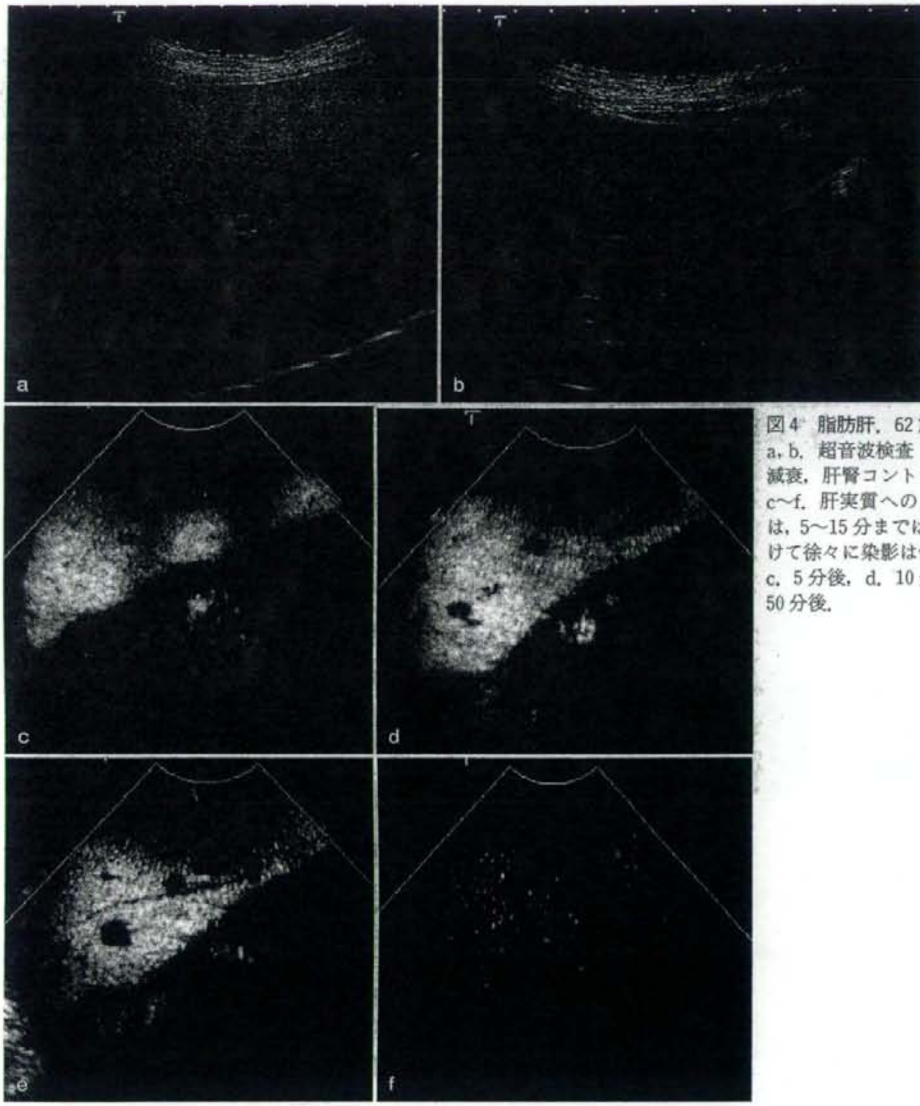

図4　脂肪肝，62歳男性
a，b．超音波検査　B-モードでは，深部減衰，肝腎コントラスト陽性を示す．
c〜f．肝実質へのLevovistの取り込みは，5〜15分まではプラトーで，50分かけて徐々に染影は低下する．
c．5分後，d．10分後，e．15分後，f．50分後．

の染影輝度は，約5分でピークに達し，約20分間ピークが続く．その後約50分かけて徐々に消失する．約20分後では，造影剤は血管内にほとんどなく，肝臓においてはマクロファージであるKupffer細胞に貪食されている．

以上の検討結果から，びまん性肝疾患の実質染影に関しては，5〜20分の間の染影の観察が最も重要であると考えている．

■症例

NASHと脂肪肝の症例を呈示する．53歳の男性．全身倦怠感と肝機能障害で受診した．超音波B-モードでは，通常の脂肪肝と鑑別できない（図3a，b）．Levovist®を投与し，肝実質へのLevovist®の取り込みを，5〜50分まで経時的に観察した．肝実質の染

影は，脂肪肝と比較して，Levovist®投与後5分から低下しており，15分の時点では，取り込みをほとんど認めない(図3c〜f)．一方，組織学的に脂肪肝と診断した62歳の男性．肝機能障害で受診した．超音波B-モードでは，脂肪肝の所見である(図4a，b)．肝実質の染影は，健常人と相違なく5〜15分までは，ほぼ染影はplateauであり，50分かけて徐々に染影は低下する(図4c〜f)

■おわりに

マクロファージに貪食され使用できる超音波造影剤は，Levovist®とSonazoid®である．2007年1月にKupffer細胞に貪食されるように設計された造影剤であるSonazoid®が発売されたが，適応は肝腫瘍であり，肝機能診断を目的とした使用は現在のところできない．一方，Levovist®のKupffer細胞への取り込みの機序は不明であるが，肝腫瘍における臨床的検討ではすでに多くの報告がある．これらの報告では，転移性肝癌においてLevovist®のdelayed parenchymal phaseで転移部が欠損像として描出される．また，良性腫瘍と悪性腫瘍の鑑別に有用であると報告されている[12]．

肝細胞癌での検討では，SPIO-MRI(superparamagnetic iron oxide particles)とLevovist®は，ほぼ同様の染影を示したり，組織分化度との検討でも，境界病変では周囲正常肝と同様の染影を示すと報告している[13]．SPIO-MRIはすでにKupffer細胞との関連が報告されており[14]，これらの事実は，Levovist®と類洞機能，特に肝マクロファージ，Kupffer細胞による気泡の貪食能と何らかの相関が示唆される．

一方，NASHの場合，脂肪肝との大きな違いは，比較的早期からLevovist®の肝実質への取り込み低下が起こる点である[15]．このことは筆者らの経験では，線維化の程度が軽度の場合でも取り込みの低下が起こり，線維化が進行するとさらに取り込みが低下する．したがって，何らかの機序でKupffer細胞の貪食機能異常が起こっている可能性が示唆される．しかし，現在のところ，NASHの経過観察例や症例の蓄積が少なく今後の検討が待たれる．

文献

1) Saadeh S, Younossi ZM, Remer EM, et al. The utility of radiological imaging in nonalcoholic fatty liver disease. Gastroenterology 2002 ; 123 : 745-750
2) Taylor KJ, Carpenter DA, Hill CR, et al. Gray scale ultrasound imaging. The anatomy and pathology of the liver. Radiology 1976 ; 119 : 415-423
3) 矢島義昭，太田恵，成井貴，他．脂肪肝の超音波診断肝腎コントラストの意義について．肝臓 1982；23：903-907
4) Ricci C, Longo R, Gioulis E, et al. Noninvasive *in vivo* quantitative assessment of fat content in human liver. J Hepatol 1997 ; 27 : 108-113
5) Ludwig J, Viggiano TR, McGill DB, et al. Nonalcoholic steatohepatitis : Mayo Clinic experiences with a hitherto unnamed disease. Mayo Clin Proc 1980 ; 55 : 434-438
6) Byron D, Minuk G. Clinical hepatology : profile of an urban, hospital-based practice. Hepatology 1996 ; 24 : 813-815
7) 西原利治，小野正文，大西三朗．NASHの診断．日消誌 2004；101：1183-1187
8) Wilson SR, Burns PN, Muradali D, et al. Harmonic hepatic US with microbubble contrast agent : initial experience showing improved characterization of hemangioma, hepatocellular carcinoma, and metastasis. Radiology 2000 ; 215 : 153-161
9) Suzuki S, Iijima H, Moriyasu F, et al. Differential diagnosis of hepatic nodules using delayed parenchymal phase imaging of levovist contrast ultrasound : comparative study with SPIO-MRI. Hepatol Res 2004 ; 29 : 122-126
10) Shimizu M, Iijima H, Horibe T, et al. Usefulness of contrast-enhanced ultrasonography with a new contrast mode, Agent Detection Imaging, in evaluating therapeutic response in hepatocellular carcinoma treated with radio-frequency ablation therapy. Hepatol Res 2004 ; 29 : 235-232
11) 飯島尋子，森安史典．造影超音波検査法の時相—肝腫瘍のKupffer imagingについて．映像情報 2002；34：75-79
12) Albrecht T, Blomley MJ, Burns PN, et al. Improved detection of hepatic metastases with pulse-inversion US during the liver-specific phase of SHU 508 A : multicenter study. Radiology 2003 ; 227 : 361-370
13) Suzuki Y, Fujimoto Y, Hosoki Y, et al. Clinical utility of sequential imaging of hepatocellular carcinoma by contrast-enhanced power Doppler ultrasonograpy. Eur J Radiol 2003 ; 48 : 214-219
14) Takeshita K, Nagashima I, Frui S, et al. Effect of superparamagnetic iron oxide-enhanced MRI of the liver with hepatocellular carcinoma and hyperplastic nodule. J Comput Assist Tomogr 2002 ; 26 : 451- 455
15) Moriyasu F, Iijima H, Tsuchiya K, et al. Diagnosis of NASH using delayed parenchymal imaging of contrast ultrasound. Hepatol Res 2005 ; 33 : 97-99

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Impact of a Left-Lobe Graft Without Modulation of Portal Flow in Adult-to-Adult Living Donor Liver Transplantation

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In adult-to-adult living donor liver transplantation (LDLT), left-lobe grafts can sometimes be small-for-size. Although attempts have been made to prevent graft overperfusion through modulation of portal inflow, the optimal portal venous circulation for a liver graft is still unclear. Hepatic hemodynamics were analyzed with reference to graft function and outcome in 19 consecutive adult-to-adult LDLTs using left-lobe grafts without modulation of graft portal inflow. Overall mean graft volume (GV) was 398 g, which was equivalent to 37.8% of the recipient standard liver volume (SV). The GV/SV ratio was less than 40% in 13 of the 19 recipients. Overall mean recipient portal vein flow (PVF) was much higher than the left PVF in the donors. The mean portal contribution to the graft was markedly increased to 89%. Average daily volume of ascites revealed a significant correlation with portal vein pressure, and not with PVF. When PVP exceeds 25 mmHg after transplantation, modulation of portal inflow might be required in order to improve the early postoperative outcome. Although the study population was small and contained several patients suffering from tumors or metabolic disease, all 19 patients made good progress and the 1-year graft and patient survival rate were 100%. A GV/SV ratio of less than 40% or PVF of more than 260 mL/min/100 g graft weight does not contraindicate transplantation, nor is it necessarily associated with a poor outcome. Left-lobe graft LDLT is still an important treatment option for adult patients.

Key words: Hepatic hemodynamics, portal vein flow, small graft

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Introduction

A crucial prerequisite for living donor liver transplantation (LDLT) is to minimize the morbidity and mortality risk to the healthy living donor. Unfortunately, sporadic donor deaths associated with right-lobe liver transplantation have been reported (1,2). From the viewpoint of minimizing the risk to the donor, left-lobe LDLT could be an ideal option in adult-to-adult LDLT. Kawasaki et al. have reported that a left-lobe graft can maintain good viability and regeneration after adult-to-adult LDLT (3). However, some authors reported that left-lobe grafts are frequently too small for adult recipients, and this may lead to small-for-size (SFS) syndrome (4,5). In the Western world, the concept of left-lobe graft donation for adult recipients has been almost abandoned, without sufficient data having been accumulated. It has been speculated that graft exposure to excessive portal vein flow (PVF) plays a major role in the development of SFS syndrome. Poor graft outcome has been reported in patients with PVF values of more than 260 mL/min 100 g graft weight in LDLT (6). In order to alleviate graft overperfusion, intraoperative modulation of graft portal inflow using techniques such as splenic artery ligation (7,8), splenectomy (8) and portosystemic shunting (9–12) has been attempted. However, hepatic hemodynamic data after adult-to-adult LDLT with a left lobe are limited, and the correlation between portal venous circulation and SFS syndrome remains unclear. In the present study, we evaluated the impact of using left-lobe grafts without modulation of graft portal inflow on the outcome of adult-to-adult LDLT.

Patients and Methods

Patients

Between January 2004 and April 2007, a total of 26 consecutive LDLTs were performed at Juntendo University Hospital after obtaining approval from the Ethics and Indication Committee of Juntendo University School of Medicine. Among the LDLT recipients, seven were pediatric patients younger than 2 years. Therefore, in the present study the remaining 19 adults (age ≥18 years) were included. The median age of the recipients was 57 years (range, 22–68 years) and twelve of them were women. The underlying disease necessitating liver transplantation was hepatitis B or C virus-related cirrhosis in 10 cases (seven of which were complicated by hepatocellular carcinoma), alcoholic cirrhosis in 1 (one of which was complicated by hepatocellular carcinoma), liver cirrhosis unknown etiology in 1 (one of which was complicated by hepatocellular carcinoma), biliary atresia in 2, Alagille syndrome in 1, primary sclerosing cholangitis in 1, primary biliary cirrhosis in 1, adult-onset type II citrullinemia in 1 and epithelioid hemagioendothelioma in 1. The overall model for end-stage liver disease (MELD) score calculated for the liver recipients before LDLT was 14 ± 6 (median; 14, range: 6–24); the MELD score was ≤20 in 4, 10–19 in 10 and ≤ 9 in 5. Among the 19 recipients, nine had Child-Pugh class C disease, five had class B disease and five had class A disease.

Graft selection criteria

We have used only a left-lobe graft, and have not performed right-lobe LDLT, as there is no doubt that right hepatic lobectomy places a serious burden on the donor. Standard liver volume (SV) of recipients was calculated according to the formula of Urata et al. (13). Estimated graft volume (GV) was predicted from the results of CT volumetric analysis. Actual GV was measured on the back table. Our general selection criteria for grafts in adult-to-adult LDLT included an estimated graft volume-to-recipient standard liver volume (GV/SV) ratio equal to or greater than 30%.

Surgical technique

Donor hepatectomy (whole left lobectomy including the middle hepatic vein) and the recipient's operation were performed as described previously (3). Briefly, the left hepatic vein and middle hepatic vein in the recipient were used for venoplasty. If necessary, hepatic graft venoplasty was also carried out using the left and middle hepatic veins. In one donor in whom segment 6 drained through the middle hepatic vein, a whole left graft without the middle hepatic vein was recovered. The left medial vein draining segment 4 joined the middle hepatic vein, and this vein and the left hepatic vein were divided separately in this donor. Venoplasty was then carried out on the back table to form a common trunk for the drainage vein of the graft. After venoplasty, end-to-end anastomosis of the hepatic veins was performed, the donor left portal vein was anastomosed to the recipient left portal vein, and the graft was reperfused. The donor left hepatic artery was anastomosed to either the recipient right hepatic artery or the left hepatic artery, depending on the size match, under direct observation with an operating microscope. All LDLTs were carried out without any modification of the graft portal inflow using techniques such as splenectomy, splenic arterial ligation and porto-systemic shunt.

Measurement of hemodynamics

In the 17 most recent cases, intraoperative blood flow measurements were taken with an ultrasonic transit time flow meter (Transonic System, Ithaca, NY) in both the donors and recipients, and expressed as both total mL/min and mL/min per 100 g graft weight. Donor left PVF and donor left hepatic artery flow (HAF) were measured before starting dissection of the liver parenchyma. In the recipient, after anastomosis of all the vessels and 15 min of equilibration, but before biliary reconstruction, the recipient PVF and recipient HAF were measured. The probes were applied just distal to the anastomosis. In the 10 most recent cases, the portal vein pressure (PVP) was measured by direct puncture with a 25-gauge needle and pressure tubing attached to the normal central venous pressure monitoring transducer. The portal vein resistance (PVR) was calculated by dividing PVP by PVF.

Postoperative care

The initial immunosuppressive regimen consisted of FK 506 and prednisone. Intensive anticoagulant treatment, carried out for more than 2 weeks after LDLT, included administration of low-dose heparin, antithrombin III and fresh-frozen plasma (FFP) containing protein C and S, and maintenance of hematocrit within the range 20–30%. Postoperative ascites production removed through indwelling drains was balanced by infusion of FFP according to the protein level in the ascites to maintain the serum protein level within the normal range.

Statistical analysis

Continuous variables were expressed as mean ± SD or the median with range, and statistical analysis of hemodynamic data was done using a paired samples t-test. Other continuous variables were compared by Student's t-test and categorical variables were compared by the chi-squared test. Linear regression was used to compare the relationship between continuous variables. Calculations were made using StatView computer software (SAS Institute Inc., NC). Differences at $p < 0.05$ were considered to be statistically significant.

Results

Liver grafts

Overall mean real GV was 398 ± 70 g (Median 400 g, range, 280–570 g), which was equivalent to 37.8 ± 5.5% (Median 38.0%, range, 26.1–47.6%) of the recipient SV. The graft-to-recipient weight ratio was 0.81 ± 0.14 (Median 0.84, range, 0.48–1.03). The GV/SV ratio was less than 40% in 13 of the 19 cases and the graft-to recipient weight ratio was less than 1.0 in 17 of the 19 recipients.

Surgical data

Seven of the 19 recipients had a history of previous abdominal surgery (Kasai procedure in two, right lobectomy in one, splenectomy in one, gastrectomy in one, cesarean section in one and cholangiographic procedure in one). Five had undergone previous ablation therapy for hepatocellular carcinomas. Median recipient operation time was 15.6 h (range, 11.9–23.3 h), with a median blood loss of 1570 mL (range, 75–12775 mL). Median transfusion volume of packed red blood cells was 0 mL (range, 0–4450 mL) and median transfusion volume of fresh frozen plasma was 1820 mL (range, 0–5695 mL). Median blood loss according to the Child classification was 1000 mL (range, 75–1.980 mL) for Child class A, 1505 mL (range, 660–3050 mL) for Child class B, and 4027 mL (range, 810–12775 mL) for Child class C. Blood loss of Child class C patients was significantly higher that of class A or B patients ($p = 0.025$, $p = 0.049$, respectively).

Hepatic hemodynamics

In the recipients, the mean PVF following portal and arterial reperfusion was much higher than the left PVF in the donors, whereas the mean HAF was almost the same as the HAF to the left lobe in the donors (Table 1). The mean portal contribution to the graft was markedly increased to 89 ± 11% (Table 1). A weak negative correlation was recognized between the GV/SV ratio and the PVF/100 g graft weight (Figure 1). The PVF/100 g graft weight was more than 260 mL/min/100 g graft weight in 11 out of 17 cases, the maximum being 833 mL/min/100 g graft weight. The mean PVP before transplantation was 16.5 mmHg (Median 15.5 mmHg, range 9–28 mmHg) and the value after transplantation was 20.5 mmHg (Median 19.5 mmHg, range 16–26 mmHg). PVP before graft implantation showed no correlation with PVF, PVF/100 g graft weight or PVR after transplantation. PVP after transplantation showed no correlation with PVF or PVF/100 g

Table 1: Hepatic hemodynamics of the left lobe measured before resection from the donor and after transplantation ($n = 17$)

Hemodynamic measurement	Donor	Recipient	p-Value*
Portal vein flow (mL/min)	217 ± 103	1341 ± 692	$p < 0.001$
Hepatic artery flow (mL/min)	149 ± 101	133 ± 121	$p = 0.713$
Portal contribution to the graft (%)	61 ± 23	89 ± 11	$p < 0.001$

Data are expressed as mean ± SD.
*A-paired sample *t*-test.

graft weight, but was significantly correlated with PVR after transplantation ($Y = -0.038 + 0.00320X$, $R2 = 0.465$, $p = 0.030$).

Postoperative graft function

Most of the liver grafts were immediately functional and showed progressive normalization. In 15 of the 19 patients, the serum levels of aminotransferase (AST) values on day 14 after LDLT returned to less than 100 IU/L, and in 16 of the 19 patients total bilirubin levels on day 14 after LDLT returned to less than 3.0 mg/dL in spite of the small GV/SV ratio. PVF, PVF/100 g graft weight, PVP or PVR after transplantation did not show any correlation with total bilirubin levels on day 14 after transplantation. Three patients had prolonged cholestasis that persisted to postoperative day 14. One of them developed early recurrent hepatitis with an elevated bilirubin level, but this gradually decreased to less than 3.0 mg/dL within several weeks as a result of response to therapy with interferon-alpha and ribavirin. In one patient, pulmonary tuberculosis that occurred soon after transplantation might have been related to the prolonged elevation of the bilirubin level. Postoperative complications are summarized in (Table 2). Episodes of rejection were encountered in four patients, each of which was treated successfully with steroid bolus therapy.

There were no vascular complications during the postoperative course in any of the 19 patients. The recipient who developed pulmonary tuberculosis responded gradually to anti-tuberculosis therapy. Although significant ascites production (average daily volume of ascites during the first 2 weeks >1000 mL) was recognized in 6 patients, all 19 patients progressed well and persistent ascites was not recognized. Median period until the daily volume of ascites was less than 200 mL was 16 days (range, 1–51 days). Median period during which indwelling drains were placed was 44 days (range, 18–154 days). Although PVF, PVF/100 g graft weight or PVR did not show any correlation with average daily volume of ascites during the first 2 weeks, PVP after transplantation revealed a significant correlation with average daily volume of ascites during the first 2 weeks (Figure 2). While there was no correlation between the incidence of posttransplant complications and preoperative MELD score, Child–Pugh classification was significantly correlated with posttransplant complications (Table 3). Overall patient and graft survival rates at 1 year were 100%, with median follow-up period of 2 years.

Discussion

The hemodynamics of standard liver transplantation have already been characterized, and increased portal flow is a common feature (14,15). Partial liver grafts are exposed to even higher portal inflow (16). The present study has shown that after reperfusion of a left-lobe graft, the hemodynamic changes are much more pronounced than those occurring in deceased donor liver transplantation, and are inversely correlated with the GV/SV ratio. An increase in flow of this magnitude could be predicted if it is assumed that a left-lobe graft, representing about 30–40% of the mass of the native organ, must passively receive all of the native portal inflow. Although HAF in the recipient was not

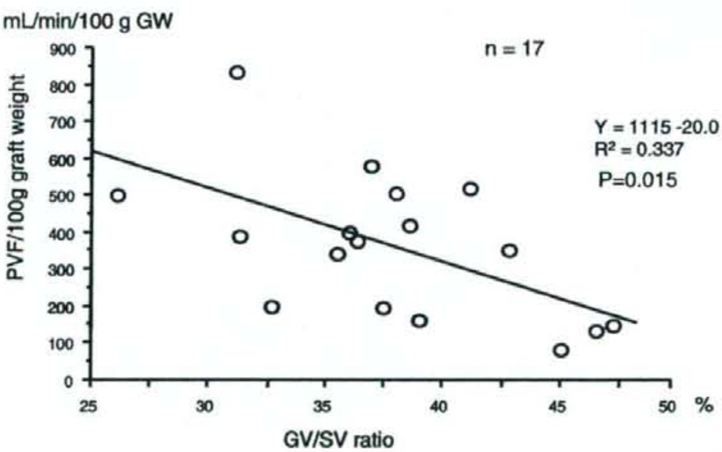

Figure 1: Correlation between GV/SV ratio and portal vein flow/100 g graft weight.

Table 2: Posttransplant complications

Complications	Number
Rejection	4
HCV recurrence	4
Gastro-intestinal bleeding	2
Acute renal failure	3
Massive ascites	6
Tuberculosis	1

Table 3: Posttransplant complications based on MELD and Child–Pugh classification

	Complication (–)	Complication (+)	p-Value*
MELD score (≤9/10–19/20≤)	3/2/0	2/8/4	0.236
Child–Pugh (A/B/C)	3/2/0	2/3/9	0.015

*The chi-square test.

significantly decreased in comparison with that to the left lobe in the donor, the mean portal contribution to the graft was increased to 89%.

In deceased donor liver transplantation using a whole liver graft, the mean PVF has been reported to be around 130 mL/min/100 g graft weight (14). Based on this figure, Shimamura et al. classified patients into two groups: one with a PVF of 260 mL/min/100 g graft weight (twice the mean PVF after whole liver graft reperfusion) or higher, and one with a PVF less than this value. They concluded that patients with a PVF exceeding 260 mL/min/100 g graft weight were characterized by a smaller GV/SV ratio and a significantly higher peak total bilirubin level with a consequently poor outcome, compared with the other group (6). Accordingly, to avoid graft congestion due to excessive portal perfusion, several techniques for modulation of graft portal inflow, such as splenic artery ligation (7,8), splenectomy (8) and portosystemic shunt (9–12), has been applied to LDLT. Troisi et al. claimed that the PVF should be reduced to less than 250 mL/min/100 g graft weight using graft inflow modification (7,12). In the present series, all the LDLTs were achieved without any intraoperative modulation of graft portal inflow, and the PVF exceeded 260 mL/min/100 g graft weight in 11 out of 17 cases, the maximum being 833 mL/min/100 g graft weight. Some of the patients who indeed showed signs of SFS syndrome such as prolonged ascites or cholestasis would have had

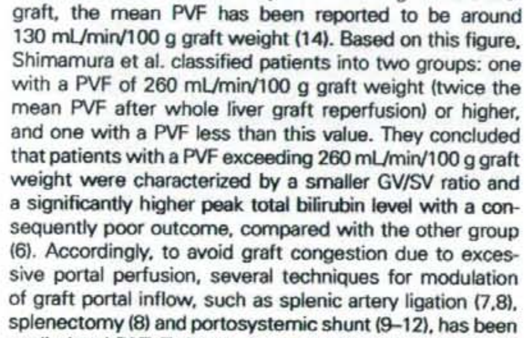

Figure 2: Correlation between average daily production of ascites during the first 14 postoperative days and posttransplant portal vein pressure.

a smoother course with graft inflow modulation. However, data on hepatic hemodynamics after adult-to-adult LDLT are limited, and the optimal portal venous circulation for a liver graft has not been still unclear.

Intractable ascites is one of the complications associated with SFS syndrome. PVP showed a significant correlation with daily production of ascites during the first 14 postoperative days. It is well known that leakage of ascites into the peritoneal space occurs as a result of sinusoidal hypertension (17). An increase in portal pressure may cause elevation of hydrostatic pressure within the liver sinusoids. Yagi et al. reported that early elevation of postoperative PVP to 20 mmHg or more was associated with a poor outcome and graft dysfunction with hyperbilirubinemia, coagulopathy and severe ascites (18). In the present study, daily production of ascites exceeding 1000 mL during the first 14 postoperative days appeared to require a minimal PVP of 25 mmHg. Although significant ascites was observed in five patients, ascites production was balanced by infusion of FFP, and in all patients the drainage tube was removed within a few weeks. However, when PVP exceeds 25 mmHg after transplantation, some attempt to modulate portal venous circulation might be required in order to improve the early postoperative course.

In split liver transplantation and LDLT, a GV/SV ratio of ≥40% (19,20) or a graft-to-recipient weight ratio (GRWR) of ≥0.8% (21) is recommended to achieve good graft and patient survival rates. On the other hand, experience gained in hepatic surgery has shown that an extended hepatectomy of up to 70–75% of the whole liver can be tolerated in noncirrhotic patients (22). Although this cannot be translated directly into a lower GV limit in LDLT, the reported minimum GV for successful adult-to-adult LDLT is 20% of the GV/SV ratio (11). While the sample was small and included several patients suffering from tumors or metabolic disease, the present series showed good results for 19 adult recipients including 13 with a GV/SV ratio of less than 40%, the smallest of which was 26%, and 17 with a GRWR of less than 1.0%, the smallest of which was 0.48%. We believe that optimal outcome is dependent on early recognition of complications and immediate postoperative management. Based on our results it is highly unlikely that adult-to-adult LDLT using a left-lobe graft with a GV/SV ratio of less than 40% is a contraindication for patients with end-stage liver cirrhosis. Although use of a left-lobe graft in LDLT may be disadvantageous for the recipient in comparison with right-lobe grafting, left-lobe graft LDLT is still an important option provided that the benefit to the recipient is balanced against the safety of the donor.

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References

1. Surman OS. The ethics of partial-liver donation. N Engl J Med 2002; 346: 1038.
2. Broering DC, Wilms C, Bok P et al. Evolution of donor morbidity in living related liver transplantation: A single-center analysis of 165 cases. Ann Surg 2004; 240: 1013–1024.
3. Kawasaki S, Makuuchi M, Matsunami H et al. Living related liver transplantation in adults. Ann Surg 1998; 227: 269–274.
4. Kiuchi T, Tanaka K, Ito T et al. Small-for-size graft in living donor liver transplantation: how far should we go? Liver Transpl 2003; 9: S29–S35.
5. Tucker ON, Heaton N. The "small for size" liver syndrome. Curr Opin Crit Care 2005; 11: 150–155.
6. Shimamura T, Taniguchi M, Jin MB et al. Excessive portal venous flow as a cause of allograft dysfunction in small-for-size living donor liver transplantation. Transplant Proc 2001; 33: 1331.
7. Troisi R, Cammu G, Militerno G et al. Modulation of portal graft inflow: a necessity in adult living-donor liver transplantation? Ann Surg 2003; 237: 429–436.
8. Shimada M, Ijichi H, Yonemura Y et al. The impact of splenectomy or splenic artery ligation on the outcome of a living donor adult liver transplantation using a left lobe graft. Hepato-gastroenterol 2004; 51: 625–629.
9. Boillot O, Delafosse B, Mechet I, Boucaud C, Pouyet M. Small-for-size partial liver graft in an adult recipient: A new transplant technique. Lancet 2002; 359: 406–407.
10. Takada Y, Ueda M, Ishikawa Y et al. End-to-side portocaval shunting for a small-for-size graft in living donor liver transplantation. Liver transpl 2004; 10: 807–810.
11. Masetti M, Siniscalchi A, De Pietri L et al. Living donor liver transplantation with left liver graft. Am J Transplant 2004; 4: 1713–1716.
12. Troisi R, Ricciardi S, Smeets P et al. Effects of hemi-portocaval shunts for inflow modulation on the outcome of small-for-size grafts in living donor liver transplantation. Am J Transplant 2005; 5: 1397–1404.
13. Urata K, Kawasaki S, Matsunami H et al. Calculation of child and adult standard liver volume for liver transplantation. Hepatology 1995; 21: 1317–1321.
14. Paulsen AW, Klintmalm GB. Direct measurement of hepatic blood flow in native and transplanted organs, with accompanying systemic hemodynamics. Hepatology 1992; 16: 100–111.
15. Payen DM, Fratacci MD, Dupuy P et al. Portal and hepatic arterial blood flow measurements of human transplanted liver by implanted Doppler probes: Interest for early complications and nutrition. Surgery 1990; 107: 417–427.
16. Marcos A, Olzinski AT, Ham JM, Fisher RA, Posner MP. The interrelationship between portal and arterial blood flow after adult to adult living donor liver transplantation. Transplantation 2000; 70: 1697–1703.
17. Garcia-Tsao G. Ascites. In: Boyer TD, Wright TL, Manns MP, eds. Zakim and Boyer's hepatology: A textbook of liver disease, 5th Ed. Philadelphia, PA: Saunders; 2006:333–346.
18. Yagi S, Iida T, Taniguchi K, Hori T et al. Impact of portal venous pressure on regeneration and graft damage after living-donor liver transplantation. Liver Transpl 2005; 11: 68–75.
19. Lo CM, Fan ST, Liu CL et al. Minimum graft size for successful living donor liver transplantation. Transplantation 1999; 68: 1112–1116.
20. Soejima Y, Shimada M, Suehiro T et al. Outcome analysis in adult-to-adult living donor liver transplantation using the left lobe. Liver Transpl 2003; 9: 581–586.
21. Kiuchi T, Kasahara M, Uryuhara K et al. Impact of graft size mismatching on graft prognosis in liver transplantation from living donors. Transplantation 1999; 67: 321–327.
22. Fan ST, Lo CM, Liu CL, Yong BH, Chan JK, Lin IO. Safety of donors in live donor liver transplantation using right lobe grafts. Arch Surg 2000; 135: 336–340.

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Hepatectomy using traditional Péan clamp–crushing technique under intermittent Pringle maneuver

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KEYWORDS:
Blood loss;
Blood transfusion;
Clamp-crushing technique;
Fresh frozen plasma;
Hepatectomy;
Morbidity;
Mortality

Abstract

BACKGROUND: The clamp-crushing technique has been proved to be the most cost-efficient approach for hepatectomy. If the advantageous characteristics, such as lower blood loss and morbidity, could be utilized, this method could be ideal.

METHODS: The records of 380 patients who underwent hepatectomy using the clamp-crushing technique with intermittent inflow occlusion between 2002 and 2006 were retrospectively reviewed. One hundred fifty patients underwent major hepatectomy, and 230 underwent minor hepatectomy.

RESULTS: Thirteen (3.4%) patients received red cell transfusion, and 21 (5.5%) patients received fresh frozen plasma. According to Clavien's classification system, grade I complications occurred in 42 (11.1%), grade II in 32 (8.4%), grade III in 14 (3.7%), grade IV in 1 (0.3%), and grade V in 2 (0.5%) patients. Female sex, preoperative albumin-to-globulin ratio, and type of resection were independent factors predictive of blood loss.

CONCLUSIONS: The present patient series, who underwent traditional Péan clamp–crushing technique under intermittent Pringle maneuver, had a low risk of complications. This procedure is an acceptable technique for hepatic parenchymal transection.

Primary and metastatic hepatic neoplasms can be resected safely, in many cases altering their natural course. Although recent surgical mortality rates have approached 0%, historically, the major pitfall of liver surgery has been intraoperative blood loss; therefore, control of hemorrhage remains a mainstay of liver resection.[1,2] Technical innovations have focused mainly on minimizing bleeding during transection of the hepatic parenchyma because excessive hemorrhage and the need for blood transfusion are associated with increased postsurgical morbidity[3,4] as well as poorer long-term outcome of patients with primary and secondary malignancies.[5–7] The clamp-crushing technique under inflow occlusion (Pringle maneuver) has been traditionally used for hepatic resection because of its effectiveness in controlling blood loss as well as its speed and low cost, which make it the "gold standard" of comparison against which any new technique is measured. However, assuming that inflow occlusion causes significant damage because of ischemia and reperfusion, there has been a growing interest in new devices that can facilitate bloodless transection, thus obviating the need for inflow occlusion. Although various techniques have been used–including ultrasonic dissection,[8] the Cavitron ultrasonic surgical aspirator (Valleylab, Boulder, Colorado),[9] sharp transection,[10] the LigaSure vessel sealing system (Valleylab),[11] and heat coagulation[12] with or without inflow occlusion–each of these

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techniques has its merits and demerits and lacks a compelling reason for adoption. For the last 4 years, we have applied the Péan clamp–crushing technique under intermittent inflow occlusion for hepatectomy. In this study, we carried out a retrospective review of our hepatectomy cases to reconsider the adequacy and safety of this traditional dissection method.

Patients and Methods

Between October 2002 and May 2007, 421 patients underwent liver resection at Juntendo University Hospital. Among them, we reviewed a cohort of 380 adult patients who were considered for elective hepatic resection with the clamp-crushing technique using intermittent Pringle maneuver. There were 119 women and 261 men, with a mean age of 63 ± 11 years (range 21 to 89). Hepatic resection was performed for hepatocellular carcinoma (n = 136), cholangiocellular carcinoma (n = 15), metastatic liver tumor (n = 152), hilar bile duct carcinoma (n = 21), gallbladder carcinoma (n = 24), and other tumors (n = 32). Seventy-two hepatectomies were carried out in patients with liver cirrhosis. Our criteria for hepatectomy were that ascites was not detected or was controlled, and the serum bilirubin level was <2.0 mg/dL. Indocyanine-green retention rate at 15 minutes (ICG-R_{15}) was the main determinant of resectability. For example, right-sided hepatectomy can be tolerated if ICG-R_{15} is <10%. For patients with ICG-R_{15} 10% to 19%, one third of the liver parenchyma can be resected, which corresponds to left-sided hepatectomy and right-sided anterior or posterior sectionectomy. When ICG-R_{15} ranges from 20% to 29%, approximately one sixth of the liver parenchyma can be resected. This resection is roughly equivalent to Couinaud segmentectomy. Limited resection is indicated in patients with ICG-R_{15} ≥30%.[1] Inclusion criteria for this study were based on tumor location and type of resection, with major hepatectomy defined as removal of at least one Couinaud sector, minor hepatectomy as segmentectomy or systematic subsegmentectomy, and limited resection as nonanatomic tumor removal. Indications for resection and the types of hepatectomy are listed in Table 1.

Table 1 Indications for resection and types of hepatectomy

Indication	No. with major hepatectomy	No. with minor hepatectomy	Total
Primary liver tumor			
Hepatocellular carcinoma	36	100	136
Cholagiocellular carcinoma	12	3	15
Metastatic liver tumor			
Colorectal metastasis	51	76	127
Other metastasis	9	16	25
Biliary malignancy			
Hilar bile duct carcinoma	21	0	21
Gallbladder carcinoma	4	20	24
Other	17	15	32
Total	150	230	380

Surgical technique

After an ultrasonographic study, the gallbladder was removed, if necessary, and the liver was mobilized. For 380 patients the intermittent Pringle maneuver was applied at the time of liver transection and consisted of cross-clamping the hepatoduodenal ligament (and the aberrant left hepatic artery, if present) using a Satinsky clamp for 15 minutes and releasing the clamp for 5 minutes until the liver resection was completed. Liver transection was performed in all patients by the traditional Péan clamp–crushing method.[13] A small amount of the hepatic parenchyma was divided by penetration with a Péan forceps. The remaining side of the parenchyma was ligated and divided with scissors, and any bleeding or bile leakage points were fine sutured. A sufficient level of anesthesia was maintained; an adequate dose of muscle relaxant was given; and tidal volume of the ventilation was reduced to 30% to 40% of the standard volume in an attempt to decrease thoracic pressure. By using a combination of anesthesia and early intraoperative fluid restriction, central venous pressure was controlled at <5 cm H_20 to decrease venous hemorrhage during transection. Red blood cells were not transfused unless hematocrit decreased to approximately <25% during surgery or <20% on the postsurgical day. Fresh frozen plasma (FFP) was generally transfused in patients with postsurgical prothrombin time (PT) <50% or who had massive blood loss either during surgery or during the first 24 hours after resection. Total hepatic vascular exclusion was not used in any patient, and no patients in the present series had hemodilution nor intraoperative or postsurgical autotransfusion. The amount of intraoperative blood loss was measured from the volume of blood collected in the container of the aspirator and the weight of the soaked gauzes.

Data presentation and statistical analysis

Preoperative, intraoperative, and postsurgical data were collected on a prospective computerized database. Values are expressed as median (range). Intraoperative blood transfusion was defined as the volume of packed red cells or FFP transfused during surgery and the immediate postsurgical period. Main outcome measures were morbidity and perioperative mortality. Morbidity was defined as any perioperative complication, including biliary complication, sepsis of any etiology, and pulmonary, cardiac or wound complications. Ascites or pleural effusion that required diuretics or paracentesis was also included as morbidity. Wound infection was diagnosed by positive culture of micro-organisms

Table 2 Surgical data and postsurgical complications for 380 hepatectomies

Variables	Major hepatectomy (n = 150)	Minor hepatectomy (n = 230)	Total (n = 380)
Mean (range) cumulative clamping time (min)	79 (37–325)	44 (7–172)	62 (7–325)
No. (range) of clamps	5 (3–19)	3 (1–11)	4 (1–19)
Mean ± SD (average, range) operative time (min)	405 ± 175 (355, 66–1145)	339 ± 131 (311, 175–1075)	349 (45–1145)
Mean blood loss (mL)	522 (30–3820)	260 (11–2050)	359 (11–3820)
No. (%) of patients with red cell transfusion	8 (5.3)	5 (2.2)	13 (3.4)
No. (%) of patients with FFP transfusion	12 (8.0)	9 (3.9)	21 (5.5)
Maximum level (range) of aspartate aminotransferase (IU/L)	318 (92–2115)	188 (51–1422)	241 (51–2115)
Maximum level (range) of total bilirubin (mg/dL)	1.63 (.64–7.24)	1.33 (.46–3.90)	1.38 (.46–7.24)
No. (%) of overall complications	40 (26.7)	51 (22.2)	91 (23.9)
No. (%) of grade I complications	23 (15.3)	19 (8.2)	42 (11.1)
No. (%) of grade II complications	8 (5.3)	24 (1.4)	32 (8.4)
No. (%) of grade IIIa complications	6 (4.0)	5 (2.2)	11 (2.9)
No. (%) of grade IIIb complications	2 (1.3)	1 (.4)	3 (.8)
No. (%) of grade IVa complications	0 (0)	1 (.4)	1 (.3)
No. (%) of grade IVb complications	0 (0)	0 (0)	0 (0)
No. (%) of grade V complications	1 (.7)	1 (.4)	2 (.5)
No. (%) of perioperative deaths (within 30 days after hepatectomy)	0 (0)	0 (0)	0 (0)

from the wound. All accumulated abdominal fluids were drained percutaneously and sent for bacterial culture, and the bilirubin level was monitored to detect any biliary leakage. We diagnosed biliary leakage when the drainage fluid was found to contain a bilirubin concentration >3 times the upper limit in serum measured after surgery. Morbidities were graded according to the classification system proposed by Clavien et al,[14] which consists of 5 major grades with subdivisions. Perioperative death was defined as death within 30 days after hepatectomy.

The following data were analyzed to determine the predictive risk of intraoperative blood loss: sex, age, preoperative ICG-R_{15}, hematocrit, hemoglobin, platelet count, PT (%), total bilirubin level, albumin level, albumin-to-globulin ratio (A/G ratio), surgical procedure (major vs minor), and presence of additional procedure(s). Multiple linear regression was used to evaluate the predictive factors of intraoperative bleeding, and $P < .05$ was considered statistically significant. Calculations were made using statistical computer software (JMP; SAS, Cary, North Carolina).

Results

Surgical data and postsurgical complications for the 380 hepatectomies are listed in Table 2. Eight patients who underwent major hepatectomy and five who underwent minor hepatectomy received perioperative red cell transfusion. Twelve patients who underwent major hepatectomy and nine who underwent minor hepatectomy received perioperative FFP.

The respective incidences of complications by diagnosis are listed in Table 3. After surgery, 91(23.9%) of the 380 patents suffered 106 complications, 88 of which were classified as grade I to II. Fifteen events were classified as grade IIIa to IIIb complications: infection (n = 2), effusion (n = 8), bile leakage (n = 2), postsurgical bleeding (n = 2), and postsurgical wound dehiscence requiring resurgery (n = 1). One case classified as grade IVa was pulmonary embolism requiring artificial ventilation. Although no perioperative death occurred, 1 patient died 4 months after minor hepatectomy from severe interstitial pneumonia, and another patient died 3 months after extended left lobectomy from rapid recurrence of cholangiocellular carcinoma.

Table 3 Incidences of complications by diagnosis

Grade	Total no. (%)	Complications					
		Infection	Effusion	Bile leakage	Bleeding	Cardiopulmonary	Miscellaneous
I	52 (13.7)	23	3	18	2	0	6
II	36 (9.5)	17	17	0	1	1	0
IIIa	12 (3.2)	2	8	2	0	0	0
IIIb	3 (0.8)	0	0	0	2	0	1
IVa	1 (0.3)	0	0	0	0	1	0
IVb	0 (0)	0	0	0	0	0	0
V	2 (0.5)	0	0	0	0	1	1
Total (%) of 380 patients	106 (28.9)	42 (11.0)	28 (7.4)	20 (5.3)	5 (1.3)	3 (0.8)	8 (2.1)

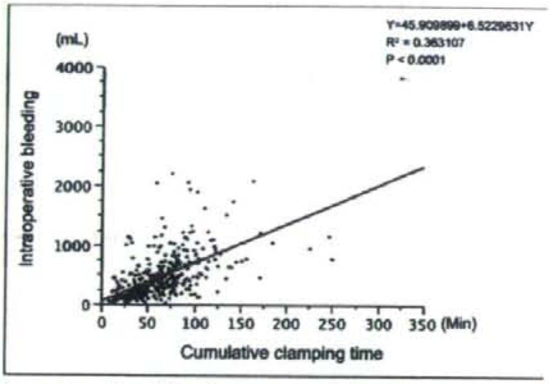

Figure 1 Correlation between cumulative clamping time and intraoperative bleeding.

Figure 1 shows the significant correlation between cumulative clamping time and intraoperative blood loss ($r^2 = .321091$, $P < .0001$). Figure 2 shows the significant correlation between maximum postsurgical aspartate aminotransferase levels and duration of ischemia ($r^2 = 0.321091$, $P < 0.0001$). However, changes in serum enzyme levels were always transient, with a tendency to return toward the preoperative level within 4 weeks.

Preoperative and intraoperative clinical factors that influenced intraoperative blood loss are shown in Table 4. Multiple linear regression analysis showed that female sex, preoperative A/G ratio, and type of resection (minor vs major) were independent factors significantly predictive of lower blood loss. The other variables, including patient age, platelet count, PT, total bilirubin level, and additional procedure did not influence intraoperative blood loss.

Comments

Effort to improve surgical techniques and minimize intraoperative blood loss can be effective for decreasing postsurgical morbidity and mortality.[3,4] Although some series have demonstrated that blood transfusion–free liver resection is possible, blood transfusion rates for patients undergoing hepatectomy are generally approximately 10% to 40%.[1,2,15–18] All of the operations in the present series were performed using the classical clamp-crushing technique with Péan forceps under routine intermittent inflow occlusion and low central venous pressure (CVP) anesthesia. To ensure technical standardization, all operations were performed by the same surgical team. Use of this technique lowered the transfusion rate: among 380 patients, only 13 (3.4%) received perioperative red cell transfusion, and 21 (5.5%) received perioperative FFP.

Although mortality rates after liver resection have decreased in recent years, complication rates remain high. Morbidity rates in large studies of unselected patients range from 22% to 45%.[3,16,19,20] Virani et al[4] reported that 22.6% of patients in the Patients Safety in Surgery sample experienced at least one complication, and 5.2% underwent a second surgery for complications. There has been considerable variation in both the reported rates and definitions of morbidity in the literature. Clavien's grading system was designed to classify deviations from the normal postsurgical course based on the therapy used to treat a specific complication.[14] We adapted this novel complication classification system to a large cohort of patients who underwent hepatectomy at Juntendo University Hospital. Complications were documented in 28.9% of patients, and 4.7% had severe (grade III to V) complications. Bile leakage remains a challenging complication, occurring in 5% to 14% of patients undergoing hepatectomy.[21,22] Symptomatic leakage requiring intervention occurred in .5% of patients. Postsurgical bleeding occurred in 5 patients (1.3%), 2 of whom (.5%) required reoperation.

In the present series, sex, preoperative A/G ratio, and type of surgical procedure were independently and significantly correlated with a risk of blood loss. The fact that men showed greater blood loss than women is not surprising because sex could merely be a surrogate for body size. Preoperative A/G ratio was significantly associated with intraoperative blood loss. Gozzetti et al[23] reported that serum albumin and bilirubin levels significantly affected the need for blood transfusion during resection of cirrhotic liver. Decreased albumin synthesis and hypoalbuminemia are well-documented consequences of chronic liver disease, and patient plasma albumin concentration has often been predictive of adverse outcome in a variety of hospitalized patients.[24] Hyperglobulinemia is also a well-recognized feature of chronic liver disease and appears to result mainly from increased levels of immunoglobulins.[25] In patients who have chronic liver disease with portal hypertension and intrahepatic portal-systemic shunting, 2 major mechanisms can be proposed to explain the increased systemic antigenic stimulus resulting in hyperglobulinemia.[26] The A/G ratio has more power to predict preoperative liver function and

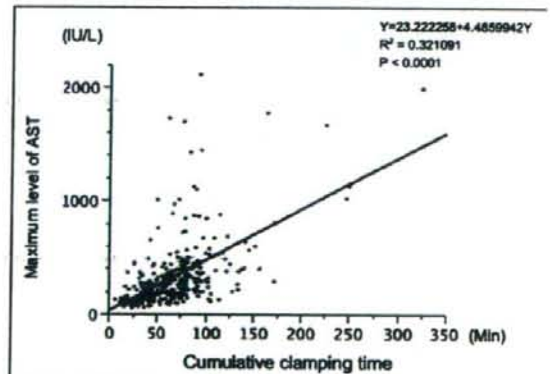

Figure 2 Correlation between cumulative clamping time and maximum aspartate aminotransferase (AST) level.

Table 4 Preoperative and intraoperative clinical factors that influenced intraoperative blood loss

Preoperative variables	Coefficient	SE	*t*	*P*
Sex (female/male)	−123.5205	28.40948	−4.35	<.0001
Age (y)	−1.368816	2.614537	−.52	.6011
ICG-R_{15}	−3.49992	4.781418	−.73	.4648
Platelet count	.7671422	3.943362	.19	.8459
Total bilirubin level	54.535212	80.34699	.68	.4979
Albumin	−92.51502	75.48989	−1.23	.2215
A/G ratio	−269.1654	129.3172	−2.08	.0384
PT	−.0713	3.011837	−.02	.9811
Type of operation (minor/major)	121.12174	28.15065	4.30	<.0001
Additional procedure (yes/no)	−42.80872	35.42681	−1.21	.228

liver fibrosis and may be related to degree of intraoperative blood loss. There was significantly more bleeding in the major hepatectomy group, which could have been related to longer transection time required. Intraoperative blood loss showed a significant correlation to duration of clamping time. The lower transfusion rate may have been caused partly by the fact that approximately 60% of the hepatectomies in this series were minor.

In conclusion, liver resection using the Péan clamp–crushing technique with intermittent inflow occlusion appears to be associated with less blood loss, lower frequency of blood and plasma transfusion, and lower morbidity.

References

1. Imamura H, Seyama Y, Kokudo N, et al. One thousand fifty-six hepatectomies without mortality in 8 years. Arch Surg 2003;138:1198–1206.
2. Fan ST, Lo CM, Liu CL, et al. Hepatectomy for hepatocellular carcinoma: toward zero hospital deaths. Ann Surg 1999;229:322–30.
3. Wei AC, Tung-Ping Poon R, Fan ST, et al. Risk factors for perioperative morbidity and mortality after extended hepatectomy for hepatocellular carcinoma. Br J Surg 2003;90:33–41.
4. Virani S, Michaelson JS, Hutter MM, et al. Morbidity and mortality after liver resection: results of the patient safety in surgery study. J Am Coll Surg 2007;204:1284–92.
5. Laurent C, Sa Cunha A, Couderc P, et al. Influence of postoperative morbidity on long-term survival following liver resection for colorectal metastases. Br J Surg 2003;90:1131–6.
6. Liu CL, Fan ST, Cheung ST, et al. Anterior approach versus conventional approach right hepatic resection for large hepatocellular carcinoma: a prospective randomized controlled study. Ann Surg 2006;244:194–203.
7. Kooby DA, Stockman J, Ben-Porat L, et al. Influence of transfusions on perioperative and long-term outcome in patients following hepatic resection for colorectal metastases. Ann Surg 2003;237:860–9.
8. Schmidbauer S, Hallfeldt KK, Sitzmann G, et al. Experience with ultrasound scissors and blades (UltraCision) in open and laparoscopic liver resection. Ann Surg 2002;235:27–30.
9. Takayama T, Makuuchi M, Kubota K, et al. Randomized comparison of ultrasonic vs clamp transection of the liver. Arch Surg 2001;136:922–8.
10. Smyrniotis V, Arkadopoulos N, Kostopanagiotou G, et al. Sharp liver transection versus clamp crushing technique in liver resections: a prospective study. Surgery 2005;137:306–11.
11. Saiura A, Yamamoto J, Koga R, et al. Usefulness of LigaSure for liver resection: analysis by randomized clinical trial. Am J Surg 2006;192:41–5.
12. Zhou XD, Tang ZY, Yu YQ, et al. Microwave surgery in the treatment of hepatocellular carcinoma. Semin Surg Oncol 1993;9:318–22.
13. Ishizaki Y, Yoshimoto J, Miwa K, et al. Safety of prolonged intermittent Pringle maneuver during hepatic resection. Arch Surg 2006;141:649–53.
14. Dindo D, Demartines N, Clavien PA. Classification of surgical complications. A new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 2004;240:205–13.
15. Wu CC, Cheng SB, Ho WM, et al. Liver resection for hepatocellular carcinoma in patients with cirrhosis. Br J Surg 2005;92:348–55.
16. Jarnagin WR, Gonen M, Fong Y, et al. Improvement in perioperative outcome after hepatic resection. Analysis of 1,803 consecutive cases over the past decade. Ann Surg 2002;236:397–407.
17. Grazi GL, Ercolani G, Pierangeli F, et al. Improved results of liver resection for hepatocellular carcinoma on cirrhosis give the procedure added value. Ann Surg 2001;234:71–8.
18. Capussotti L, Muratore A, Massucco P, et al. Major liver resections for hepatocellular carcinoma on cirrhosis: early and long-term outcomes. Liver Transplant 2004;10:S64–S68.
19. Belghiti J, Hiramatsu K, Benoist S, et al. Seven hundred forty-seven hepatectomies in the 1990s: an update to evaluate the actual risk of liver resection. J Am Coll Surg 2000;191:38–46.
20. Dimick JB, Cowan JA Jr, Knol JA, et al. Hepatic resection in the United States: indications, outcomes, and hospital procedural volumes from a nationally representative database. Arch Surg 2003;138:185–91.
21. Tanaka S, Hirohashi K, Tanaka H, et al. Incidence and management of bile leakage after hepatic resection for malignant hepatic tumor. J Am Coll Surg 2002;195:484–9.
22. Nagino Y, Togo S, Tanaka K, et al. Risk factor and management of bile leakage after hepatic resection. World J Surg 2003;27:695–8.
23. Gozzetti G, Mazziotti A, Grazi GL, et al. Liver resection without blood transfusion. Br J Surg 1995;82:1105–10.
24. Daley J, Khuri SF, Henderson W, et al. Risk adjustment of the postoperative morbidity rate for the comparative assessment of the quality of surgical care: results of the National Veterans Affairs Surgical Risk Study. J Am Coll Surg 1997;185:328–40.
25. Berger SR, Helms RA, Bull DM. Cirrhotic hyperglobulinemia: increased rates of immunoglobulin synthesis by circulating lymphoid cells. Dig Dis Sci 1979;24:741–5.
26. Triger DR. The liver as an immunological organ. Gastroenterology 1976;71:162–4.

救急医療に役立つ画像診断：CTを中心に

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要旨　救急疾患の画像診断のコツは，1）診断に直結する現病歴を得ること，2）良質な画像を撮影すること，3）優れた観察装置で読影すること，である。

key words：救急，画像診断，CT，MRI

はじめに

今日の医療における画像診断が果たす役割は大きい。なかでも，迅速かつ的確な診断が要求される救急診療においては，画像診断の質が診療の是非を大きく左右する。

本稿では，消化器疾患に限らず，腹部～骨盤の救急疾患における画像診断のポイントを，今日の救急診療で中心的役割を果たしているCTを中心に述べる。

1．撮影：画像診断の“でき”を決定するファーストステップ

- 読者諸兄は画像診断で医師が力を出すのは，撮影が済んでからと思っていないだろうか？　しかし，考えてほしい。呼吸停止がなされていない，体動が激しい，見たい臓器が撮影範囲に入っていない，造影の撮影タイミングが外れている，そのような画像しか得られないとき，困るのは撮影をオーダーした医師本人ではないだろうか。
- それならば，撮影し直せばよいとの意見もあろう。しかし，それは果たして現実的であろうか？　救急診療での再撮影は，患者とチームの負担が大きい。仮に，一度造影剤を使ったのであれば時間を空けなければ追加の造影は行えない。すなわち，救急診療では，撮影のやり直しは事実上ないと考えたほうがよい。
- 画像診断に長けた医師は撮影を重視する。撮影がきちんとなされれば，読影が容易になるのを彼らは知っている。それでは医師が何をすればより良い撮影ができるか？　CTの撮影を例にしよう。

1）CT室入室前

①検査の重要性と内容についての患者への説明
②妊娠の有無のチェック
③ヨード過敏の有無のチェック
④ヨード造影剤使用について説明を行い，同意の有無をチェック

なかでも①は検査の質を大きく左右する。救急疾患の患者は，いろいろな意味で余裕がない。撮影に対しても同様で，体動や呼吸停止について協力する余裕はないことが少なくない。だからこそ説明は十分行いたい。

具体的には，1）患者本人にCTが重要であることを十分理解してもらい，体を動かさない，呼吸停止を行うなど，撮影への協力を要請する，2）痛みが強くて体位保持や呼吸停止が難しいようであれば，十

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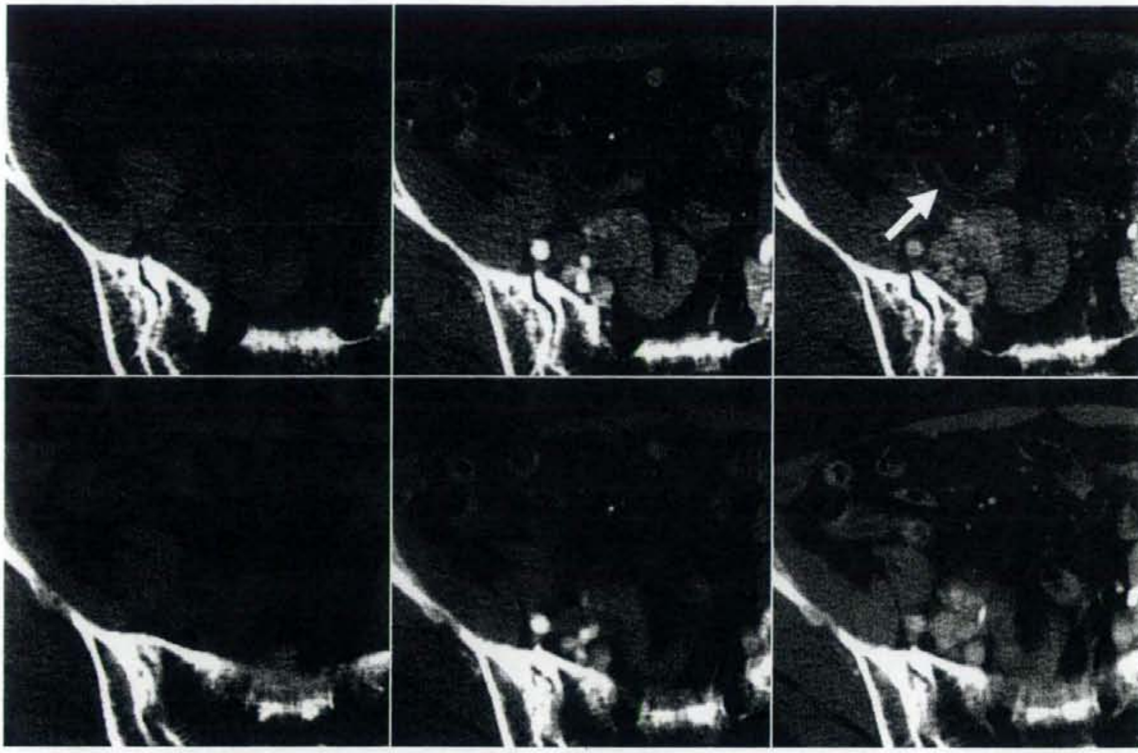

図 1　虫垂炎のCT像

上段は2.5 mm厚，下段は7.5 mm厚のCT。CTでは薄いスライス厚と造影剤を用いれば虫垂を同定しやすいことがわかる。

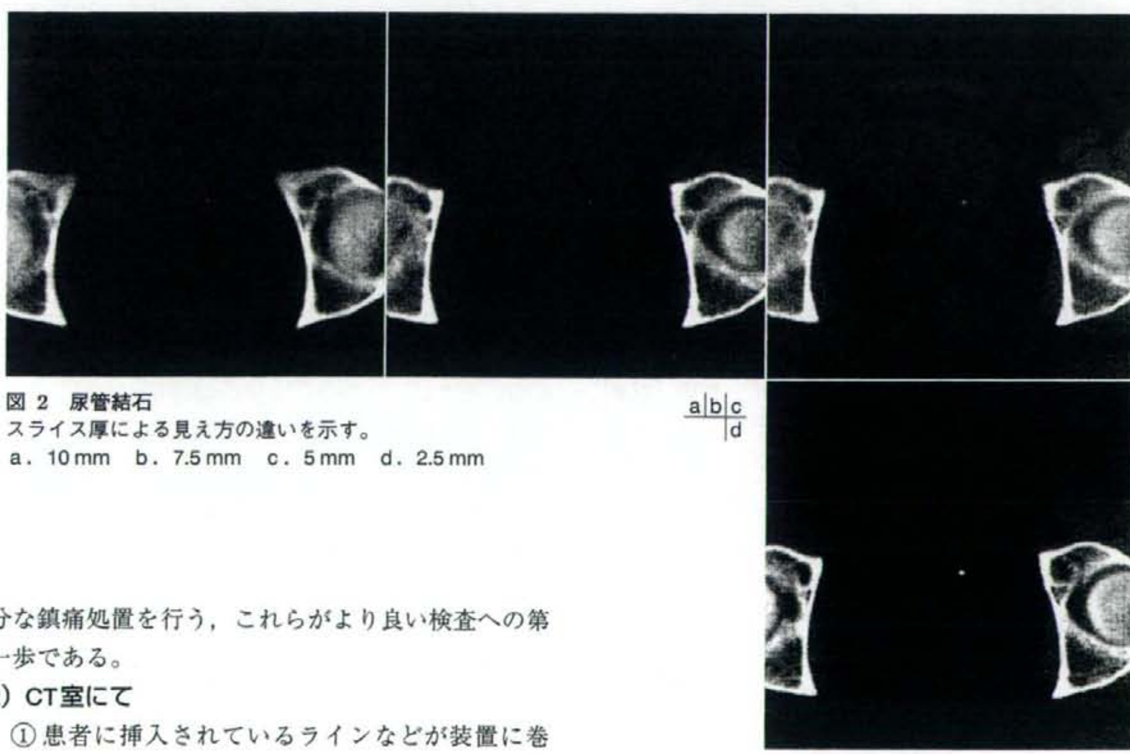

図 2　尿管結石

スライス厚による見え方の違いを示す。

a．10 mm　b．7.5 mm　c．5 mm　d．2.5 mm

a|b|c / d

分な鎮痛処置を行う，これらがより良い検査への第一歩である。

2）CT室にて

①患者に挿入されているラインなどが装置に巻

き込まれないかのチェック

② 転落しないよう患者固定のチェック

③ 造影剤注入前に注射針(留置針)と延長チューブの接続が確実かのチェック

を行う。救急ではCT室に医療者が多く同行するが，撮影が始まるとCTコンソールのモニタの周囲に医療者が集まり，撮影室には患者だけという光景をよく目にする。

撮影されたての画像に夢中になるのはわからなくはないが，画像は検査後集中して観察するほうが正確な読影ができ，結果として結論が出るのも早いことが多い。それゆえ，検査中は検査が終わるまで患者の観察を怠らないのはもちろん，通常よりも声掛けを頻繁に行い，検査が事故なく確実に遂行されるよう，万全を尽くすのがCT室でのポイントである。

3) 撮影条件

- 腹部のCTの撮影条件では，なかでもスライス厚，造影の撮影タイミングが重要である。
- 撮影条件は機器の性能に左右されるが，スタッフが撮影プロトコールの設定に慣れていなければ救急時に撮影プロトコールを根本から考える余裕はないと予想されるので，基本的なものはあらかじめ決めておくとよい。
- スライス厚が薄くなると，ノイズは増えるが頭尾方向の空間分解能が向上するため，消化管や尿管をみるには有利である(図1，図2)。
- 造影の撮影タイミングは，痛みが強いときや炎症が強いと，造影剤の循環は速くなっているので撮影タイミングを早める必要がある一方，ショックを起こしている場合は，循環が遅くなっているので，反対に撮影タイミングを遅らせる必要がある。

2. 観察：画像診断の仕上げ

画像の観察は画像診断の仕上げといえよう。その仕上げを素早く正確に行う技術を習得するには，優れたツール(画像viewer)を使用するのが手っ取り早く，確実である。

画像viewerが腹部の救急疾患の画像診断に役立つには，次の3つの機能は少なくとも有している必要がある。

1) スピーディなページング表示機能

- 近年，画像の観察はモニタ上で行われるようになっている。腹部ではモニタ上でページめくりの要領で画像を観察するのが(ページング)基本である。
- この方法で観察すると，消化管，血管，胆管，尿管などの連続性が観察しやすく，立体的な情報が得られるとともに，多数の断面を素早く観察することができる。すなわち，短い時間で質の高い読影ができるので是非用いたい読影法である。

2) ダイナミックスタディの頭出し表示機能

- 造影剤を静注して異なる撮影時相の画像を撮影するダイナミックスタディは，一般には臓器や腫瘍の血流解析に用いられ，救急疾患では臓器の血行状態や出血の状態を判断する際に威力を発揮する。
- 撮影時相を変えて同じ位置の画像を比較すると，血流の状態が詳細にわかるので，ダイナミックスタディが撮影される。
- ダイナミックスタディは，多くの場合，撮影装置がすべての画像を単一のシリーズにひとまとめにしてしまうので，同じ位置の撮影時相の異なる画像をすばやく並べて表示される機能が必須である。

3) 比較読影が容易になる三次元補正同一断面表示機能

- 経過をみれば，どう対処すべきかがわかる。短期間で状態が大きく変化するのが救急疾患の特徴であるため，経過観察が果たす役割は大きく，それには画像診断が用いられることが多い。
- 過去と現在の画像を比較するには，同一断面を並べて観察するのがよい。
- しかし，その比較読影の妨げになるのが，異なるFOV(field of view)や患者の呼吸による画像のズレである。それらを補正する機能があれば，素早く正確に経過がわかる。
- これらのポイントが押さえられていれば，画像診断はより簡単になり，習得も速い。

a. 急性虫垂炎(図1，図3)

- 虫垂の同定に尽きる。CTなら9割以上の確率で同定できる。単純CTに加え造影剤注入後60秒後に厚さ3 mm未満で撮影するのが，小児や脂肪の少

a|b|c

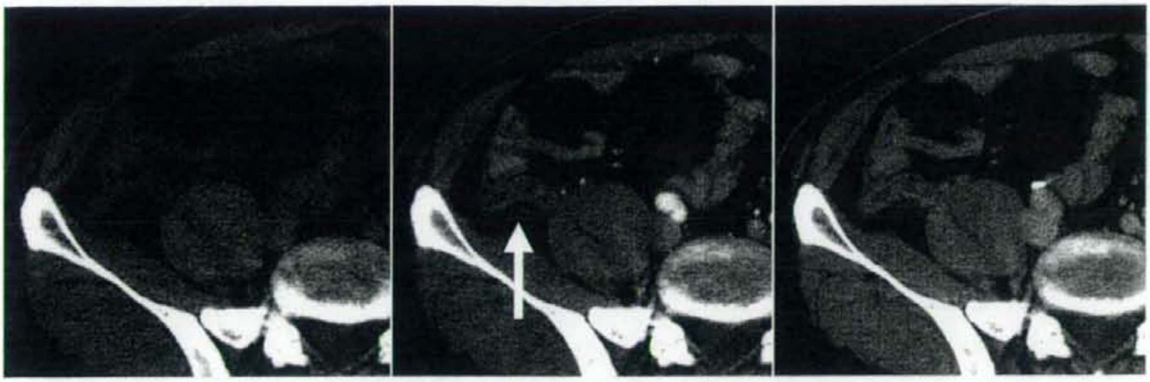

図 3　後腹膜腔に存在する虫垂に虫垂炎が生じた例のCT像

a．単純　b．造影早期　c．造影晩期

虫垂の腫大と周囲の脂肪組織の濃度上昇をみる。虫垂が腹膜腔内にある場合は，軽症であっても腹痛や圧痛が強いが，後腹膜腔にある場合は，臨床像や触診所見が重症度と相関しないため，画像診断の役割は大きい。

a|b|c

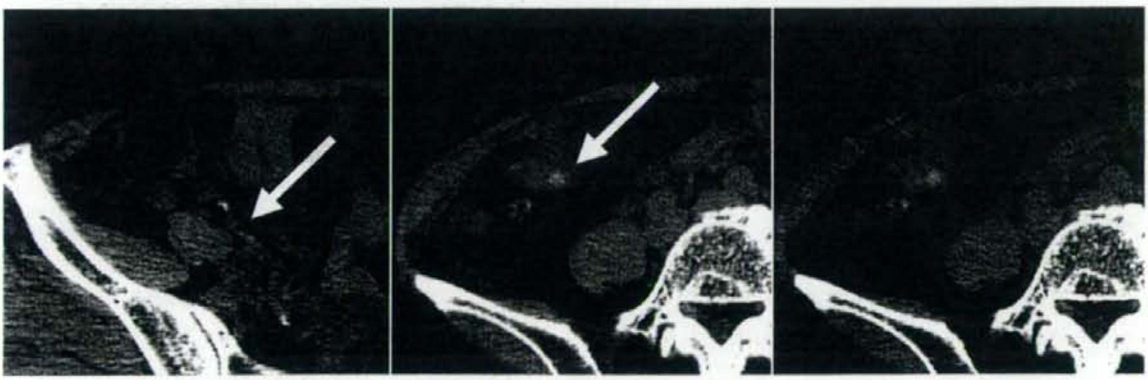

図 4　憩室炎のCT像(単純)

a．虫垂(矢印)を同定し，虫垂炎がないことを確認する。その後，結腸周囲の脂肪組織の濃度が上昇していないかチェックする。

b．脂肪濃度上昇とその内部に高濃度の内容を有した憩室に気づいたら，その憩室が炎症の責任であることが多い。
なお，腸管を観察する際は，腸管周囲および腸間膜の脂肪組織を併せて観察するのがよい。ウインドウを拡げて観察するのが脂肪組織を観察するポイントである(bのほうがcよりも腸管周囲の脂肪が観察しやすい)。

ない成人でも同定するコツである。

■ 底部の位置は人により一定しないが，根部はどんな例でもほぼ似た位置にある。回盲弁の2 cm尾側あたりから約20度時計回りの方向に向かって盲腸壁から出る構造が根部であり，それに連続する盲端の構造があれば，それが虫垂である。

■ 虫垂を同定したら，周囲の脂肪組織の濃度上昇，液体貯留をチェックするとともに，ダグラス窩に腹水がないか，小腸の内容液貯留をみる。

■ なお，虫垂が腹膜腔内にある場合は，軽症であっても腹痛や圧痛が強いが，後腹膜腔にある場合は，臨床像や触診所見が重症度と相関しない。

■ 小児は穿孔しやすいので成人に比べ，積極的な加療が必要になることが多い。切除せずに経過をみるなら，より綿密に観察する必要がある。

b．結腸憩室炎(図4)

■ 上行結腸や盲腸の憩室炎は，虫垂炎の除外が必要である。

■ まず，虫垂を同定し，虫垂炎がないことを確認しよう。その後，結腸周囲の脂肪組織の濃度が上昇していないかチェックする。

■ 脂肪濃度上昇とその内部に高濃度の内容を有した

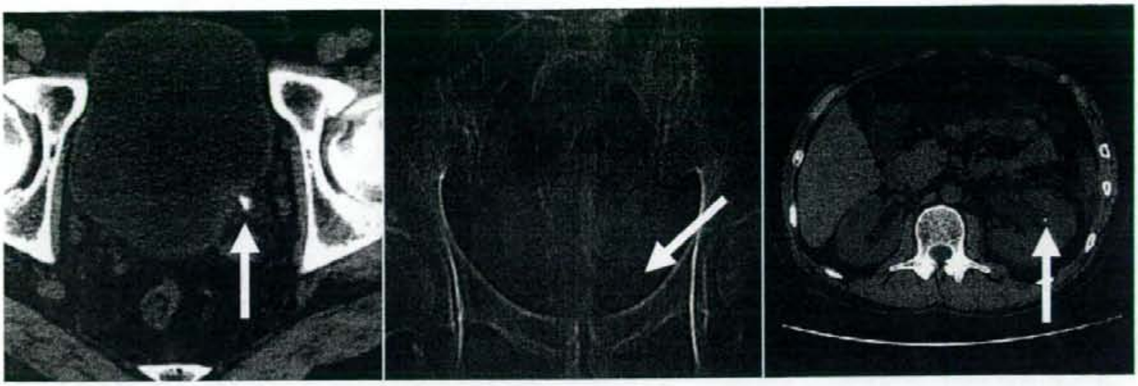

図 5　尿管結石

薄いスライスでCTを撮影し高速ページングをもつviewerがあれば石灰化結石はCTで確実に診断できる。

a|b|c

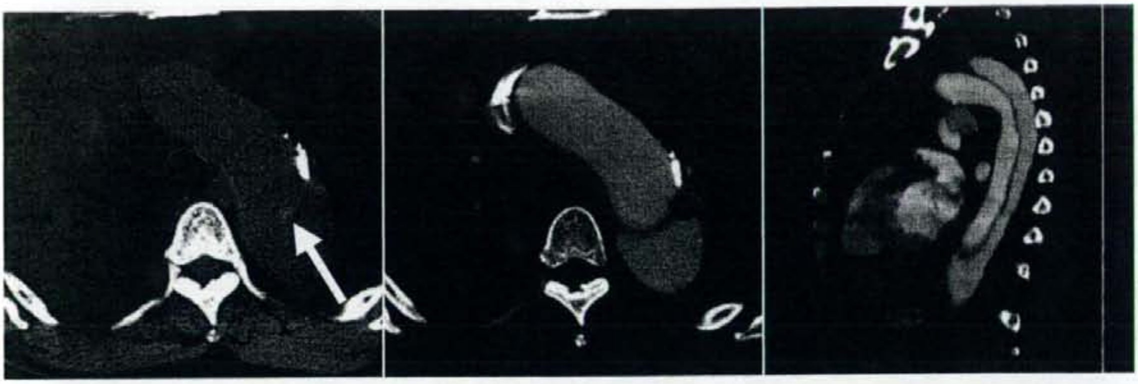

図 6　解離性大動脈瘤

AM 11:00頃，車を運転中に背部痛出現。その後腹部全体に痛みが拡がった。単純CT(a)でも内膜の石灰化が壁から遊離していることより(矢印)，大動脈解離は診断可能であるが，造影を行い(b)，MPR(multiplanar reconstruction)で観察すると(c)，解離の拡がりがわかりやすい。

憩室に気づいたら，その憩室が炎症の責任であることが多い。

c．尿管結石(図2，**図5**)

- 痛みの発生した時刻を患者が覚えていて，血尿があれば画像診断は必要ないかもしれない。しかし，そのような臨床像をとらない例では診断がつかない可能性がある。そのような場合は，CTが有用である。
- 薄いスライスでCTを撮影し，高速ページングをもつviewerがあれば，石灰化結石なら単純CTで確実に同定でき，確定診断に至ることができる。

d．腸重積

- いかにして特徴像を捉えるかが本症を診断するポイントである。薄いスライスで撮影し，MPRで観察すれば，腸がどのような角度で走行していても特徴像を捉えることができる。
- 造影すれば血管と重積との位置関係が把握しやすい。なお，重積の原因となる腫瘍がないか，閉塞部先端をチェックしよう。
- 小児ではCTよりも超音波が有用である。

e．解離性大動脈瘤(図6)

- 造影すれば診断は容易である。単純CTでも石灰化についた内膜が壁から離れているのがみられたり，偽腔が高濃度化しているのに気づけば診断に至ることができる。
- 解離性大動脈瘤の診断がついたら，頭尾方向の拡がりをMPRで観察する。

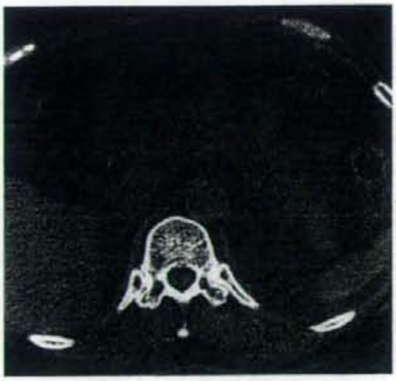

図 7　急性膵炎のCT像
膵の輪郭のボケ，腫脹など膵の形態の異常，周囲の脂肪組織の濃度上昇，後腹膜腔の液体貯留，脂肪組織の濃度上昇がみられる。

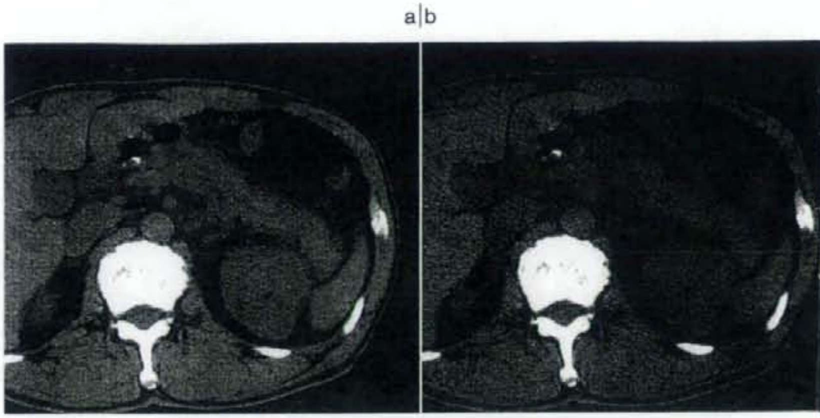

図 8　急性膵炎
a．ウインドウ 450　b．ウインドウ 300
膵自体の変化は，軽微な例では隣接する組織の異常が膵炎に気づくきっかけになる。ウインドウ幅を400〜500，レベルを20前後にして脂肪と空気が区別しやすい条件にすると，それらの変化を拾いやすい。

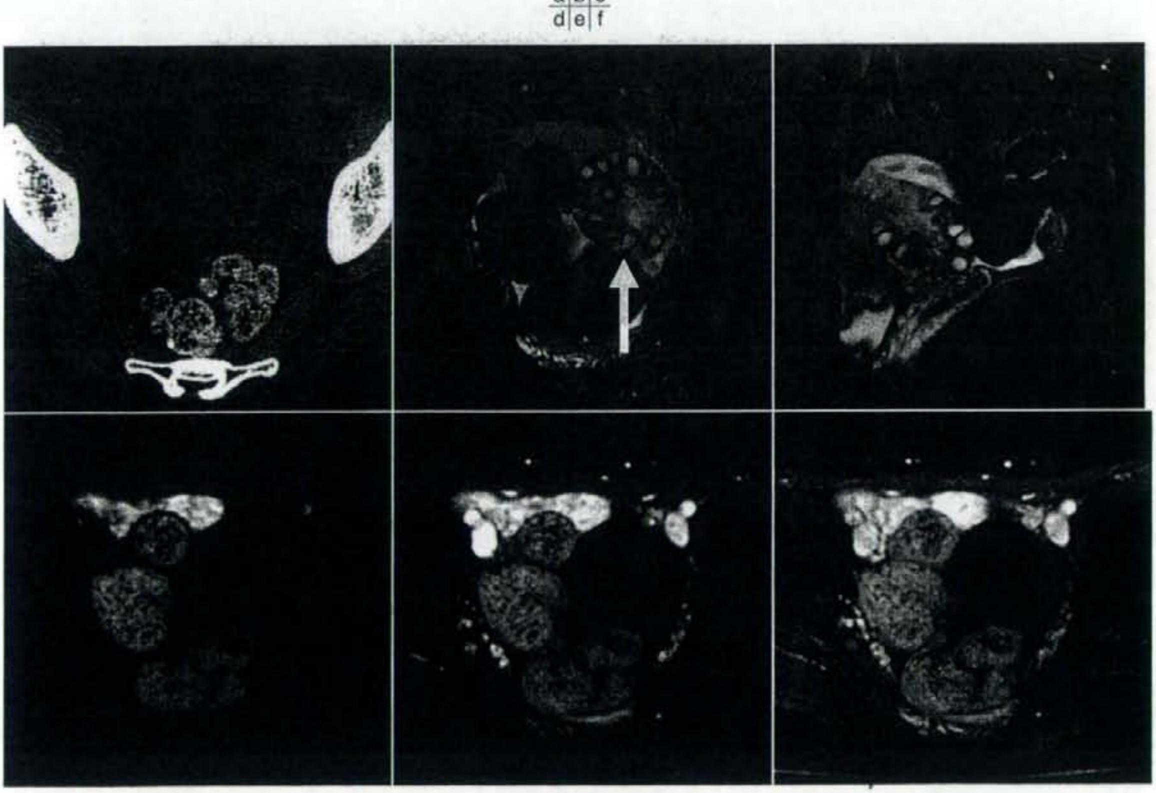

図 9　卵巣捻転
4時間前から左下腹部通が出現し，次第に増悪した。1時間前に救急外来を受診。CTを撮影したところ，卵巣の高吸収と腫大を認めた(a)ため，婦人科受診を勧めた。しかし，婦人科では診断に至らず，MRIを施行した(b，c;T2，d〜f;ダイナミック)。MRIでは，卵巣腫大が増悪し，造影効果がないことが明らかで，卵巣捻転と容易に診断できる。

f．急性膵炎(図7，図8)

■ 3 mm以下のスライス厚で撮影され，ページング機能のあるviewerがあれば診断は容易である。膵の輪郭のボケ，腫脹など，膵の形態に異常がない

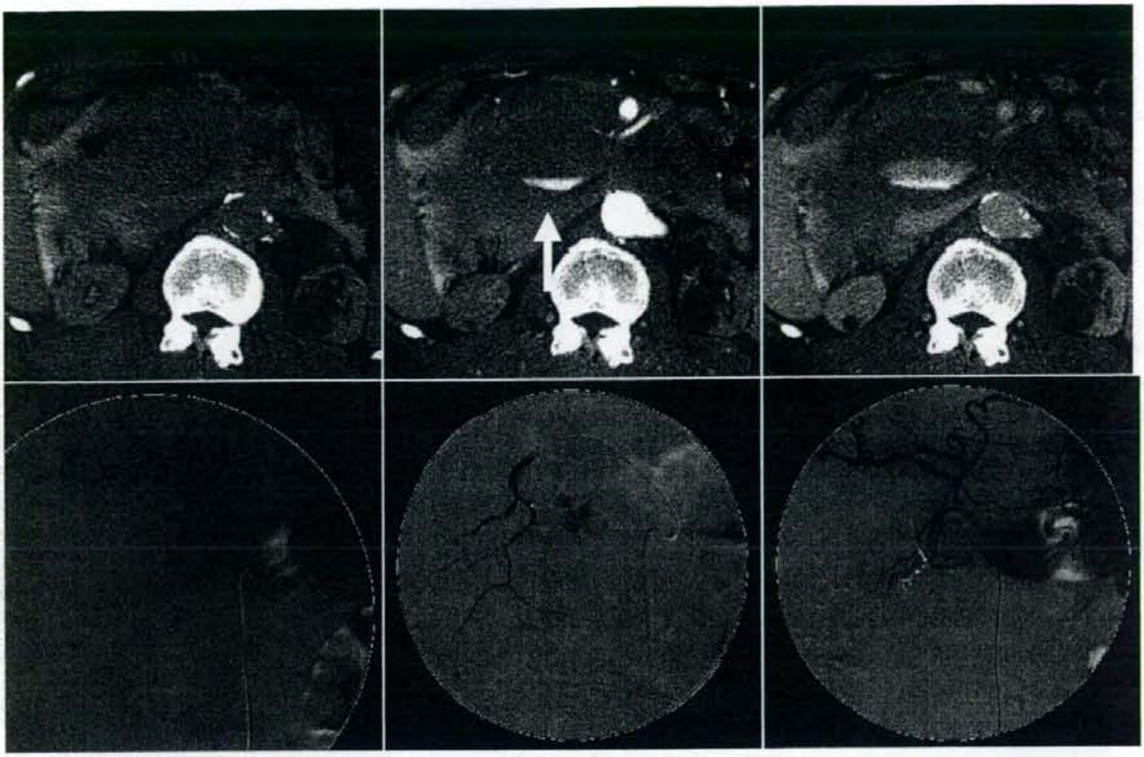

図 10　後腹膜腔出血

右胃大網動脈と下壁の冠動脈にバイパス術後の確認目的に行った心カテーテル検査後，透析中に強い腹痛を訴えた。ガイドワイヤー挿入により生じた胃十二指腸分枝由来の後腹膜出血である。ダイナミックCT(上段)にて鏡面形成を伴う造影剤の動脈性血管外漏出がみられる(矢印)。CTで出血点がある程度絞られたため，引き続き血管造影(下段)にて出血点を同定し，金属コイルにて止血した。

か，周囲の脂肪組織の濃度上昇がないか，後腹膜腔の液体貯留，脂肪組織の濃度上昇，胆道結石の有無をチェックする。

- 膵自体の変化は，軽微な例では隣接する組織の異常が膵炎に気づくきっかけになる。

g. 卵巣捻転(図9)

- 典型例では，急激に発症する激しい下腹部痛を呈する。しかし，捻転と解除が交互に起きる例では，非定型的な臨床像を呈することも少なくない。
- まずは本症を鑑別疾患の一つにあげることが正診への一歩である。
- もし，画像診断を行う前に，臨床像から卵巣疾患が疑われればMRIを選択する。卵巣捻転では，MRI上，卵巣に出血や浮腫と造影効果が著しく減弱しているのがみられ，診断は容易である。
- 臨床診断が卵巣疾患でない場合は，まず施行されるのはCTかもしれない。その場合，卵巣捻転の診断は難しいかもしれないが，その他の疾患を除外でき，その結果，本症が鑑別疾患としてあがるであろう。

h. 消化管出血(図10)

- 動脈性出血あるいは食道静脈瘤破裂などの静脈性の大量出血が救急疾患になりうる。動脈性出血の原因には，胃十二指腸などの消化性潰瘍からの出血や，メッケル憩室炎，大腸憩室炎，腸管の動静脈奇形，炎症の波及によって生じた偽動脈瘤の腸管内穿破，腫瘍がある。
- CTで出血点が捉えられるには，撮影中に十分な量の動脈性出血が起こっている必要がある。
- 単純CTで出血点を同定するのは難しい。造影CTでも至適タイミングで撮影されていなければ同様に難しいのでダイナミックCTを行うのがよい。
- 血管造影では，0.5/secの出血があれば容易に検出できる。

i. 消化管穿孔(図11)

- 原因として最も多い疾患は消化性潰瘍であり，な

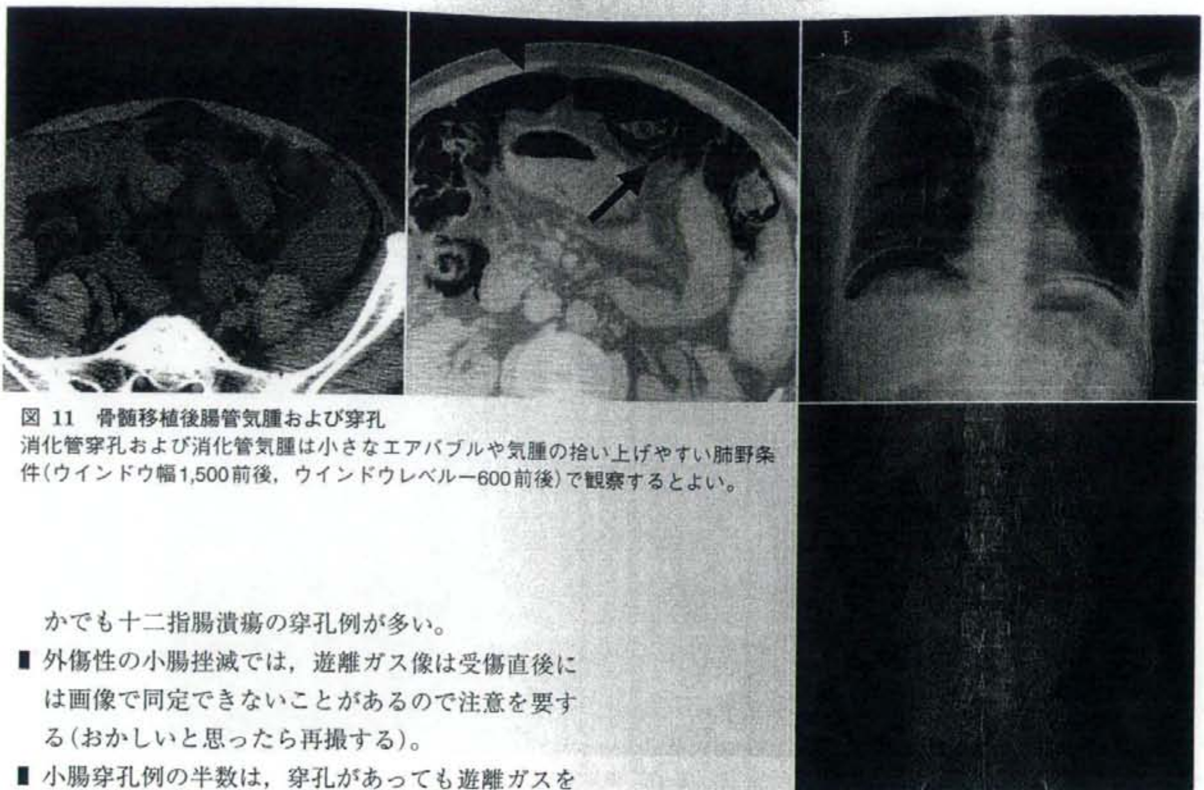

図 11　骨髄移植後腸管気腫および穿孔
消化管穿孔および消化管気腫は小さなエアバブルや気腫の拾い上げやすい肺野条件(ウインドウ幅1,500前後，ウインドウレベル−600前後)で観察するとよい。

かでも十二指腸潰瘍の穿孔例が多い。

- 外傷性の小腸挫滅では，遊離ガス像は受傷直後には画像で同定できないことがあるので注意を要する(おかしいと思ったら再撮する)。
- 小腸穿孔例の半数は，穿孔があっても遊離ガスを単純写真で認めない。
- 大腸の穿孔では遊離ガス像は腹部全体に拡散せず，局所の強い組織反応を伴い，泡沫状の腸管外ガス像集積を示すことが多い。
- 遊離ガス像の検出にCTは有用で，液体貯留の部位や腸管周囲の脂肪組織の炎症所見などから，穿孔部位が可能である。
- 微量の遊離ガスを描出するためには，画像表示のウインドウを広く設定するのがポイントである。

j. 消化管閉塞

- 閉鎖孔ヘルニアや大腿ヘルニアを想定して，骨盤底部まで撮影する。
- 腸間膜動静脈血栓症を疑う場合には，ダイナミックCTを行う。
- 薄いスライスの撮影とページング，ならびにMPRによる観察を駆使すれば，閉塞はある程度同定できる。

おわりに

救急診療における画像診断のポイントは，決められたことを確実に行うことにある。1) 診断に直結する現病歴を得ること，2) 質の高い画像を撮影すること，3) 優れた観察装置を備えておくこと。

これらが揃えば救急疾患の画像診断は容易である。