matic circulationから主に栄養され，細い腎被膜動脈，副腎動脈，肋間動脈，腰動脈，背側膵動脈などのminor diaphragmatic circulationからも一部栄養される。さらに再発するとminor diaphragmatic circulationから主に栄養され，回復した肝動脈からも一部栄養される。また下横隔動脈，内胸動脈，肋間動脈などは他の血管を塞栓後に顕著化する。腫瘍の位置とTACE歴を参考に栄養血管を検索する必要がある。肝外側副路の予防的な塞栓は，合併症を増加させるばかりか他の側副路の発達を助長する。腫瘍への供血が明らかな場合にのみ，肝動脈で使用する半量程度の薬剤を用いてTACEを行う。

肝外側副路選択に有用なカテーテル技術

肋間動脈など屈曲の強い血管では，ガイドワイヤーの先端をU字型にした状態で進めると血管損傷が生じにくい。角度が急峻でガイドワイヤーが挿入できない血管では，形状を付けたマイクロカテーテルで選択するが，これにはブレードの入っていないカテーテルが適している。ガイドワイヤーが挿入できてもマイクロカテーテルが追従しない場合には，ガイドワイヤー法にてより細く柔軟なマイクロカテーテルに交換する。腹腔動脈や腎動脈の起始部から急峻に分岐する血管の選択には側孔付カテーテルが[10]，大動脈から急峻に分岐する血管では側溝付カテーテルが有用である[11]。直接選択できない場合は金属コイルやバルーンカテーテルでの血流改変を併用する[6,12]（**図9**）。

おわりに

肝外側副路経由のTACEが予後の延長に寄与するというエビデンスはない。しかしそれは肝外側副路のTACEを否定するものではなく，肝癌診療に携わるものは肝外側副路のTACEが有効であった症例を多数経験しているであろう。肝外側副路のTACEほど技術の差が出る手技はなく，難しい血管も工夫を凝らし塞栓することで予後が延長すると確信している。肝外側副路の解剖やカテーテル技術に精通することはもちろん大切であるが，効果的な肝動脈からのTACEを行い，局所再発を生じさせない日々の努力が最も重要である。

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特集2 IVRの最新デバイス Part 2

ASAHI CHIKAI Vの使用経験

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はじめに

ガイドワイヤーに求められる要素は優れたコーティングとトルク伝達性である。ワイヤー先端部の微かな動きや抵抗から血管分岐位置が認識でき、わずかに先端が入った状態でも、マイクロカテーテルを送り込むことができるものが優れたワイヤーと評価される。個人的な見解としては、コーティングの点ではGT WIRE(テルモ社製)が最も優れており、当院での第1選択のマイクロガイドワイヤーはリシェイプタイプ0.016インチGT WIRE 70°アングルであり、腹部領域では2F Progreat α(テルモ社製)、最近では1.8F Carnelian® PIXIE(東海メディカルプロダクツ社製)を組み合わせている。しかし、GT WIREは先端形状の形成が難しく、リシェイプタイプといえども複雑な形状付けはやはり困難である。また先端部がやや硬く、強く屈曲した部分を越えるのに難渋することもある。そのような場合、我々は0.012インチGT WIRE 90°アングルを使用してきたが、先端形状付けができない、シャフトが弱いなどの問題点があった。最近ASAHI CHIKAI V(朝日インテック社製 センチュリーメディカル社販売)が発売され、GT WIREでの選択が困難な例を中心に使用している。本稿では我々の使用経験について概説する。

ASAHI CHIKAI Vのスペック

朝日インテック社製のガイドワイヤーと聞けば真っ先にビギンが連想されるが、CHIKAI Vは0.014インチのステンレススチールコアシャフトにスプリングワイヤーを巻いた先端部と、ビギンとは全く異なる構造となっている。先端部には独自の中腔ワイヤーロープが使われており、非常に柔軟性がある。コーティングはこの手のガイドワイヤーに多用されているPTFEコートではなく、SilverSpeed(ev3)などと同様に親水性ポリマーコートが施されている(図1)。当初は頭部用として開発されたため、使い始めたころの全長は200cmであったが、その後腹部用として180cm長のものが追加された。先端形状はストレートで、使用開始時に用手的に先端を形成する。先端部から5cm長がradiopaqueとなっており、透視での視認性も非常によい。

ASAHI CHIKAI Vの使用感

先端は他のスプリングワイヤータイプのものと比べるとやや形成しにくいが、血管内での形状保持はよく、形状付けが容易なワイヤーにありがちな、蛇行部分で操作すると先端柔軟部が"ヨレヨレ"になってしまうことはない。形状付けが難しいといってもリシェイプタイプGT WIREよりはかなり容易である。トルク伝達性はよく、コーティングもステンレスタイプのワイヤーとしては比較的よくすべり、耐久性もあって長時間の使用でも劣化が少ない。特にワイヤー先端をS字状に形成しなければ選択できない分枝や径の細い分枝の選択の際に、威力を発揮する(図2)。しかし、先端部はかなり柔らかいため、ガイドワイヤーが十分奥

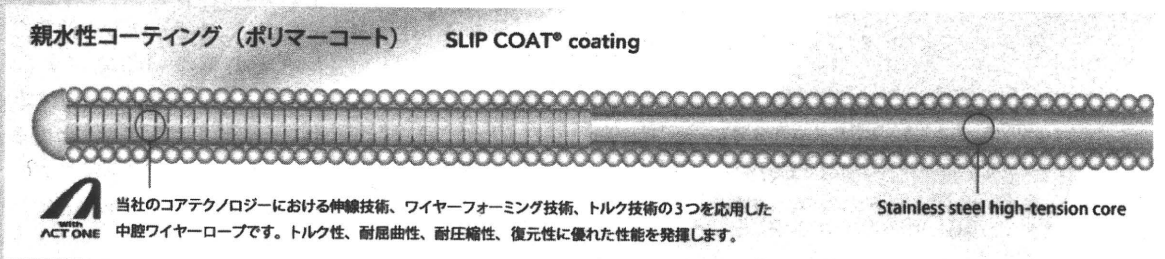

図1 ASAHI CHIKAI Vの先端部(朝日インテック社資料より)

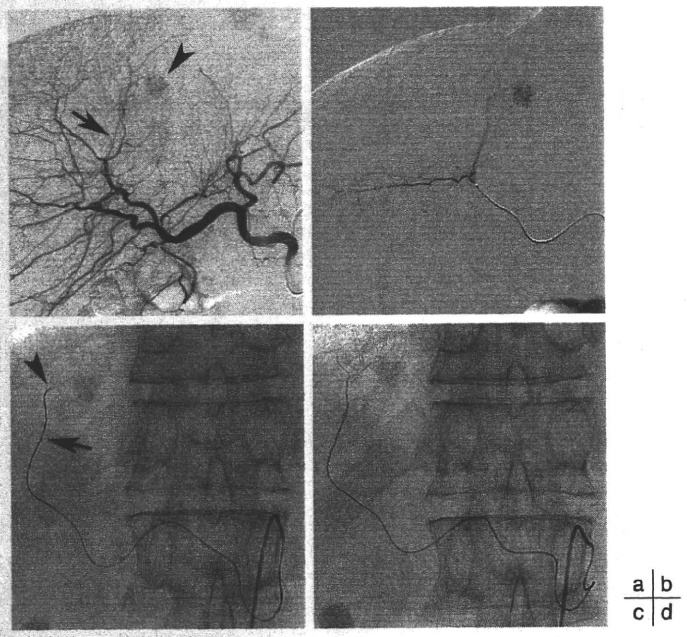

図2 肝細胞癌に対する超選択的TACE
a A8の1枝(矢印)から栄養される小さな腫瘍を認める(矢頭)。
b 栄養血管は細く分岐部は強く屈曲している。
c GT WIREでは屈曲部を越えられなかったため起始部よりTACEを開始したが、backflowが多いために先端をS字状に形成したASAHI CHIKAI Vを使用したところ、選択に成功した(矢頭はASAHI CHIKAI V、矢印はマイクロカテーテル先端を示す)。
d 塞栓時のスポット撮影。

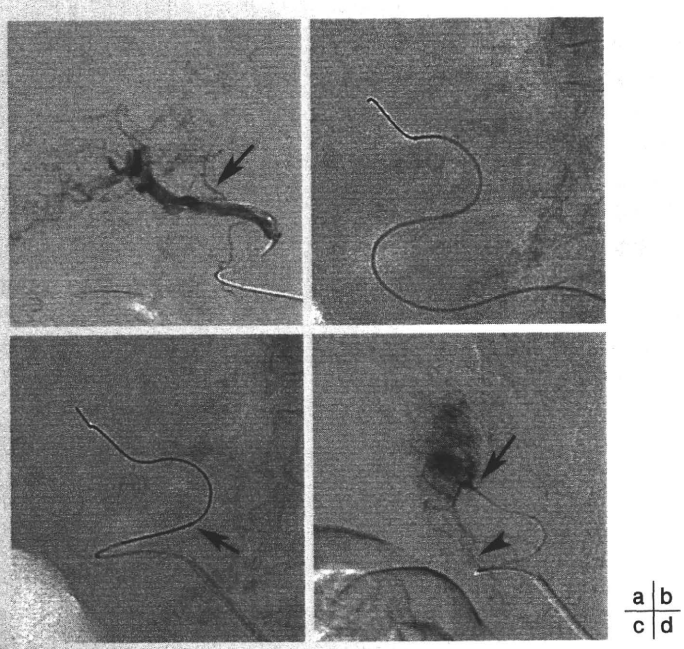

図3 肝細胞癌に対する超選択的TACE
a 右肝動脈より分岐する尾状葉枝(矢印)が腫瘍の栄養血管となっていた。
b GT WIREは挿入可能であったが、1.8Fマイクロカテーテルが挿入困難であった。
c そこでASAHI CHIKAI Vとnanoの組み合わせに変更したところ、選択に成功した(矢印は挿入途中のマイクロカテーテル先端を示す)。
d 選択造影にて腫瘍濃染を認め、TACEを施行した(矢印はカテーテル先端を示す)。尚、胆管動脈も描出されている(矢頭)。

まで挿入できない場合には、カテーテルが追従しにくい印象がある。また径が0.014インチのため、内腔の広いマイクロカテーテルと組み合わせて使用した場合にはカテーテル先端部に隙間ができ、屈曲の強い血管入口部では引っかかり感が生じる可能性がある。

ASAHI CHIKAI Vへの期待

まだ少数例での使用経験であるが、ASAHI CHIKAI Vは超選択的なカテーテル挿入用のガイドワイヤーとして十分な性能を有している印象がある。特にGT WIREの先端部がやや硬いと感じていたり、先端形状付けが難しいと感じている術者には、歓迎されるガイドワイヤーであろう。また0.014インチ径であるため、PCI用のデバイスや1.6Fマイクロカテーテルnano(クリエートメディック社製)と組み合わせることも可能である。2F以下の細径カテーテルの必要性については議論のあるところであるが、1.8Fカテーテルでは選択できない細枝が1.6Fカテーテルで選択できる場合も多く(図3)、個人的には細径カテーテルには強い関心がある。最初に1.6Fマイクロカテーテルを別のガイドワイヤーと組み合わせて使用した際は、カテーテルを押してもなかなか前に進まない"もたつき感"があったが、ASAHI CHIKAI Vと組み合わせることで、もたつき感はかなり軽減された。今後、微細な血管の選択の際に試してみたいデバイスの組み合わせである。

おわりに

現状ではマイクロカテーテルの性能がガイドワイヤーの性能を追い越して、ガイドワイヤーがカテーテル挿入の律速段階となり、カテーテルの性能を十分に引き出せていない印象がある。ASAHI CHIKAI Vはその問題に対する現段階での一つの答えであり、このガイドワイヤーの登場を契機に、各社のガイドワイヤー開発技術に拍車がかかることを期待している。

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PICTORIAL ESSAY

Hepatocellular carcinoma in the caudate lobe of the liver: variations of its feeding branches on arteriography

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Abstract There are usually multiple caudate arteries arising from the right, left, and middle hepatic arteries, and they are frequently connected to each other. Therefore, hepatocellular carcinoma (HCC) in the caudate lobe is frequently fed by multiple branches arising from different origins. HCC located in the Spiegel lobe is usually fed by the caudate arteries derived from the right and/or left hepatic artery. HCC in the paracaval portion is mainly fed by the caudate artery derived from the right hepatic artery; with low frequency, it is fed by the caudate artery derived from the left hepatic artery. HCC in the caudate process is usually fed by the caudate artery derived from the right hepatic artery. Because of the complexity and overlap of vascular territories, the tumor-feeding branch of a recurrent HCC lesion in the caudate lobe frequently changes on follow-up arteriograms. In addition, several extrahepatic collateral vessels supply the recurrent tumor. To perform effective transcatheter arterial chemoembolization (TACE) for HCC in the caudate lobe, radiologists should have sufficient knowledge of vascular anatomy supplying HCC in the caudate lobe.

Key words Hepatocellular carcinoma · Caudate lobe · Vascular anatomy · Chemoembolization

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Introduction

The caudate lobe is centrally located in the liver, between the right and left lobes. Because of this anatomical location, hepatocellular carcinoma (HCC) arising in the caudate lobe is difficult to treat. Surgical resection of the caudate lobe has a high mortality rate, in addition to a high recurrence rate of the tumor.[1,2] Percutaneous ablation therapy (e.g., radiofrequency ablation) is a useful alternative treatment,[3,4] but the procedure might be technically difficult because of the deep tumor location and adjacent large vessels. Therefore, transcatheter arterial chemoembolization (TACE) plays an important role in the treatment of HCC in the caudate lobe.[5,6]

Because there are usually multiple caudate arteries arising from the right, left, and middle hepatic arteries, HCC in the caudate lobe is frequently fed by multiple branches arising from different origins.[5–9] In addition, the feeding branches become more complex when the tumor recurs after TACE. These factors might make it more difficult to control HCC in the caudate lobe by TACE. To perform effective TACE for HCC in the caudate lobe, radiologists should have sufficient knowledge of vascular anatomy supplying HCC in the caudate lobe.

Subsegments of the caudate lobe

The caudate lobe is divided into three subsegments according to portal vein ramification: Spiegel lobe, paracaval portion, caudate process. The Spiegel lobe is the protuberant hepatic portion to the left of the intrahepatic vena cava.[10] The paracaval portion is in front of the intrahepatic vena cava and is surrounded by the right

and middle hepatic veins.[10,11] The caudate process is a tongue-like projection between the vena cava and adjacent portal vein.[10] Theoretically, there are multiple caudate arteries supplying these three subsegments.

Caudate artery anatomy

A cadaver dissection study by Mizumoto and Suzuki[7] reported that the caudate arteries arose from the posterior segmental artery of the right hepatic artery and left hepatic artery in 32.1%, from the posterior segmental artery of the right hepatic artery and middle hepatic artery in 26.4%, and from the three arteries in 20.8%. However, in a previous angiographic observation, the incidences of the caudate artery derived from the left hepatic artery and the posterior segmental artery of the right hepatic artery were low. Because the left hepatic lobe has limited depth, identification of the caudate artery is difficult even on stereoarteriograms.[9] In addition, the caudate artery derived from the posterior segmental artery is frequently difficult to recognize because it mimics the posterior segmental artery of the right hepatic artery.[9]

With advances in digital subtraction angiography systems and catheter technology, two or more caudate arteries arising from the right hepatic, middle hepatic, and/or left hepatic artery can be demonstrated in almost all cases. In the right hepatic artery, the caudate artery arises between the proximal portion of the right hepatic artery and the main trunk of the anterior or posterior segmental artery of the right hepatic artery (Figs. 1–7). On the left side, the caudate artery usually arises between the proximal portion and umbilical portion of the left hepatic artery (Figs. 3, 8). The caudate artery also arises from the proximal portion of the middle hepatic artery or medial segmental artery (Fig. 9). It infrequently arises with the cystic artery as a common trunk (Fig. 10). Additionally, it infrequently arises from the proper hepatic (Fig. 11), common hepatic, or extrahepatic artery (Fig. 12).

Among the caudate arteries derived from the right hepatic artery, the paracaval branch runs upwardly (Fig. 4), and the Spiegel lobe branch runs to the left (Figs. 1–5, 11). These branches frequently arise as a common trunk (Figs. 4, 13). Selective arteriography of the Spiegel lobe branch shows a typical hepatogram indicating the contour of the Spiegel lobe (Figs. 1, 9, 11, 13). The caudate process branch usually mimics the posterior segmental artery of the right hepatic artery (Fig. 13). Among the caudate arteries derived from the left hepatic artery, the Spiegel lobe branch usually mimics the lateral segmental artery (Fig. 3), and the paracaval branch mimics the medial segmental artery (Figs. 9, 13).

The caudate arteries are frequently connected to each other as well as to the medial segmental artery (Fig. 7).[12–14]

Hepatocellular carcinoma

HCC in the Spiegel lobe

HCC located in the Spiegel lobe is usually fed by the caudate arteries derived from the right and/or left hepatic artery.[5,6] Almost all feeding branches mainly arise from the proximal portion of the right and left hepatic artery (Figs. 1–3). In addition, the caudate artery arising from the proximal portion of the middle hepatic or medial segmental artery supplies tumors in the Spiegel lobe (Fig. 9). Because the Spiegel lobe protrudes from the liver, a large tumor is frequently found to be fed by extrahepatic collateral vessels at the initial discovery.

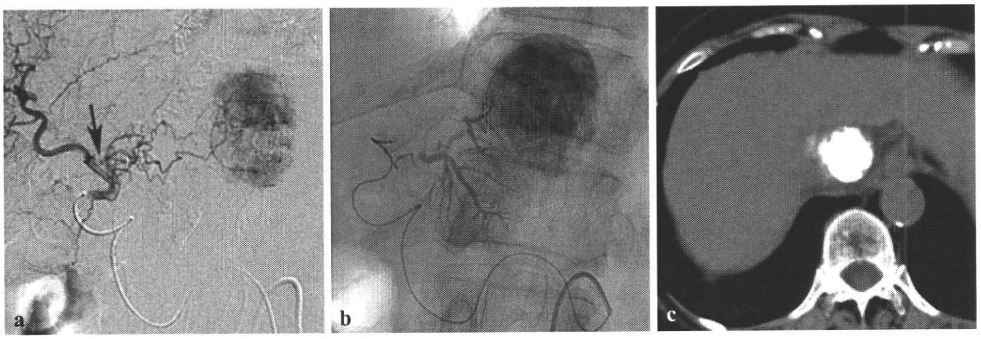

Fig. 1. Hepatocellular carcinoma (HCC) in the Spiegel lobe. **a** Arteriogram of the right hepatic artery shows a tumor stain in the Spiegel lobe supplied by the caudate artery derived from the right hepatic artery (*arrow*). **b** The caudate artery was selected, and transcatheter arterial chemoembolization (TACE) was performed. The contour of the Spiegel lobe is clearly seen. **c** Computer tomography (CT) 1 week after TACE shows dense iodized oil accumulation in the tumor

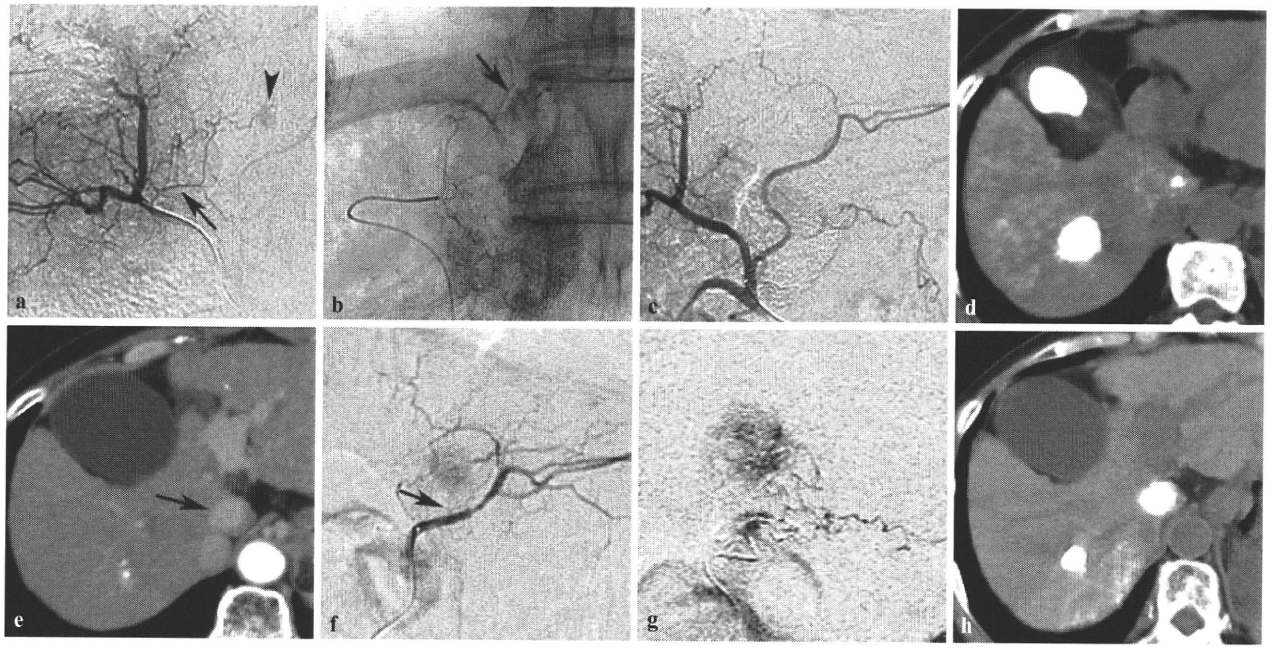

Fig. 2. HCC in the Spiegel lobe. **a** Arteriogram of the right hepatic artery obtained after TACE of the anterosuperior subsegmental artery of the right hepatic artery shows a tumor stain (*arrowhead*) supplied by the caudate artery derived from the anterior segmental artery of the right hepatic artery (*arrow*). **b** The caudate artery was selected, and TACE was performed. The contour of the Spiegel lobe was clearly seen. *Arrow* points to the tumor. **c** Proper hepatic arteriogram obtained immediately after TACE shows no residual tumor stain. **d** CT 1 week after TACE shows dense iodized oil accumulation in both tumors. **e** Arterial phase CT 3 years after TACE shows a recurrent tumor in the Spiegel lobe (*arrow*). **f** Follow-up arteriogram shows a tumor stain supplied by the caudate artery derived from the left hepatic artery (*arrow*) that was not seen in **c**. **g** The branch was selected, and TACE was performed. **h** CT 1 week after additional TACE shows dense iodized oil accumulation in the tumor

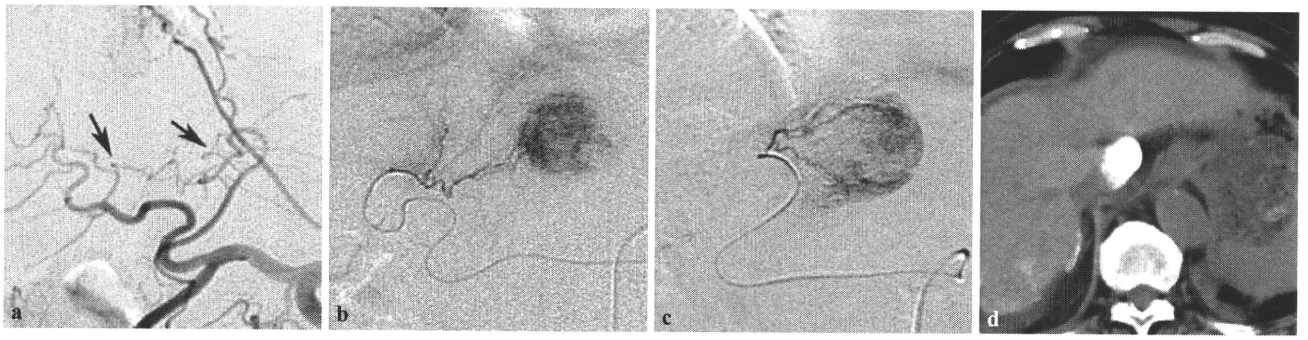

Fig. 3. HCC in the Spiegel lobe. **a** Celiac arteriogram shows two caudate arteries derived from the right and left hepatic artery, respectively (*arrows*). **b** First, the caudate artery derived from the right hepatic artery was selected, and TACE was performed. **c** Second, the caudate artery derived from the left hepatic artery was selected, and TACE was performed. **d** CT 1 week after TACE shows dense iodized oil accumulation in the tumor. Iodized oil was also accumulated in the right adrenal gland because the right inferior phrenic artery was subsequently embolized to treat another tumor (not shown)

HCC in the paracaval portion

When HCC is in the paracaval portion, it is mainly fed by the caudate artery derived from the right hepatic artery.[5,6] Several feeding branches frequently arise between the right hepatic artery and the proximal portion of the anterior or posterior segmental artery of the right hepatic artery (Fig. 6). Another feeding branch also arises from the left hepatic artery (Fig. 13). The tumor in the paracaval portion is rarely supplied by the caudate artery derived from the left hepatic artery alone (Fig. 8).

HCC in the caudate process

HCC in the caudate process is usually fed by the caudate artery derived from the right hepatic artery (Fig. 4).[5,6]

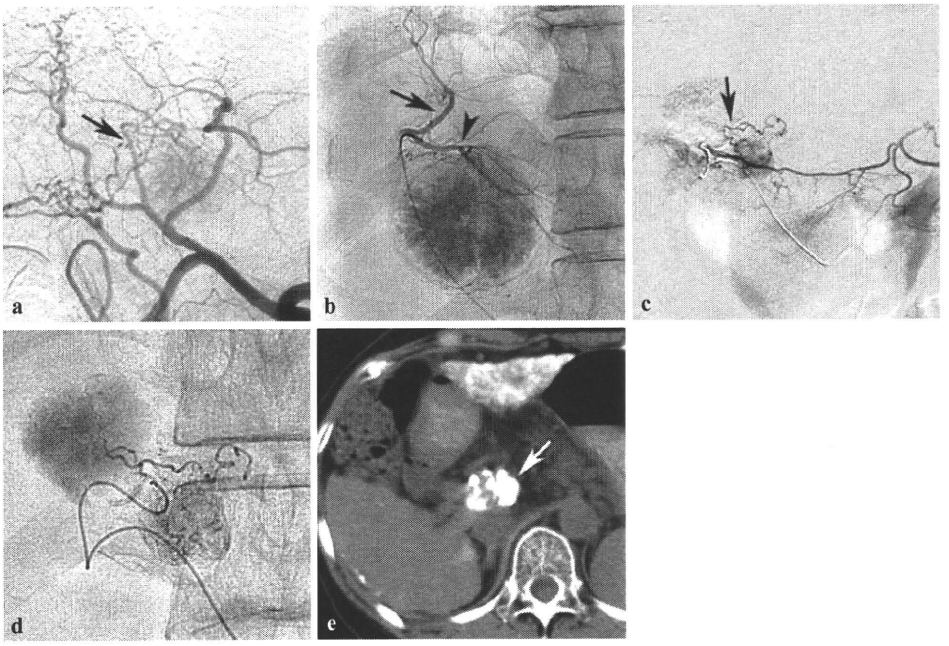

Fig. 4. HCC in the caudate process. **a** Celiac arteriogram shows a tumor stain supplied by the hypertrophied caudate artery derived from the right hepatic artery (*arrow*). **b** Spot radiograph obtained during TACE showed that the Spiegel branch (*arrowhead*) and paracaval branch (*arrow*) arose as a common trunk. **c** Two years later, a new lesion developed near the previous tumor site. Arteriogram of the right gastric artery shows a tumor stain supplied by a small branch (*arrow*). **d** The branch was selected, and TACE was performed. **e** CT 1 week after TACE shows dense iodized oil accumulation in the tumor (*arrow*). Iodized oil was also seen in the left lobe of the liver because the left hepatic artery was subsequently embolized to treat other tumors (not shown)

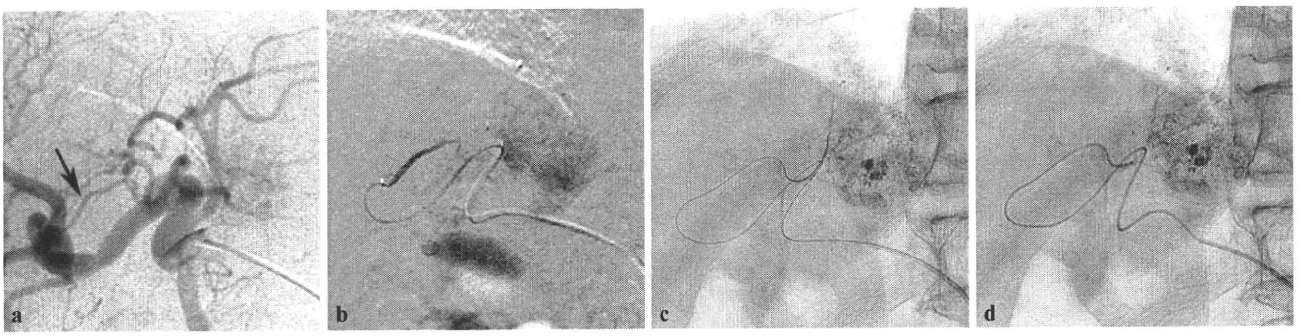

Fig. 5. HCC in the Spiegel lobe. **a** Celiac arteriogram shows a tumor stain supplied by the right hepatic artery (*arrow*). **b** The caudate artery was selected using a shaped microcatheter. The guidewire was advanced into the caudate artery, but the microcatheter could not be advanced into it. **c** The shaped microcatheter was withdrawn and exchanged for a thinner flexible microcatheter. **d** The microcatheter was deeply advanced into the caudate artery using an over-the-wire technique, and TACE was completed

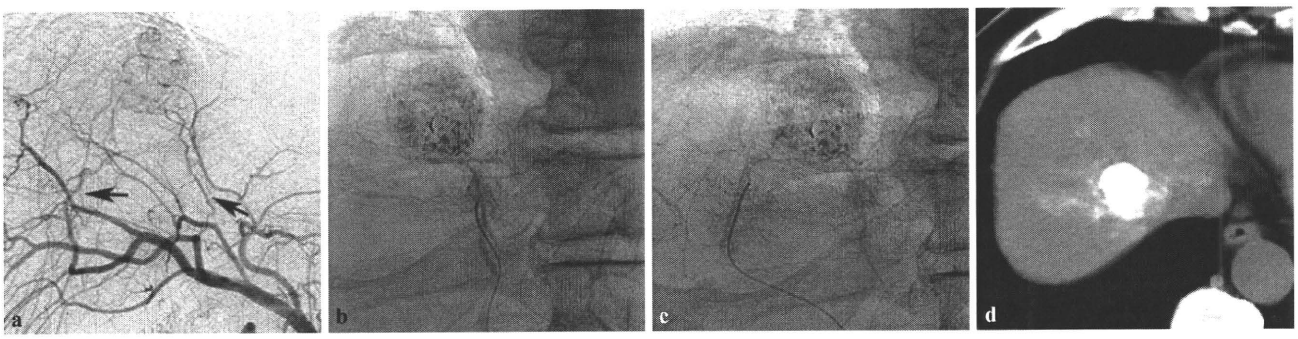

Fig. 6. HCC in the paracaval portion. **a** Common hepatic arteriogram shows a tumor stain supplied by two caudate arteries derived from different sites (*arrows*). **b** First, the caudate artery derived from the anterior segmental artery of the right hepatic artery was selected and TACE was performed. **c** Second, the caudate artery derived from another anterior segmental artery of the right hepatic artery was selected, and TACE was performed. **d** CT 1 week after TACE shows dense iodized oil accumulation in the tumor

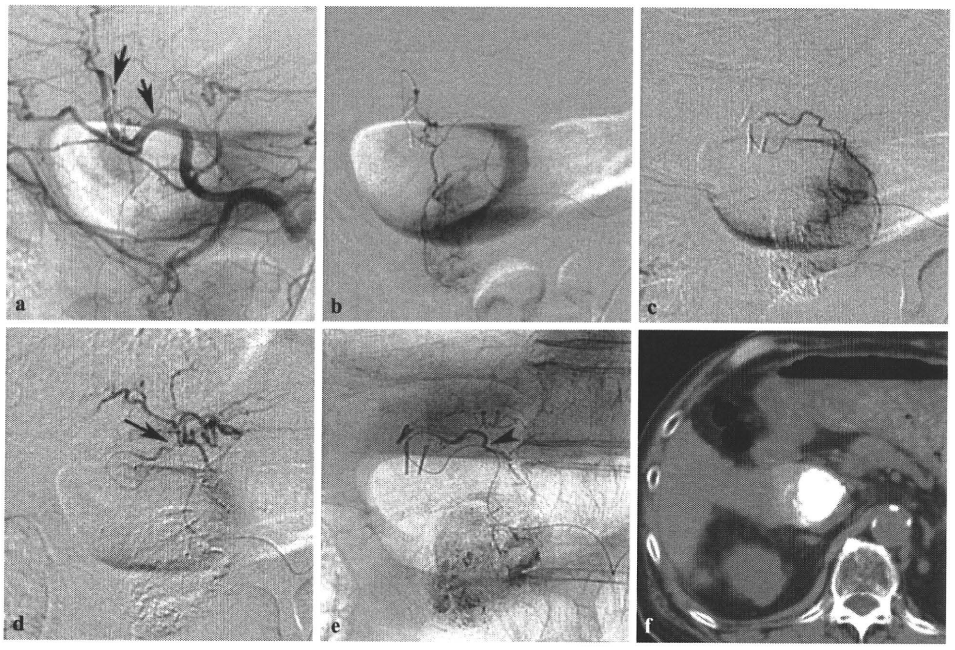

Fig. 7. HCC in the Spiegel lobe. **a** Celiac arteriogram shows two caudate arteries derived from the anterior segmental artery of the right hepatic artery (*arrows*). **b** First, one of the caudate arteries was selected, and TACE was performed. **c** Second, another caudate artery was selected, and TACE was started. **d** Arteriogram obtained during TACE shows the left hepatic artery through the anastomosis (*arrow*). **e** Then, the microcatheter was advanced distally to the anastomosed branch, and TACE was completed. **f** CT 1 week after TACE shows dense iodized oil accumulation in the tumor

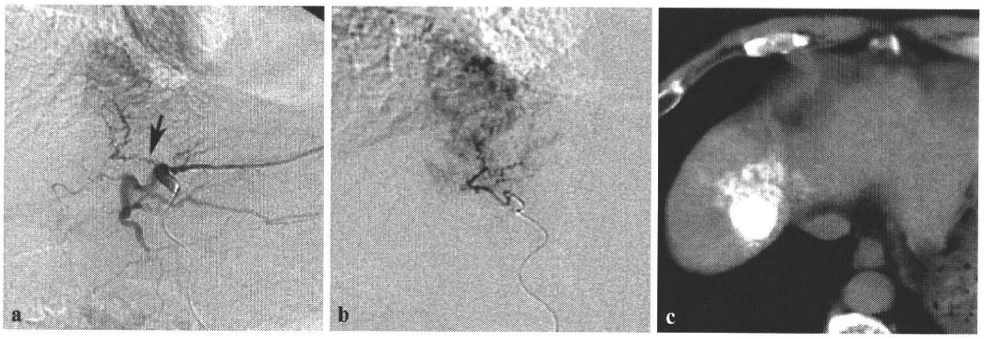

Fig. 8. HCC in the paracaval portion. **a** Arteriogram of the left hepatic artery shows a tumor stain supplied by the caudate artery derived near the umbilical portion of the left hepatic artery (*arrow*). **b** The vessel was selected, and TACE was performed. **c** CT 1 week after TACE shows dense iodized oil accumulation in the tumor

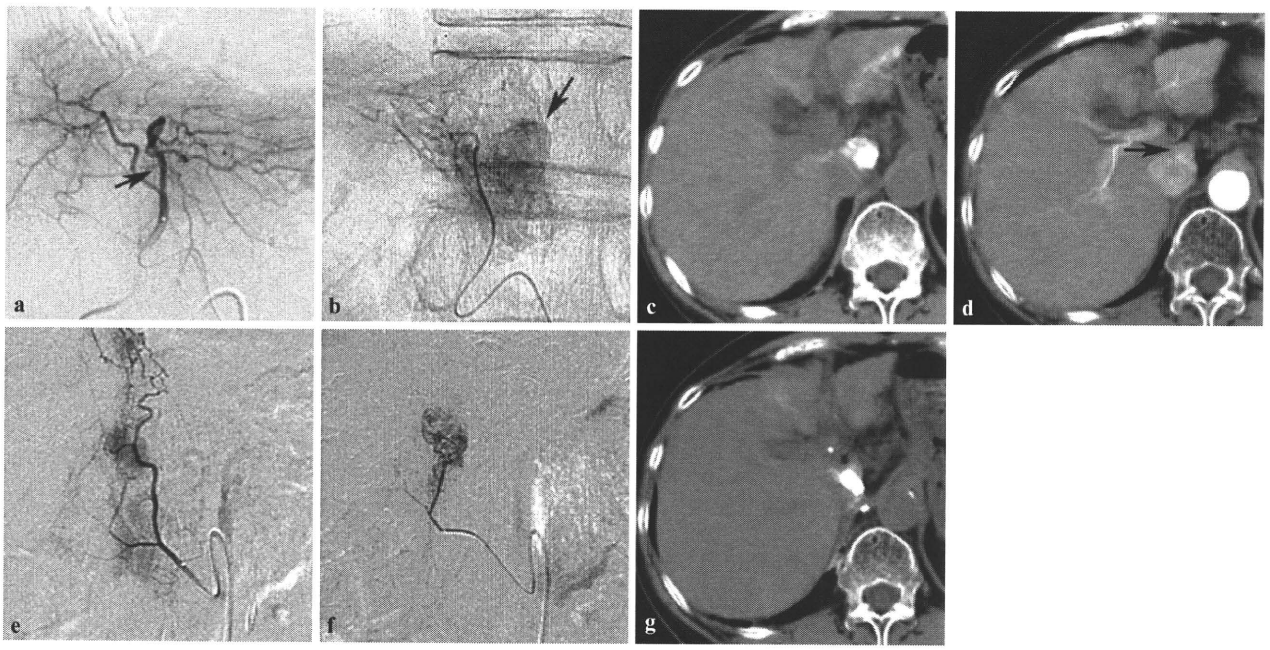

Fig. 9. HCC in the Spiegel lobe. **a** Arteriogram of the left hepatic artery shows the caudate artery derived from the medial segmental artery (*arrow*). **b** The vessel was selected, and TACE was performed. The contour of the Spiegel lobe was seen. *Arrow* points to the tumor. **c** CT 1 week after TACE shows dense iodized oil accumulation in the tumor. **d** However, CT 13 months after TACE shows a recurrent tumor (*arrow*). **e** On additional angiography, the previously embolized caudate artery was occluded (not shown). The tumor was supplied by the right inferior phrenic artery alone. **f** The tumor-feeding branch was selected, and TACE was performed. **g** CT 1 week after TACE shows dense iodized oil accumulation in the tumor

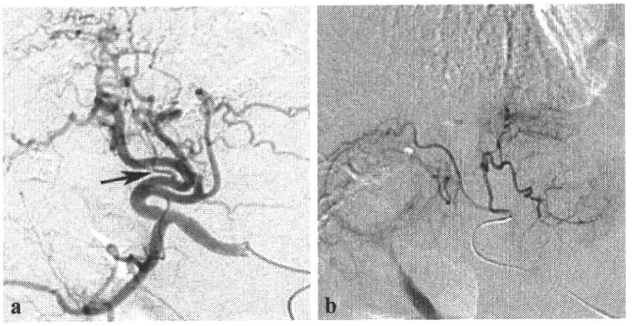

Fig. 10. Caudate artery derived from the cystic artery. **a** Common hepatic arteriogram shows that the cystic artery derived from the proximal portion of the right hepatic artery (*arrow*). **b** Selective arteriogram shows that the caudate artery was derived from the cystic artery

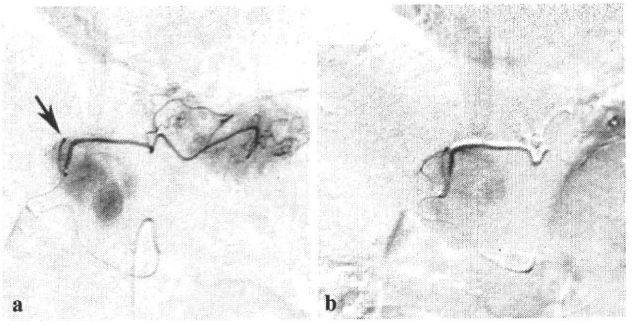

Fig. 12. HCC in the Spiegel lobe. **a** Arteriogram of the accessory left gastric artery shows a tumor stain supplied by a small branch (*arrow*). **b** The branch could not be directly selected; therefore, TACE was performed after embolization of the accessory left gastric artery using metallic coils and *n*-butyl-cyanoacrylate

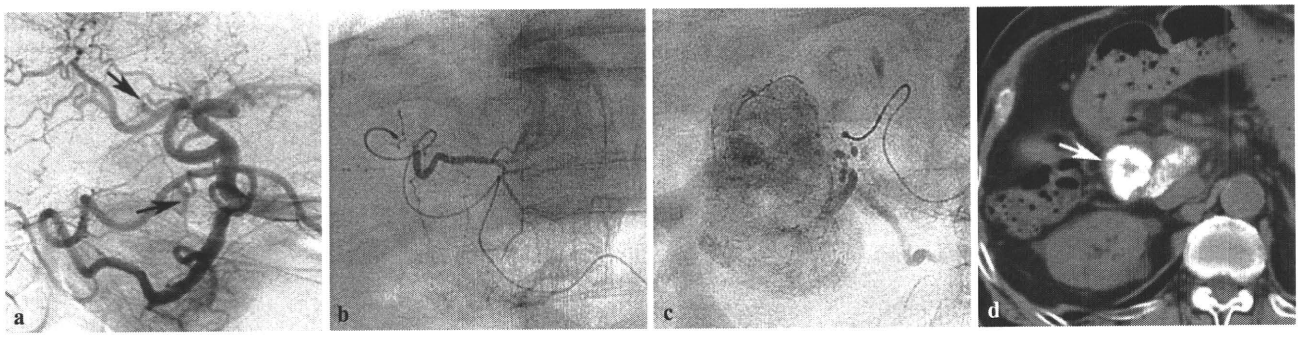

Fig. 11. HCC in the caudate process. **a** Common hepatic arteriogram shows two caudate arteries (*arrow*). **b** First, the Spiegel lobe branch derived from the right hepatic artery was selected, and TACE was performed. The contour of the Spiegel lobe is clearly seen. **c** Second, the caudate process branch derived from the proper hepatic artery was selected, and TACE was performed. This vessel was a main feeder of the tumor. **d** CT 1 week after TACE shows dense iodized oil accumulation in the tumor (*arrow*)

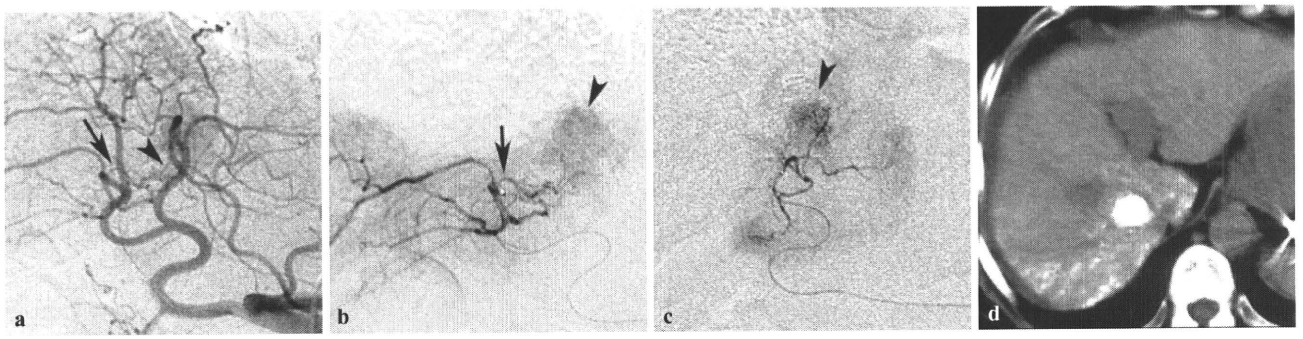

Fig. 13. HCC in the paracaval portion. **a** Celiac arteriogram shows two caudate arteries derived from the left hepatic artery (*arrowhead*) and the posterior segmental artery of the right hepatic artery (*arrow*). **b** Arteriogram of the posterior segmental artery of the right hepatic artery shows a tumor stain (*arrowhead*). *Arrow* indicates the caudate artery. **c** Arteriogram of the caudate artery derived from the left hepatic artery also shows the tumor stain (*arrowhead*). **d** CT 1 week after TACE shows dense iodized oil accumulation in the tumor

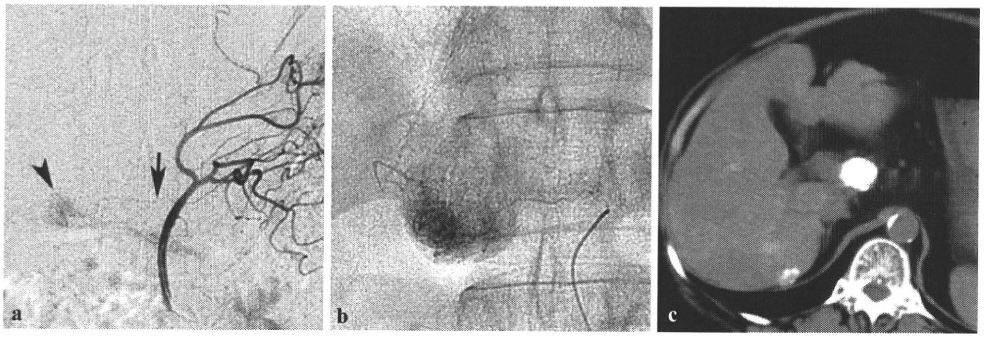

Fig. 14. Recurrent HCC in the Spiegel lobe. **a** Arteriogram of the left gastric artery shows a tumor (*arrowhead*) supplied by a small branch (*arrow*). **b** The branch was selected, and TACE was performed. **c** CT 1 week after TACE shows dense iodized oil accumulation in the tumor

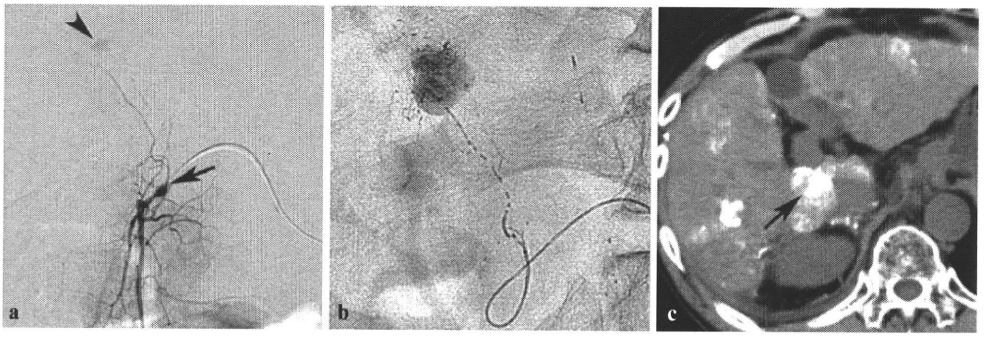

Fig. 15. Recurrent HCC in the caudate process. **a** Arteriogram of the posterosuperior pancreatoduodenal artery shows a small tumor stain (*arrowhead*) supplied by the 3 o'clock and 9 o'clock arteries (*arrow*). **b** The vessel was selected, and TACE was performed. **c** CT 1 week after TACE shows dense iodized oil accumulation in the tumor (*arrow*)

The caudate artery derived from the proper hepatic artery also supplies tumors in the caudate process (Fig. 11).

Changes in tumor-feeding branches of recurrent tumors

Because of the presence of multiple caudate arteries and the overlap of these vascular territories, the tumor-feeding branch of a recurrent tumor in the caudate lobe frequently changes on follow-up arteriograms.[6] Another caudate artery arising from a different origin replaces the tumor-feeding branch; in particular, a small feeding branch becomes sufficiently hypertrophied to be detected on angiography (Fig. 2).

Extrahepatic arteries frequently supply the recurrent tumor in the caudate lobe, particularly the tumor in the Spiegel lobe. The right inferior phrenic (Fig. 9), right or left gastric (Figs. 4, 14), dorsal pancreatic, right adrenal, and right renal capsular arteries are possible collateral vessels for recurrent tumors in the Spiegel lobe. The 3 o'clock and 9 o'clock arteries are also possible collateral vessels for recurrent tumors in the caudate process (Fig. 15). In addition, recurrent HCC in the paracaval portion is supplied by the right inferior phrenic artery.

Catheterization technique in the caudate artery

Owing to proximal branching of the caudate artery, non-selective TACE is not effective for HCC in the caudate lobe.[8,9] Because the caudate artery usually has a small caliber, a microcatheter with a tip less than 2F facilitates selective catheterization. As the caudate artery frequently arises at an acute angle, shaping the microcatheter by steam-heating is useful for selective catheterization. When the tip of the microcatheter faces the orifice of the caudate artery, a guidewire is inserted into the caudate artery, and the microcatheter is then advanced into the branch. An over-the-wire technique to exchange the shaped microcatheter for a flexible one is also useful if the shaped microcatheter cannot be advanced into the caudate artery (Fig. 5). For arterial blockage distal to the caudate artery, use of a microballoon catheter has been reported.[15] In a small branch derived from extrahepatic collateral pathways, embolization using a metallic coil and/or *n*-butyl-cyanoacrylate at the distal portion of the small feeding branch is also useful when it cannot be directly selected (Fig. 12).

Multiple caudate arteries frequently anastomose to each other to form an arcade.[12,14] When the embolic materials are injected from one of the caudate arteries,

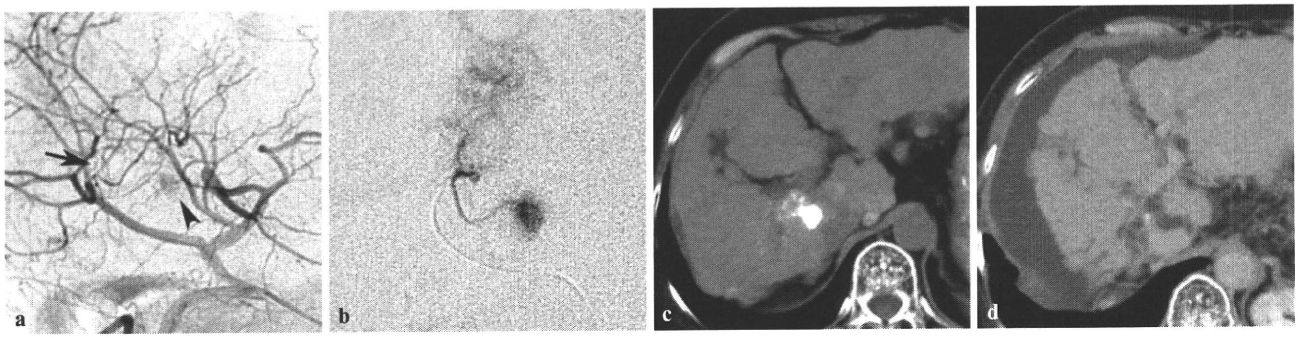

Fig. 16. Bile duct dilatation after TACE of the caudate artery. **a** Common hepatic arteriogram shows a small tumor stain (*arrowhead*) supplied by the caudate artery derived from the anterior segmental artery of the right hepatic artery (*arrow*). **b** The caudate artery was selected, and TACE was performed. **c** CT 1 week after TACE shows dense iodized oil accumulation in the tumor. **d** CT 6 years after TACE shows that the tumor was well controlled. However, the bile duct was dilated in the right lobe of the liver, and the right lobe of the liver was atrophied

collateral blood flow through the other caudate arteries reverses the blood flow in the embolized artery and pushes back the embolic materials.[5,9] If possible, the microcatheter should be advanced distal to the anastomosis branch to avoid inadvertent widespread embolization (Fig. 7). Small branches supplying the main bile duct usually arise from the caudate artery[12]; therefore, bile duct stricture may occur after TACE of the caudate artery (Fig. 16).[14] This is a rare but serious complication of TACE through the caudate artery.

Conclusion

The caudate artery usually arises from the proximal portion of the hepatic artery. The vascular supply to HCC in the caudate lobe is complex because of the presence of multiple caudate arteries and their overlapped vascular territories. In addition, several extrahepatic collateral vessels feed recurrent tumors in the caudate lobe. Identification of the tumor-feeding caudate artery and selective catheterization is essential to perform effective TACE.

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PICTORIAL ESSAY

Inferior phrenic arteries: angiographic anatomy, variations, and catheterization techniques for transcatheter arterial chemoembolization

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Abstract The inferior phrenic artery (IPA) is the most common extrahepatic collateral vessel to hepatocellular carcinoma (HCC); however, there are many anatomical variations in its origin and branches. In addition, the IPA is frequently reconstructed through several pathways, mainly through the retroperitoneal network, because of the occlusion of its orifice due to atherosclerosis or previous catheter manipulation. Infrequently, selective catheterization into the IPA is impossible even using a microcatheter, particularly in the IPA that originates from the proximal or distal portion of the celiac trunk or from the aorta with an acute angle. In this article, we describe anatomical variations of the IPA and catheterization techniques, such as a catheter with a large side hole and a catheter with a cleft, to facilitate catheterization into the IPA that is difficult using a conventional coaxial technique. Radiologists should have sufficient knowledge of such variations and catheterization techniques to perform transcatheter arterial chemoembolization for HCCs through the IPA effectively and safely.

Key words Inferior phrenic artery · Anatomy · Catheterization technique · Transcatheter arterial chemoembolization

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Introduction

The inferior phrenic arteries (IPAs) are the major blood source to the diaphragm. There is close contact between the posterior portion of the liver and diaphragm at the bare area and branches of the IPA that are in direct contact with the liver.[1] In addition, the left IPA has the potential to communicate with intrahepatic arteries of the lateral segment of the liver.[1] Therefore, hepatocellular carcinoma (HCC) located near the diaphragm frequently receives its blood supply from the IPA, especially when the hepatic arterial circulation is interrupted by repeated transcatheter arterial chemoembolization (TACE) or placement of the catheter for infusion chemotherapy.[2–4] Furthermore, IPA parasitization is also seen even at the initial TACE for tumors located bare area of the liver.[2–5] The right IPA is the most common extrahepatic collateral supplying HCCs[3,4]; therefore, TACE of the IPA is necessary during the subsequent course of treatment for an HCC in most cases.

The IPAs and their branches have several anatomical variations and pathological conditions,[6,7] and several catheterization techniques are required in some cases in which the IPA has a difficult branching pattern.[5,8–10] Therefore, radiologists should have sufficient knowledge of such variations and catheterization techniques to perform TACE through the IPA effectively and safely.

Anatomical variations of IPAs

The IPAs originate with almost equal frequency from the aorta and celiac axis, either as a common trunk or independently.[6] These vessels may also arise from the renal (15.7%), left gastric (3.7%), hepatic (2.1%) (Fig. 1), supe-

rior mesenteric (0.3%), or spermatic arteries.[6] In 58% of cases, the right IPA originates directly from the aorta, and the most common level of origin is the supraceliac aorta, followed by the aorta between the celiac trunk and superior mesenteric artery, and the juxtaceliac aorta with the celiac trunk.[11] The independent right IPA USUALLY ARISES FROM THE RIGHT SIDE OF THE MAJOR ARTERY OR aorta; however, rarely it arises from the left renal artery (Fig. 2).[5]

Variations of IPA branches

Figure 3 shows the major branches derived from the IPAs. The right and left IPAs give rise to anterior (ascending), posterior (descending), superior suprarenal, and middle suprarenal branches. In addition, the right IPA gives rise to the inferior vena caval (Fig. 4) and diaphragmatic branches (Fig. 5); and the left IPA gives rise to gastric, esophageal (Fig. 6), and accessory splenic

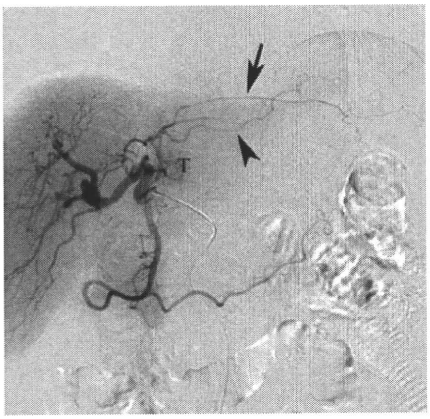


Fig. 1. Posterior branch of the left inferior phrenic artery (IPA) arises from the left hepatic artery (*arrow*), and the accessory left gastric artery arises from the left hepatic artery (*arrowhead*). Tumor stain in the caudate lobe of the liver is also seen (*T*)

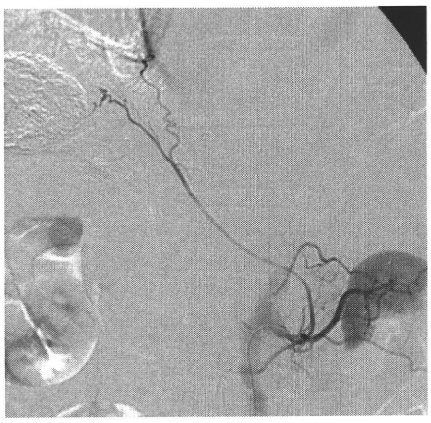


Fig. 2. Right IPA arises from the left upper polar renal branch. (From Miayama et al.,[5] with permission)

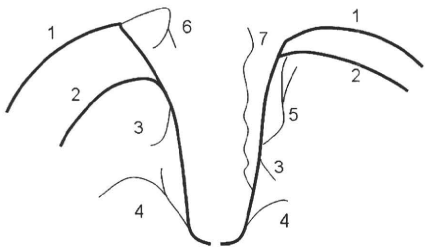


Fig. 3. Major branches derived from the IPAs. *1*, anterior branch; *2*, posterior branch; *3*, superior suprarenal branch; *4*, middle suprarenal branches; *5*, gastric branch; *6*, diaphragmatic branch; *7*, esophageal branch

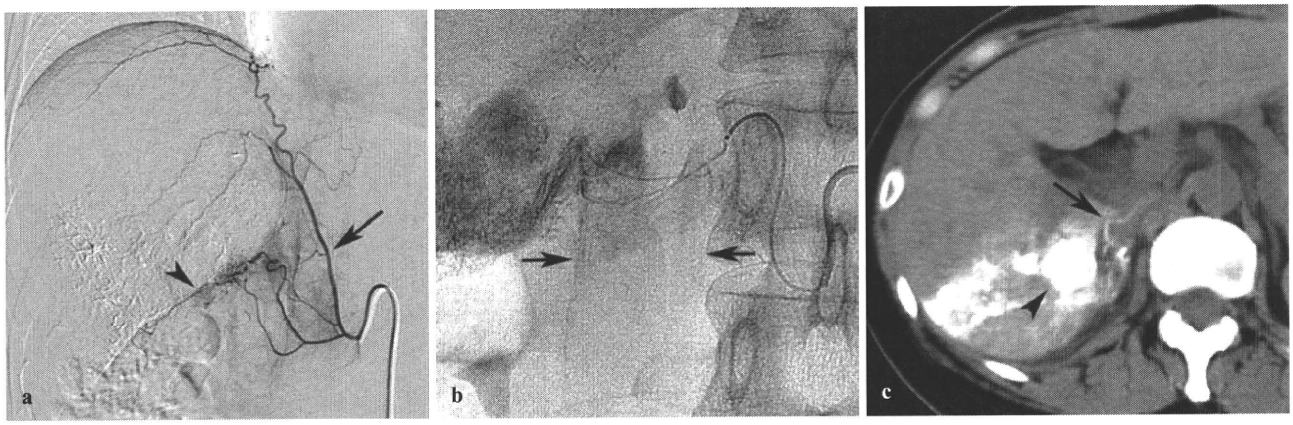


Fig. 4. **a** The tumor was mainly supplied by the branch of the posterior inferior subsegmental artery of the right hepatic artery, and the branch was embolized (not shown). Arteriography of the right IPA obtained after transarterial chemoembolization (TACE) of the hepatic arterial branch shows a residual tumor stain (*arrowhead*) supplied by a small branch (*arrow*). **b** The branch was selected, and TACE was performed. The branch was one of the inferior vena caval branches, therefore, iodized oil accumulation along the inferior vena cava (IVC) was demonstrated during TACE. **c** On a computed tomography (CT) scan obtained 1 week after TACE, iodized oil accumulation is seen in the IVC wall (*arrow*). Iodized oil is also accumulated in the right adrenal gland because the suprarenal branch was sequentially embolized during the TACE procedure (not shown). *Arrowhead* indicates the tumor

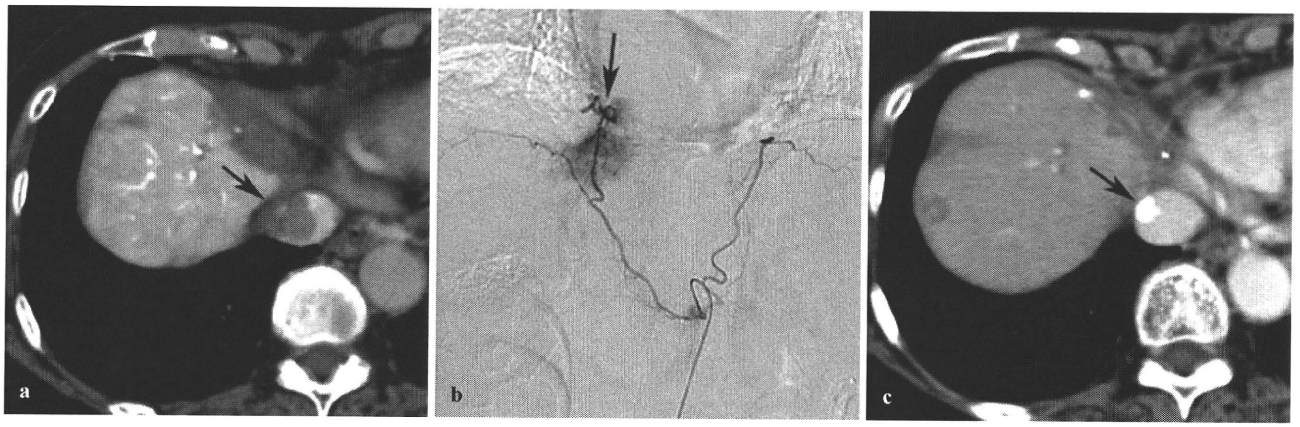


Fig. 5. a Computed tomography during arterial portography shows a tumor thrombus in the IVC (*arrow*). **b** Arteriography of the bilateral IPAs shows the tumor stain supplied by the diaphragmatic branch of the right IPA (*arrow*). The branch was selected, and TACE was performed (not shown). **c** Arterial phase CT scan obtained 1 year after TACE shows that the tumor thrombus is decreased in size, with dense iodized oil accumulation

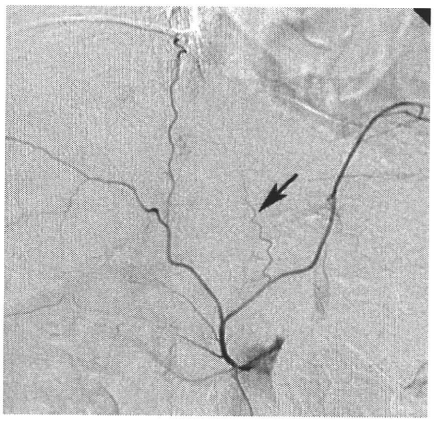


Fig. 6. Esophageal branch arises from the left IPA (*arrow*)

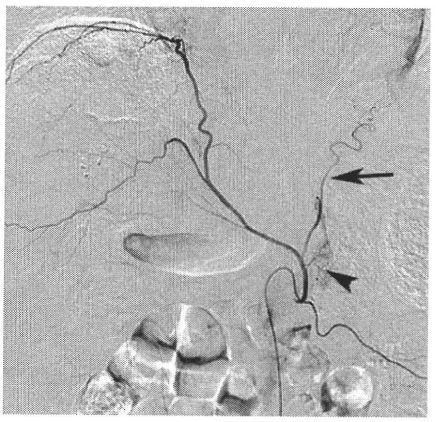


Fig. 7. Gastric branch (*arrow*) and left suprarenal branch (*arrowhead*) arise from the right IPA arising from the aorta

branches.[1,6] In our experience, the gastric and esophageal branches have several anatomical variations. The gastric branch infrequently arises from the right IPA (Fig. 7) or superior mesenteric artery (Fig. 8); or it may independently arise from the aorta (Fig. 9). In addition, anastomosis between the right IPA and the esophageal branch is also seen.

The anterior and posterior branches of the left IPA frequently arise from separate origins (Figs. 1, 10–12). The anterior branch of the left IPA frequently arises from the right IPA (Figs. 10, 11).[7] In such a branching pattern, the posterior branch of the left IPA arises either as a common trunk (Fig. 11) or independently. In addition, the posterior branch of the left IPA infrequently arises from the left hepatic artery (Fig. 1).

Two or three inferior vena caval branches derive from the right IPA,[12] and these branches supply HCCs adjacent to the inferior vena cava (IVC) (Fig. 4). The inferior vena caval and diaphragmatic branches are also the major blood source to the tumor thrombus of an HCC in the IVC (Fig. 5).[13]

The right IPA communicates with the pericardiacophrenic artery arising from the right internal mammary artery. A vascular blush caused by transpleural systemic–pulmonary arterial anastomosis from the IPA is frequently seen in patients with chronic pleural and/or pulmonary inflammation (Fig. 13).[6]

Variations of reconstructed pathways of occluded IPAs

Stenosis or occlusion of the orifice of the IPA may occur owing to atherosclerotic change or previous catheter manipulation.[14] Arcuate ligament compression may also cause stenosis or occlusion of the IPA orifice. The IPA has many anastomoses between the contralateral IPA, internal mammary, posterior intercostal and lumbar, left gastric, dorsal pancreatic, and adrenal arteries; therefore, it is reconstructed from various vessels when the

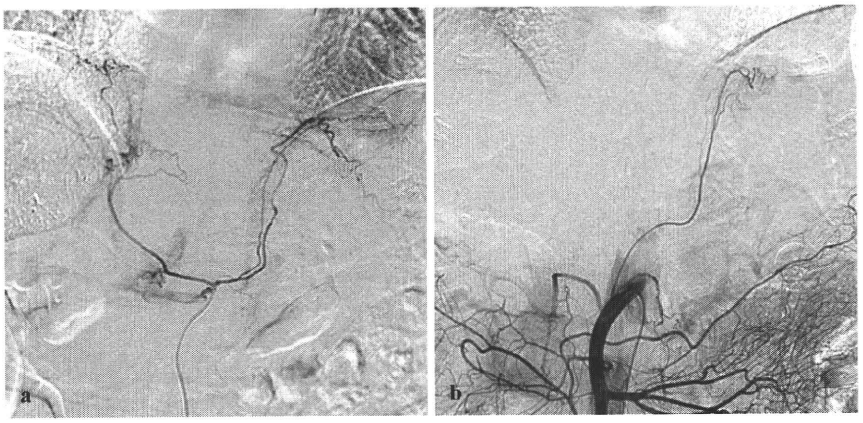


Fig. 8. **a** Bilateral IPAs arise from the celiac trunk. The gastric branch is not derived from the left IPA. **b** Gastric branch arises from the superior mesenteric artery

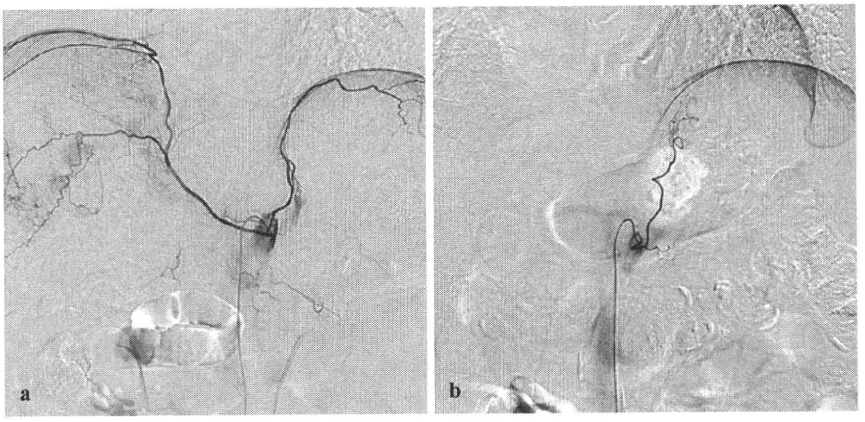


Fig. 9. **a** Bilateral IPAs directly arise from the aorta. The gastric branch is not derived from the left IPA. **b** Gastric branch independently arises from the aorta

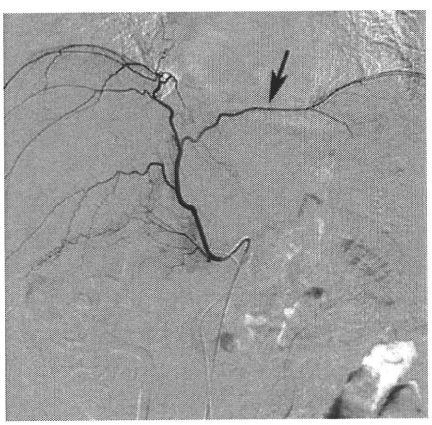


Fig. 10. Anterior branch of the left IPA arises from the right IPA (*arrow*)

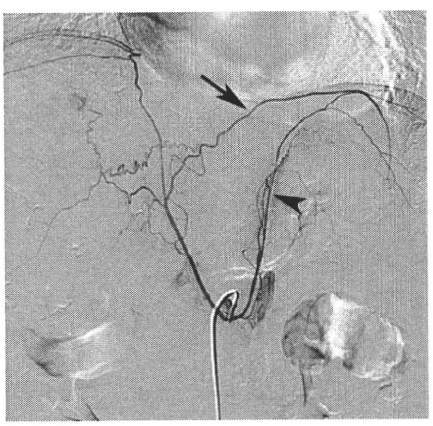


Fig. 11. Anterior branch of the left IPA arises from the right IPA (*arrow*). Posterior branch of the left IPA arises with a common trunk (*arrowhead*)

orifice is occluded (Figs. 14–18).[5,6,14,15] The occluded IPA is mainly opacified through the retroperitoneal network; the dorsal pancreatic artery is the most common collateral to the IPAs (Figs. 14, 15), followed by the right adrenal arteries (Fig. 16), left gastric artery (Figs. 14, 15), and contralateral IPA.[14] The IPAs are also reconstructed through an unnamed small branch arising from the celiac trunk (Fig. 17) or renal artery (Fig. 18). In addition, the IPAs are frequently opacified through more than two individual arteries (Fig. 14, 15).[14]

Catheterization technique into IPAs

With advances in the technology of catheters and guidewires, almost all IPAs can be selected.[4] However, cath-

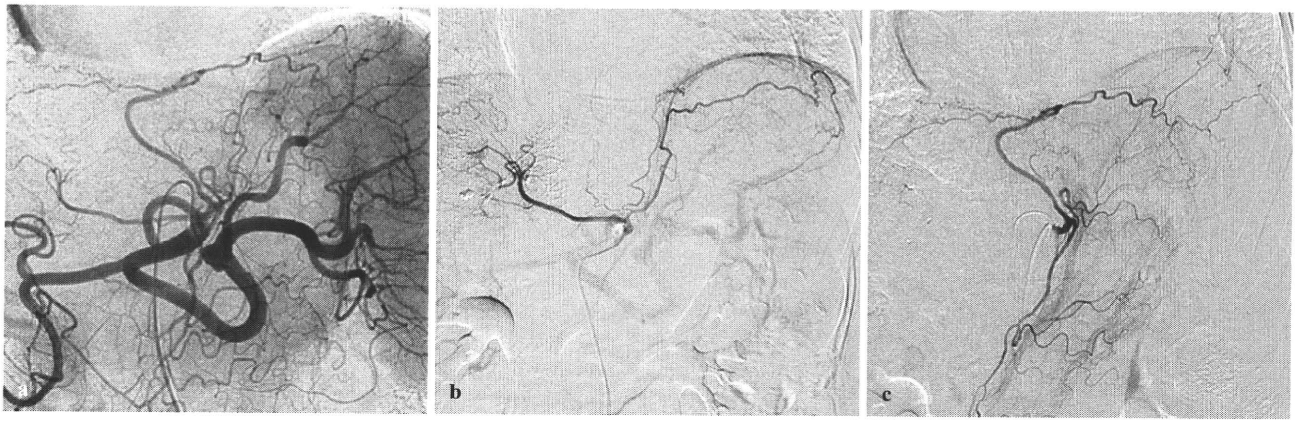


Fig. 12. **a** Celiac arteriogram. **b** Anterior branch of the left IPA arises with the right IPA as a common trunk from the celiac artery. **c** Posterior branch of the left IPA arises from the left gastric artery

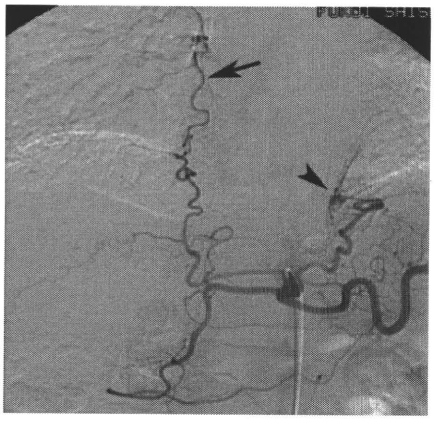


Fig. 13. Right IPA communicates with the pericardiacophrenic artery arising from the right internal mammary artery (*arrow*). Vascular blush caused by a transpleural systemic–pulmonary arterial anastomosis from the left IPA is also seen (*arrowhead*)

eterization into several types of IPA remains impossible even using a conventional coaxial technique. An IPA that arises from the proximal portion of the celiac trunk or from the aorta with an acute angle at the orifice is difficult to catheterize. Using a catheter with a large side hole or turn-back technique is useful when selecting IPAs arising from the proximal portion of the celiac trunk.[8,9] For IPAs arising from the aorta with an acute angle, a catheter with a cleft facilitates catheterization (Fig. 19).[10] Both the large side hole and the cleft can easily be created on a conventional angiographic catheter during the procedure according to the individual circumstances.[8,10] In addition, selective catheterization into the IPA arising from the distal portion of the celiac trunk is frequently difficult because the tip of the angiographic catheter does not closely face the IPA orifice. For selective catheterization into such IPAs, a catheter with a large side hole is useful (Fig. 20). Shaping a nonbraided microcatheter by steam-heating is also useful for selective catheterization.

For TACE through a reconstructed IPA supplying an HCC, selection of a less tortuous root is key to successful catheterization and TACE when the IPA is demonstrated through more than two separate arteries. The anastomotic branch should be selected using a microcatheter with a tip of less than 2F because the anastomotic branch is usually small and tortuous. When the anastomotic branch cannot be directly selected, embolization of the parent artery using metallic coils at a level distal to the anastomotic branch is also useful for avoiding nontarget embolization (Fig. 14).[6]

Direct catheterization into the stenotic vessel is possible in some cases when the IPA orifice can be demonstrated during the TACE procedure (Fig. 15).[14]

TACE techniques to avoid complications

The gastric and esophageal branches of the IPA should not be embolized. Inflow of embolic material into the pulmonary vessels through the shunt may cause pleural effusion, basal atelectasis, and infrequently systemic embolization. Patients with advanced liver disease are likely to have a pulmonary arteriovenous shunt; and a right-to-left shunt from the IPA to the pulmonary vasculature is a possible route causing cerebral embolism of iodized oil,[15] a rare but severe complication of TACE. Therefore, the tumor-feeding branch should be selectively embolized when obvious pleural and pulmonary staining is demonstrated (Fig. 21). Embolization of the branch toward the pleural and pulmonary staining using metallic coils before TACE is useful if the tumor-feeding

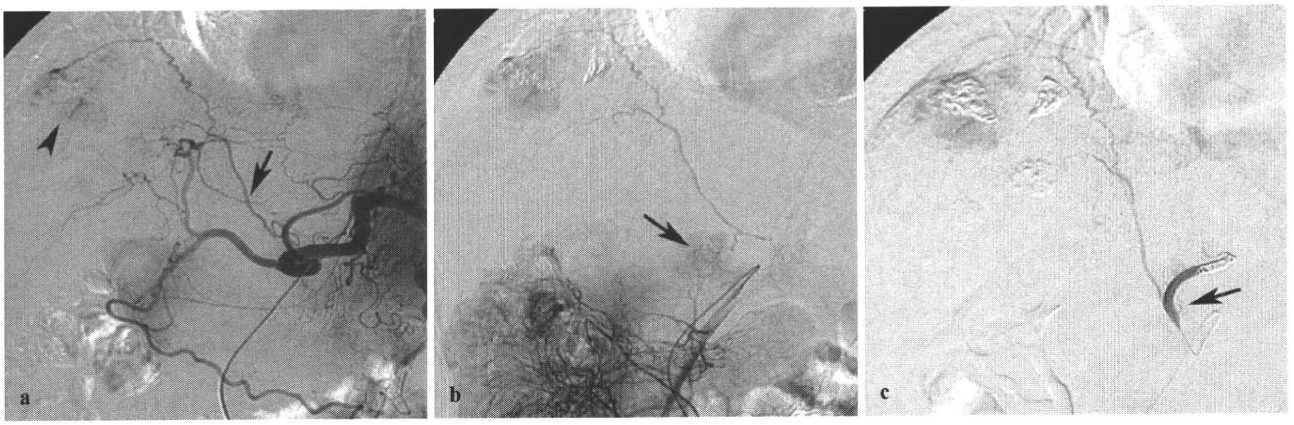


Fig. 14. **a** Celiac arteriography shows a tumor stain (*arrowhead*) supplied by the reconstructed right IPA through the left gastric artery (*arrow*). **b** Superior mesenteric arteriography also shows the reconstructed right IPA through the dorsal pancreatic artery (*arrow*). Because the anastomotic branch derived from the dorsal pancreatic artery was tortuous, catheterization through the left gastric artery was attempted. However, catheterization into the anastomotic branch was impossible because of acute angle branching. **c** TACE was performed after coil embolization of the left gastric artery distal to the anastomotic branch. *Arrow* indicates the anastomotic branch

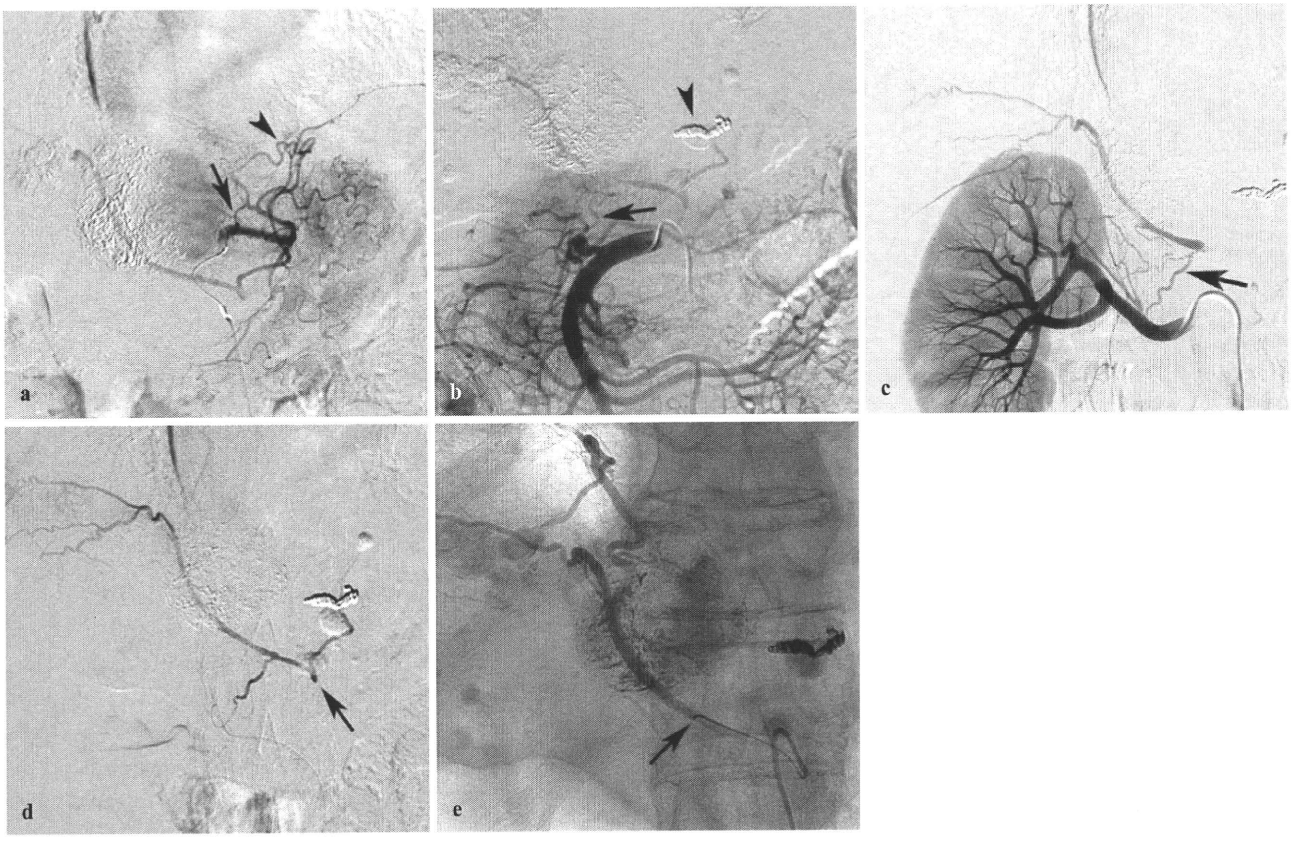


Fig. 15. **a** Arteriography of the left gastric artery shows a tumor-feeding branch (*arrow*) and an anastomotic branch between the left gastric artery and the left IPA (*arrowhead*). TACE was performed after coil embolization of the left gastric artery distal to the tumor-feeding branch (not shown). **b** Bilateral IPAs are opacified through the dorsal pancreatic artery (*arrow*) derived from the superior mesenteric artery obtained after TACE of the left gastric artery. *Arrowhead* indicates the metallic coils in the left gastric artery. **c** Right IPA is also opacified through the right inferior adrenal artery (*arrow*). **d** This anastomotic branch was selected, and TACE was performed. During TACE, the stenosed orifice of the common trunk of the bilateral IPAs was demonstrated (*arrow*). **e** Selective catheterization into the stenosed orifice of the common trunk was possible. *Arrow* indicates the catheter tip

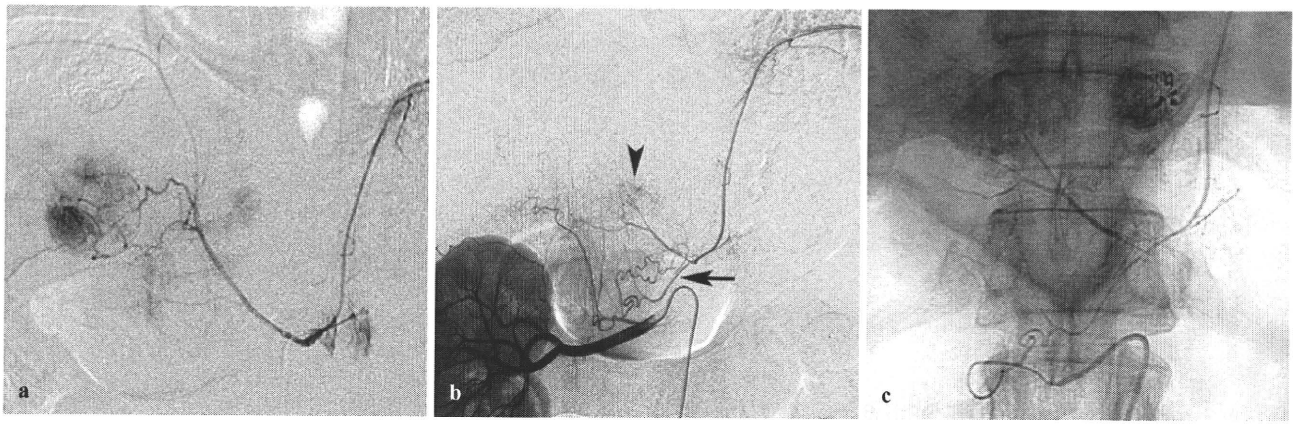


Fig. 16. **a** Tumor in the caudate lobe of the liver is supplied by the right IPA arising from the aorta. TACE was performed through the right IPA. **b** At 2 years 1 month later, the tumor has recurred (*arrowhead*), supplied by the reconstructed right IPA through the right inferior adrenal artery (*arrow*). **c** Spot radiograph obtained during the procedure. The anastomotic branch was selected, and TACE was performed

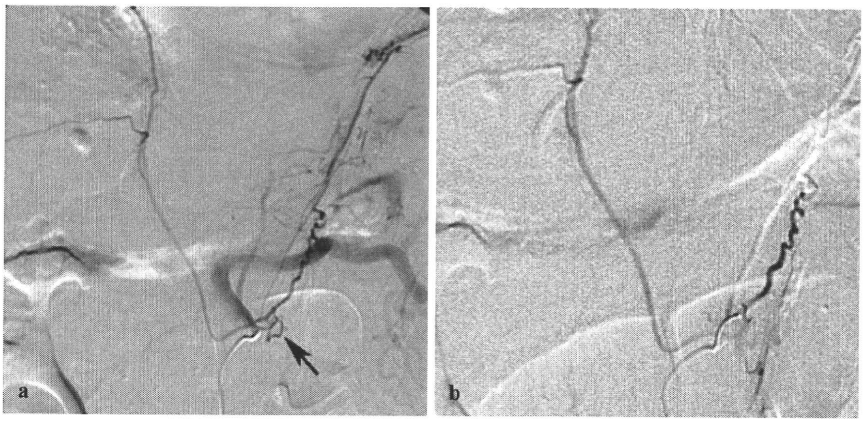


Fig. 17. **a** Bilateral IPAs are reconstructed through a small branch arising from the celiac trunk (*arrow*). **b** The branch is successfully selected

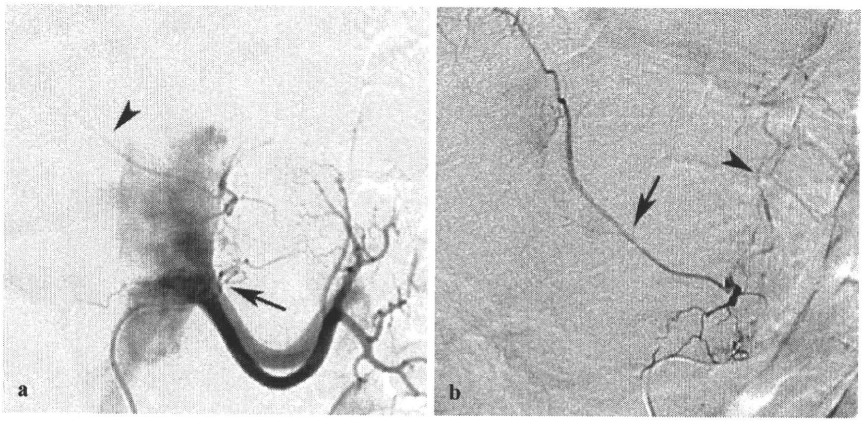


Fig. 18. **a** Arteriography of the left renal artery shows that the right IPA (*arrowhead*) is opacified through a small branch arising at the proximal portion (*arrow*). **b** Selective arteriography of the branch shows the right IPA (*arrow*) and gastric branch (*arrowhead*) through a retroperitoneal fine network

branch cannot be selected (Fig. 22). Bland embolization without iodized oil and anticancer drugs is a less risky alternative.

Embolic materials injected with slight force at the distal level may flow into the other extrahepatic collateral vessels through the anastomosis and may cause unexpected nontarget embolization.[16] Careful observation is needed during injection of embolic materials. In addition, the dosage of infused iodized oil and anticancer drugs should be properly reduced compared with

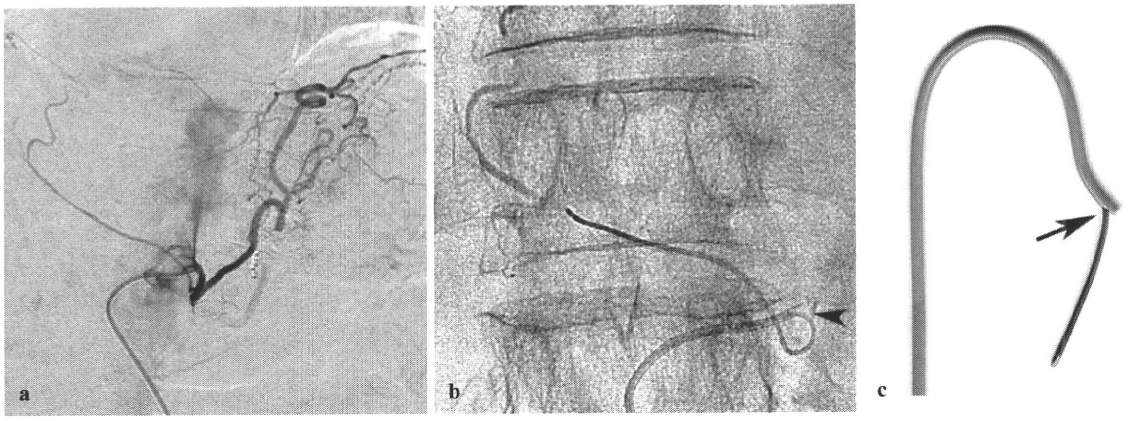
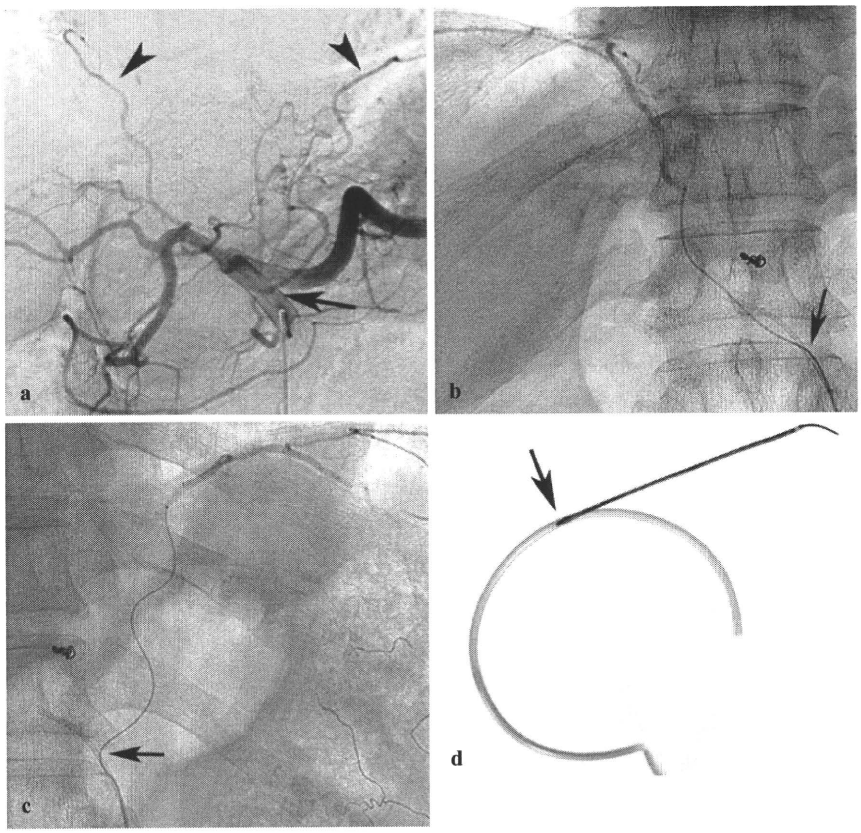


Fig. 19. **a** Common trunk of the bilateral IPAs turns downward, with an acute angle at the orifice. **b** Microcatheter is successfully introduced into the right IPA through the cleft at the caudal aspect (*arrowhead*). **c** Photograph of a cleft catheter and a microcatheter. *Arrow* indicates the cleft

Fig. 20. **a** Celiac arteriogram shows the bilateral IPA (*arrowheads*) arising from the distal portion of the celiac trunk (*arrow*). **b** The microcatheter is successfully introduced into the right IPA through a large side hole of the catheter (*arrow*). **c** The left IPA is also selected successfully through the side hole (*arrow*). **d** Photograph of a catheter with a large side hole and a microcatheter. *Arrow* indicates the side hole



that used for TACE of the hepatic artery[4] (i.e., to almost half the dosage).

Conclusion

The IPA, although a small vessel, is the most common extrahepatic collateral vessel supplying HCCs. Because in addition to the complexity of reconstructed pathways frequently the origin of the IPA and its branches varies, thorough knowledge of the vascular anatomy and variations of the IPA is critical to transcatheter management of HCCs. Several techniques may facilitate effective, safe TACE through an IPA that is difficult to select by the conventional coaxial technique; such techniques can reduce both the procedural time and the incidence of complications.

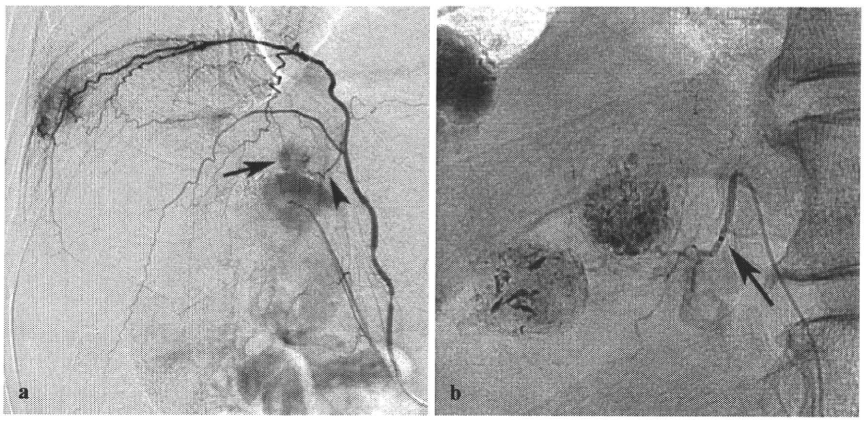


Fig. 21. **a** Arteriography of the right IPA arising from the right superior polar renal artery shows a tumor stain (*arrow*) supplied by a small branch derived from the anterior branch (*arrowhead*). Pleural and pulmonary staining and pulmonary vessel are also seen. **b** The small vessel was successfully selected, and TACE was performed. *Arrow* indicates the catheter tip

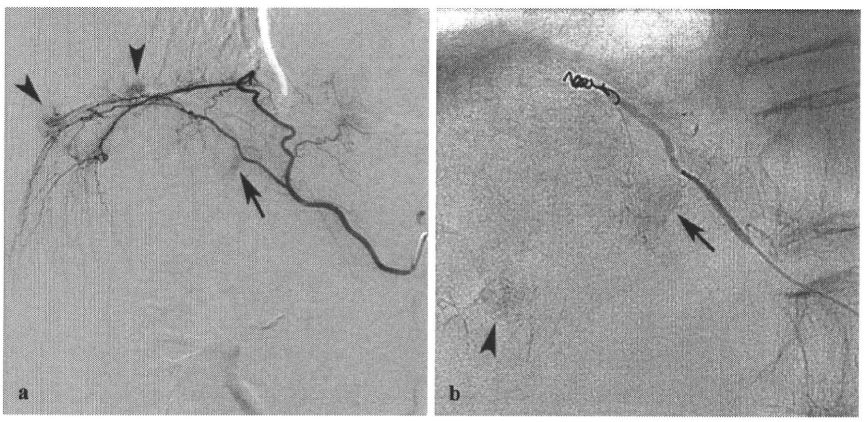


Fig. 22. **a** Arteriography of the right IPA shows a tumor stain (*arrow*) and pulmonary staining (*arrowheads*) from the posterior branch. **b** The tumor-feeding branch was small and could not be selected. TACE was performed after coil embolization of the posterior branch distal to the feeding branch. *Arrow* indicates iodized oil accumulation in the tumor. *Arrowhead* shows the tumor that was simultaneously embolized through the hepatic branch

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