolization, caudate tumors can be supplied by the right inferior phrenic artery. Therefore, in chemoembolization of caudate HCC, a right inferior phrenic arteriogram should be obtained, especially in repeated chemoembolization procedures for locally recurrent tumors. When the tumor is located at the caudate process, one should pay attention to the adrenal artery derived from the right inferior phrenic artery.

This study has an important limitation: we determined the subsegmental location of the HCCs on CT scans. Although we used anatomic landmarks such as portal veins, hepatic veins, and the vena cava for exact and consistent localization, it might be inaccurate in some cases because of vague borders among the subsegments of the caudate lobe. However, it is impossible to differentiate the subsegments clearly with use of current imaging techniques. Moreover, the distribution of the origin of the feeding arteries showed apparent differences among the subsegmental locations determined on CT. Therefore, we think localization with use of anatomic landmarks on CT is a clinically acceptable and practical method.

In conclusion, the origins of the tumor-feeding arteries of caudate HCC are different according to the subsegmental location of the tumor. HCC in the caudate process and the paracaval portion are almost exclusively sup-

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**Figure 4.** Images of a 52-year-old woman with an HCC in the paracaval portion of the caudate lobe supplied by multiple feeding vessels. (a) Posteroanterior arteriogram of the hepatic artery shows a hypervascular tumor stain, which is supplied by two tumor-feeding arteries derived from the main RHA. These arteries were selected and embolized. (b) Transverse CT image obtained 2 weeks after chemoembolization shows iodized oil accumulation in the entire tumor without defect. (c) Posteroanterior arteriogram of the hepatic artery obtained 3 months later showed a recurrent tumor stain (arrow). The tumor-feeding arteries are replaced by a newly developed tumor-feeding artery derived from the distal part of the anterior RHA (arrowhead).
plied by caudate arteries derived from the RHA. On the contrary, HCC in the Spiegel lobe can be supplied by tumor-feeding arteries derived from the RHA and LHA. When treating recurrent caudate HCC, it is important to identify replacement of tumor-feeding arteries and extrahepatic collateral routes such as the inferior phrenic artery.

References
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CME TEST QUESTIONS
Examination available at [http://directory.sirweb.org/jvircme](http://directory.sirweb.org/jvircme)

1. Subsegments of the caudate lobe according to Kumon’s classification include all of the following except?
   a. Caudate process
   b. Paramedian lobe
   c. Paracaval portion
   d. Spigel lobe

2. Regarding arterial supply to tumors in the caudate lobe, which of the following did the authors note during initial chemoembolization procedures?
   a. Tumors arising in the paracaval portion were statistically more likely to demonstrate extrahepatic supply than tumors in the remainder of the caudate lobe.
   b. The most common origin of the feeding artery for caudate process tumors was the right main hepatic artery.
   c. Tumors arising in the Spigel lobe were statistically more likely to derive supply from multiple feeding arteries than tumors arising in the remainder of the caudate lobe.
   d. Tumors arising in the Spigel lobe were more likely to derive supply from the left hepatic artery than tumors arising in the remainder of the caudate lobe.

3. What difference did the authors note when contrasting their angiographic study with a large published cadaver study?
   a. Lower frequency of supply from multiple caudate arteries in the current angiographic study
   b. Higher frequency of left hepatic artery caudate supply in the current angiographic study
   c. Lower frequency of extrahepatic caudate supply in the current angiographic study
   d. Right more common than left hepatic caudate supply in the current study

4. In the current study, which extrahepatic collateral was most often identified providing supply to a caudate lobe hepatocellular carcinoma?
   a. Left inferior phrenic artery
   b. Right superior adrenal artery
   c. Right inferior phrenic artery
   d. Left gastric artery