Intraoperative Cholangio Ultrasound in the Study of the Biliary Tree

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9.1 Introduction

It has been shown how IOUS is able to provide precise details about the anatomy of intrahepatic bile ducts, even when not dilated (see Chap. 3), and their variants with their centripetal bifurcation pattern as compared to the portal branches (Fig. 9.1). This aspect is crucial in liver surgery as major hepatectomies are at major risk for biliary complications and among them those at major risk of damage are the left-sided hepatectomies, due to the possibility of having a right posterior section draining into the left bile duct [1] (Fig. 9.2). Other than IOUS, also CEIOUS may play a role in this sense since it provides a negative image of the biliary tree as compared to the enhanced surrounding liver parenchyma (Fig. 9.3). On the other hand, bile duct injury during major hepatectomy occurs in 8 % of patients and in 22 % of left-sided major resection [2]. These complications are often life-threatening and, in the experience of Lo et al. [2], 39 % of patients with biliary complications died. Help in reducing this risk is achieved by performing intraoperative cholangiography (IOC) and intraparenchymatous division of the bile ducts peripherally to the confluence of the main bile ducts and the confluence of those draining the caudate lobe. IOC, in particular, still represents the gold standard for studying the anatomy of the biliary tract as well as for guiding reconstruction in case of bile duct resection. Moreover, with the advent of living donation, IOC is the standard reference for evaluating preoperative imaging [3]. IOUS in this sense does not play a central role within the current surgical practice, if not for guiding intraoperatively dilated bile duct drainage [4]. However, we believe that IOUS could play an important role for the following indications:

1. resection guidance for biliary tumors;
2. providing details about the integrity of the intrahepatic biliary tree after a resection; and
3. proper drainage of the bile duct stump.

9.2 Resection Guidance for Biliary Tumors

Concerning resection guidance, with the exclusion of the mass-forming type of cholangiocarcinoma for which the role of IOUS guidance is similarly relevant as for CLM, the above-mentioned limitations are actually real and linked to the features of the target. Indeed, perihilar cholangiocarcinomas are generally isoechoic (see Chap. 4), and thus less visible even by IOUS (Fig. 9.4a). However, more important, these tumors tend to expand within the bile duct wall frustrating any attempt to

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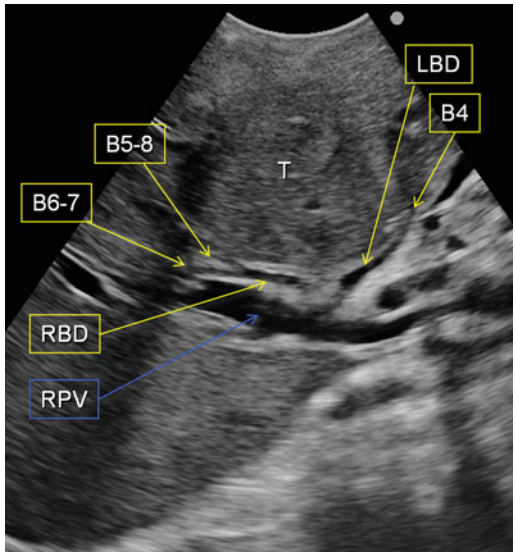


Fig. 9.1 IOUS can provide anatomical details of the intrahepatic biliary tree even if not dilated, with details of its centripetal bifurcation pattern: in a single scan one can recognize the right bile duct (*RBD*), the one draining the right anterior (*B5-8*), the one draining the right posterior (*B6-7*), the left bile duct (*LBD*), and the duct draining segment 4 (*B4*), while only the right portal vein (*RPV*) is to be seen

disclose the real tumor margin in a reliable way (Fig. 9.4b), and thus accounting for the still considerable rate of palliative resections [5]. This limitation together with the low visibility of the main lesion impacts also the capability of IOUS to disclose an eventual vascular encasement by the tumor (Figs. 9.4c–e, 9.5a, b), which accounts for the need of extemporary vascular reconstruction, in spite of the encouraging results of such a policy [5]. However, as IOUS can recognize the intrahepatic biliary tree anatomy, it can also play a role in avoiding its damage by providing fundamental information for planning the surgical strategy (see Chap. 7) or guiding the liver dissection (see Chap. 8) (Fig. 9.6a–g). Another aspect which is relevant both for planning the surgical strategy and guiding the resection is its ability of reveal even minimal bile duct dilation: this is particularly the case for tumor-vessel relationships for establishing the risk of tumor invasion of the glissonian sheath, and, as a consequence, the need for its resection and for the extension of the

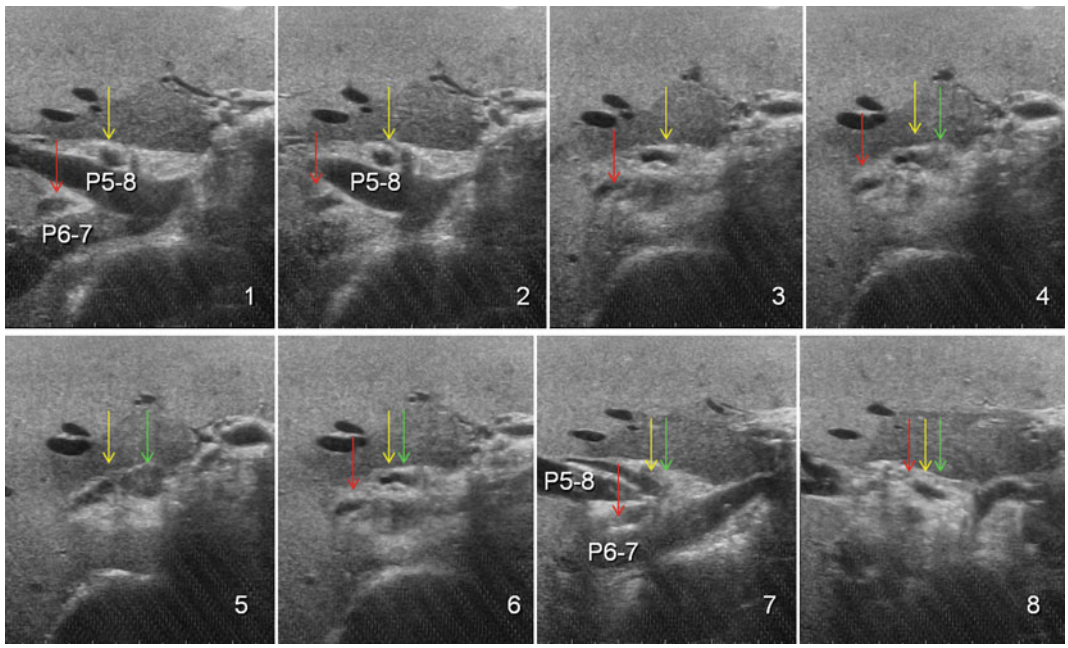


Fig. 9.2 IOUS images from 1 to 8 show how in this patient the right anterior bile duct (*B5-8* indicated by *yellow arrow*) is flowing into the left bile duct (*green arrow*) which together meet the right posterior bile duct (*B6-7* indicated by *red arrow*) in frame number 8; portal branch to the right anterior section (*P5-8*); portal branch to the right posterior section (*P6-7*)

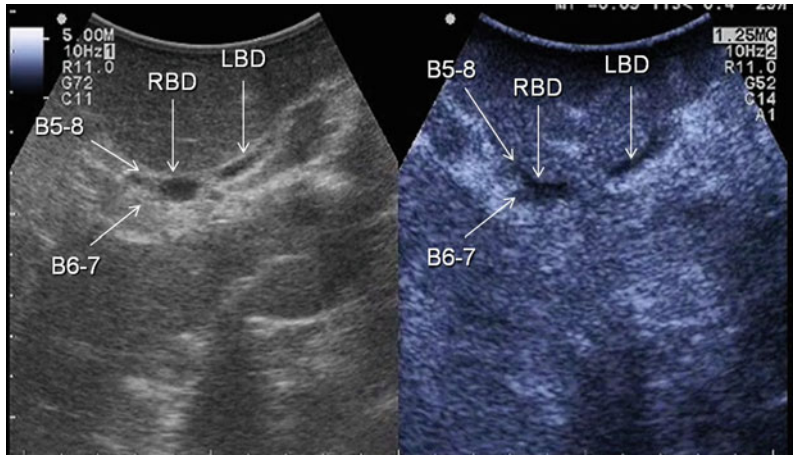


Fig. 9.3 On the left, IOUS of the intrahepatic biliary confluence showing the right anterior bile duct (*B5-8*), the right posterior bile duct (*B6-7*), the right (*RBD*) and the left bile ducts (*LBD*), and, on the right, the same scan by CEIOUS

resection area according to the criteria mentioned earlier [6] (see Chap. 7). IOUS allows the precise definition of this occurrence in patients with tumors in contact with an intrahepatic glissonian sheath (Fig. 9.7) but also its exclusion (Figs. 9.8, 9.9).

9.3 Intrahepatic Biliary Tree Integrity

Confirming biliary tree integrity is important in case of suspected damage after surgical dissection and is crucial to avoid postoperative morbidity and the consequent need for invasive procedures and even repeated surgery. A simple and self-made contrast agent can be employed for this purpose and which can be visualized by IOUS—becoming a true *intraoperative cholangio ultrasound* (IOCUS). The contrast agent consists of a compound of air and saline. Their ratio varies from that of pure air (Fig. 9.10) in having the same amounts of saline and air (Fig. 9.11a–c). The higher the concentration of injected air, the higher is the pressure with which the contrast is injected, the more evident will be a parenchymatous effect (Fig. 9.12), and the less clear will be the anatomical detail, and vice versa (Fig. 9.13). Indeed, the lower the air concentration, the lower is also the presence of those artefacts that can interfere with anatomical evaluation (Fig. 9.14a–c). The other important aspect to be taken into account, as just mentioned, is the pressure with which the compound is injected. Even pure air, if injected slowly thus enabling its slow flowing into the bile ducts and the progressive mixture with the bile juice, may provide anatomical details with sufficient panoramicity for disclosing the entire biliary tree (Fig. 9.15) or for checking the integrity of the biliary tract draining a certain part of the liver (Figs. 9.16a–c, 9.17a–d, 9.18a–e).

9.4 Proper Drainage of the Bile Duct Stump

Guiding the biliary reconstruction is fundamental for ensuring a proper patient's outcome once a bile duct has been resected and the proper biliary drainage has to be restored. This is particularly true in patients operated for perihilar cholangiocarcinoma, in whom the proper function of each residual segment is crucial, both to rule out morbidity linked to an undrained portion of the liver as well as to maintain the critical

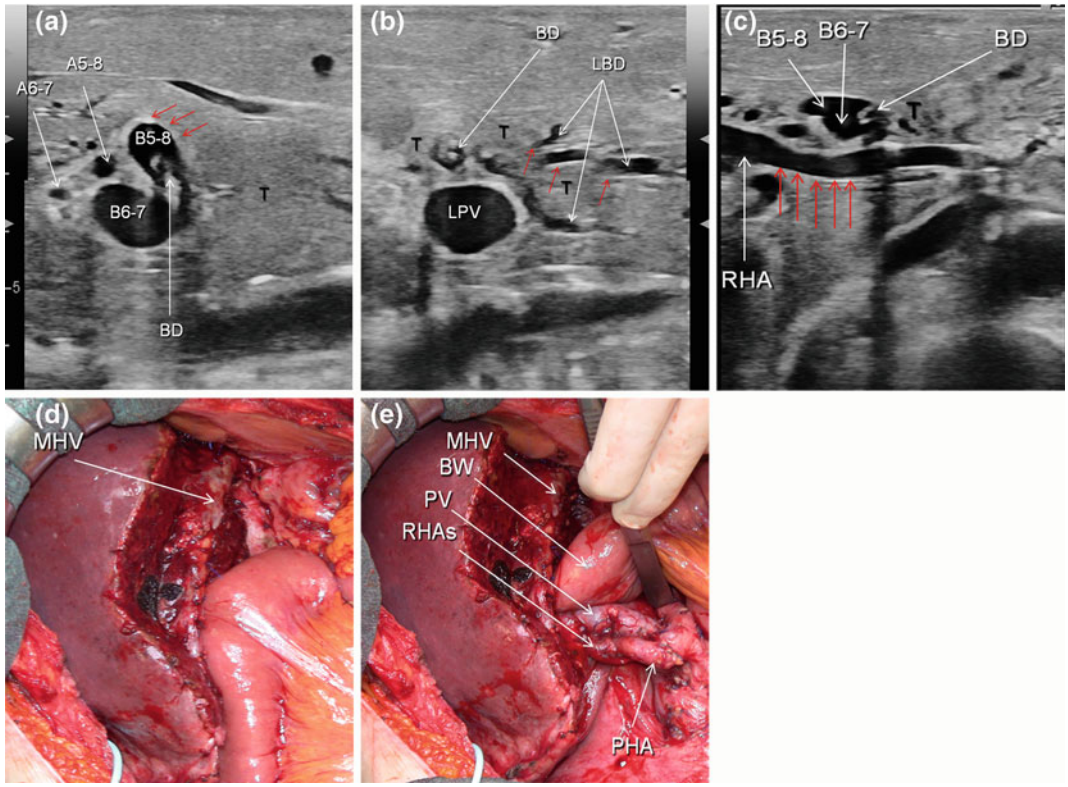


Fig. 9.4 **a** IOUS image of the main lesion (*T*) which is slightly hypoechoic compared to the surrounding liver, with undefined margins especially with regard to their intramural extension (*red arrows*) at the level of the right anterior (*B5-8*) and right posterior (*B6-7*) bile ducts, in which the biliary drainage is visible (*BD*); **b** the tumor extends to the left bile duct (*LBD*), but there are no reliable criteria to establish precisely the extent of the intramural extension (*red arrows*); **c** the right hepatic artery, passing in contact with the tumor except a slightly reduced caliper and an unusual straightness (*red arrows*), does not show in IOUS other aspects which could help to define whether it is invaded by the tumor or not; **d** with the bile duct stump frozen section free of tumor, a right hepatectomy together with segment 1 was carried out; **e** the right hepatic artery was resected, and, in absence of a left hepatic artery suitable for being tilted and anastomosed with its stump (*RHAs*), the latter was anastomosed to the proper hepatic artery (*PHA*), which remained long; hepatic artery to the right anterior section (*A5-8*); hepatic artery to the right posterior section (*A6-7*); bowel (*BW*); left portal vein (*LPV*); middle hepatic vein (*MHV*); portal vein (*PV*)

volume for a functioning liver parenchyma, and preventing liver failure. In this sense, IOCUS can be adopted both for providing an anatomical detail for disclosing each bile duct draining the remaining segments (Fig. 9.19a–f), and for disclosing a parenchymatous phase which should be considered sufficient for ruling out the risk of undrained liver portions (Figs. 9.20, 9.21).

9.5 Summary and Conclusion

IOCUS comes at no extra costs, not only because ultrasound is used anyway for staging and guidance, but also because the contrast agents used are air or a compound of air and saline. The advantages of ultrasound versus IOC

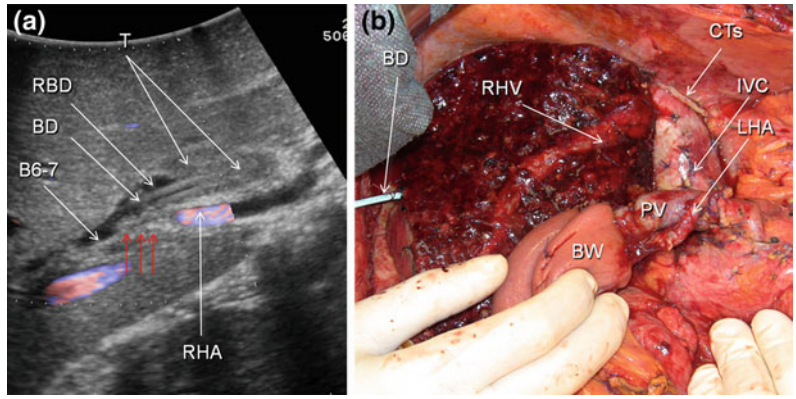


Fig. 9.5 **a** IOUS image showing the main lesion (*T*) which is isoechoic in relation to the surrounding liver, with undefined margins especially with regard to its intramural extension at the level of the right bile duct (*RBD*) just at the level of the confluence of the right posterior bile duct (*B6-7*); furthermore, the right hepatic artery (*RHA*) has stopped (*red arrows*); **b** a left trisectionectomy together with the left hepatic artery (*LHA*) tilting to revascularize the stump of the right posterior hepatic artery was carried out; biliary drainage (*BD*); bowel (*BW*); stump of the common trunk of the middle and left hepatic veins (*CTs*); inferior vena cava (*IVC*); portal vein (*PV*)

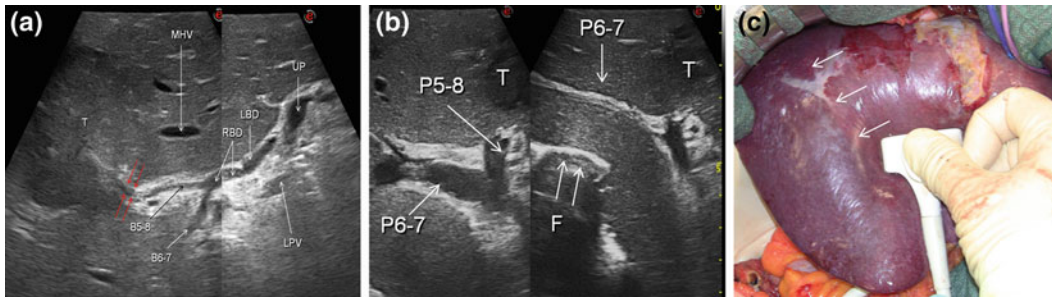
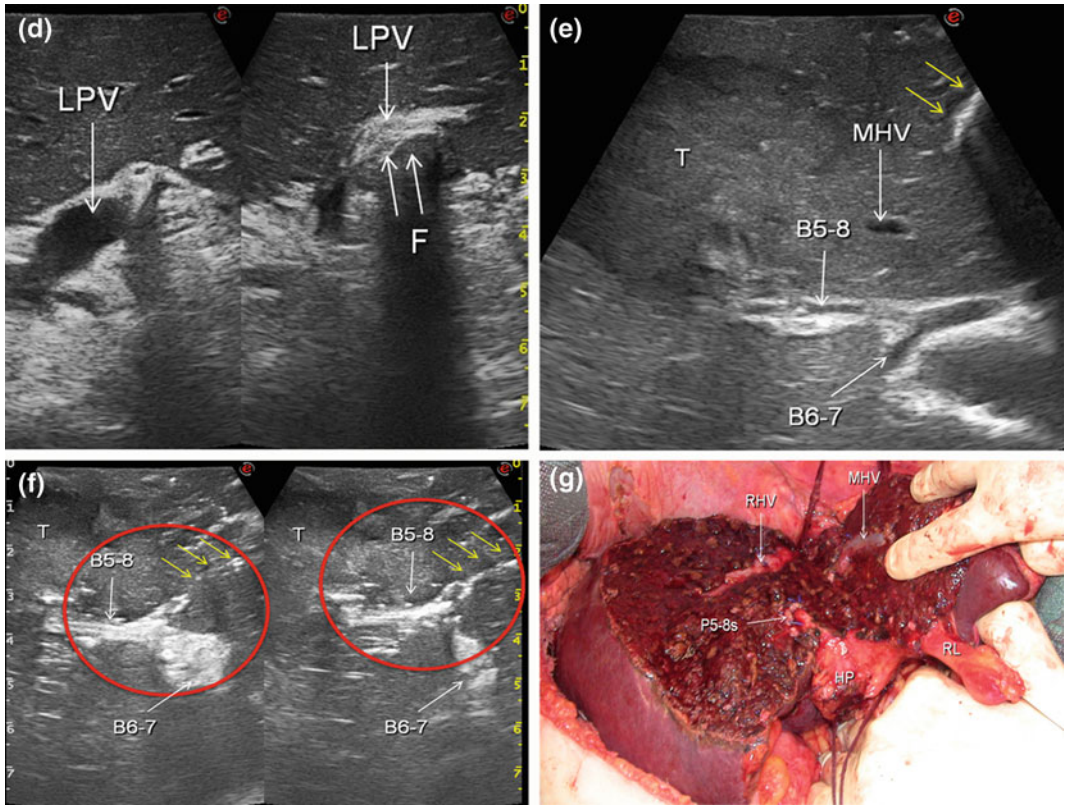


Fig. 9.6 **a** IOUS image showing the main lesion (*T*) infiltrating the right anterior pedicle including its bile duct (*B5-8*) (*red arrows*); despite this, IOUS was able to also perfectly disclose the anatomy of the biliary tree showing the right-sided confluence of B5-8 and the bile duct from the right posterior section (*B6-7*) into the right bile duct (*RBD*), and the confluence of the latter with the left bile duct (*LBD*) into the common bile duct; **b–d** then, a right anterior compression sectionectomy was planned as described in Chap. 8, by compressing the right posterior portal branch (*P6-7*) (**b**), which made evident the right-sided demarcation line on the liver surface (*arrows*) (**c**), compressing the left portal vein (*LPV*) (**d**), and marking also the related demarcation line; **e** dissection was carried out (*yellow arrows*) approaching the middle hepatic vein (*MHV*) first, and then the B5-8 distant from its confluence with B6-7; **f** once the right anterior pedicle was reached and encircled, before its division, the hooking technique was performed as previously described (see Chap. 8), to confirm the preservation of B6-7 (*red circles* focus the point of encirclement and traction, *yellow arrows* the dissection line); **g** then a right anterior sectionectomy was carried out; finger (*F*); hepatic pedicle (*HP*); portal branch to the right anterior section (*P5-8*); stump of the portal branch to the right anterior section (*P5-8 s*); right hepatic vein (*RHV*); round ligament (*RL*); umbilical portion (*UP*)



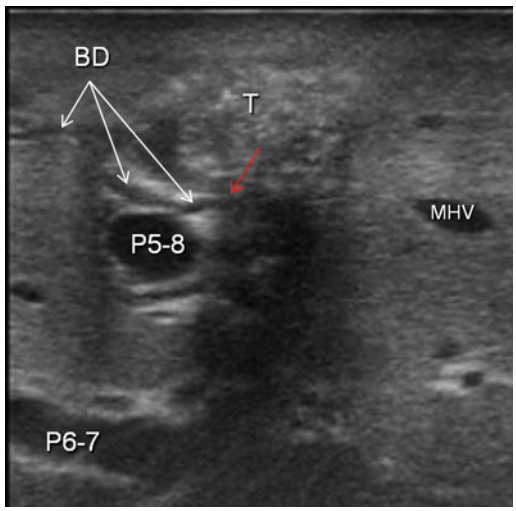


Fig. 9.7 A bile duct (*BD*) infiltrated (*red arrow*) by a tumor (*T*) and thus visible with its peculiar serpiginous path; middle hepatic vein (*MHV*); portal branch to the right anterior section (*P5-8*); portal branch to the right posterior section (*P6-7*)

in terms of cost saving have already been pointed out in regard to laparoscopic cholecystectomy [7].

Compared to IOC, which bears the disadvantage of radiation risk, IOCUS does not disclose just the biliary tree, but also the context in which a problem has eventually occurred. In that sense, IOCUS plays a role in resection guidance even in such patients. Other procedures have been recently promoted as alternatives to IOC, such as intraoperative exploration of biliary anatomy using indocyanine green (ICG) fluorescence imaging . This technique seems promising and has been validated experimentally and clinically [8, 9]. However, the reported experience was limited to the recognition of biliary anatomy without any additional information concerning relations with surrounding structures. Furthermore, although fluorescence imaging

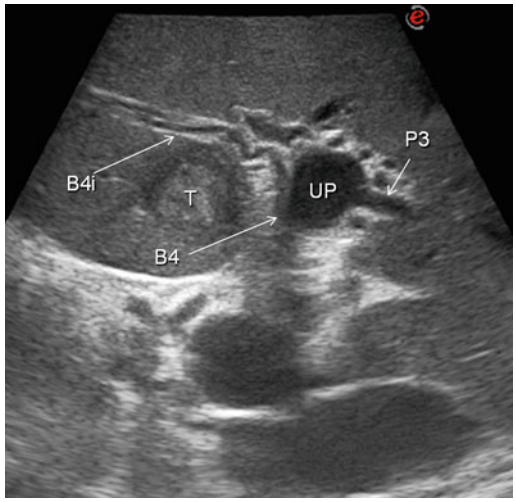


Fig. 9.8 IOUS is able to disclose that despite the adjacency to the tumor (*T*), and somehow a serpiginous path, the bile duct draining segment 4 inferior (*B4i*), and that draining the entire segment 4 (*B4*) are not invaded; portal branch to segment 3 (*P3*); umbilical portion (*UP*)

allows to avoid x-ray, as well as canulation of the cystic duct, it requires an infrared camera.

The main drawback of IOCUS consists in the need for an experienced operator in advanced ultrasound and thus may be of limited value. However, ultrasound has helped surgeons in reducing major morbidity in laparoscopic cholecystectomy [10], and it is now considered in several reports the gold standard for this operation rather than IOC [11]. This has happened in spite of the more difficult learning curve with ultrasound compared to IOC [12]. The same applies for IOCUS in liver surgery and the herein reported experience should act as proof of its reliability and promote its more extensive use.

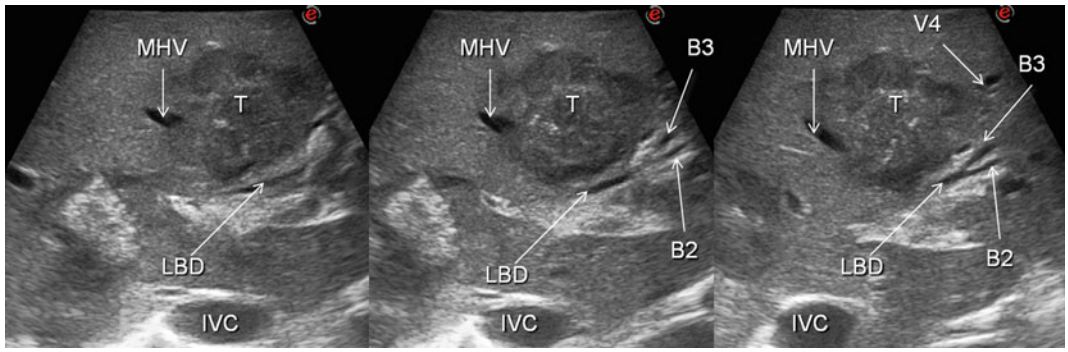


Fig. 9.9 Lack of contact between the tumor (*T*), the left bile duct (*LBD*), and the bile ducts draining segment 3 (*B3*) and 2 (*B2*) is well demonstrated in IOUS; inferior vena cava (*IVC*); middle hepatic vein (*MHV*); vein draining segment 4 (*V4*)

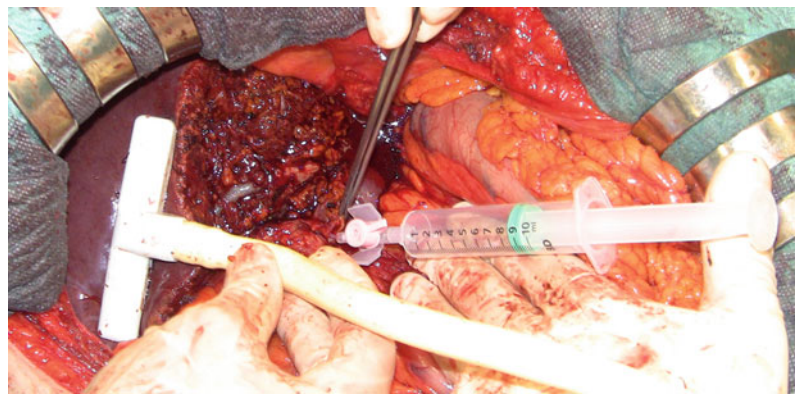


Fig. 9.10 Air is directly injected into the bile duct stump under IOUS guidance

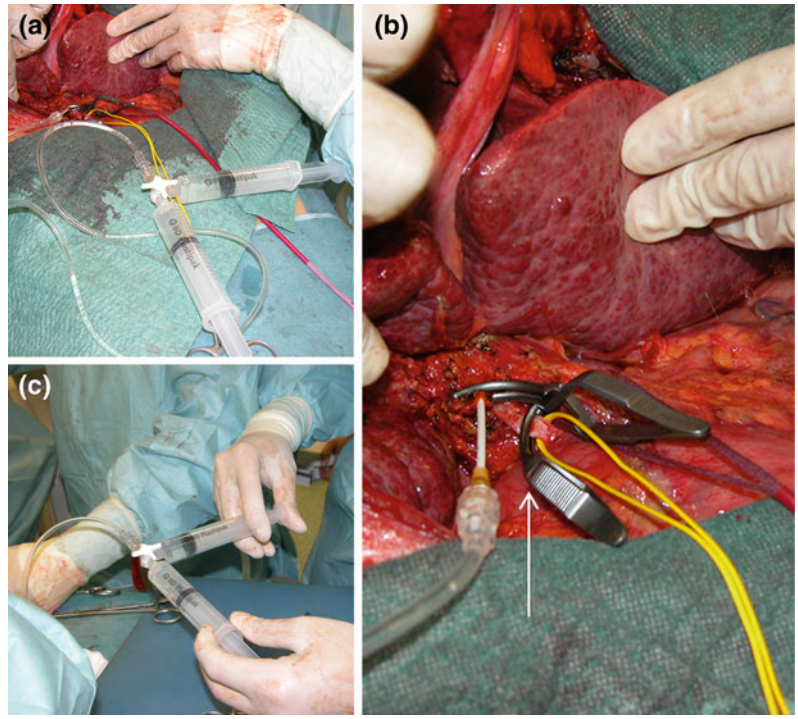


Fig. 9.11 Two syringes filled, respectively, with air and saline are prepared and connected to each other and with a deaerated tube (**a**), cannulating the cystic duct with the coledochus, which is clamped (*arrow*) (**b**), then the air and the saline are mixed in order to be injected (**c**)

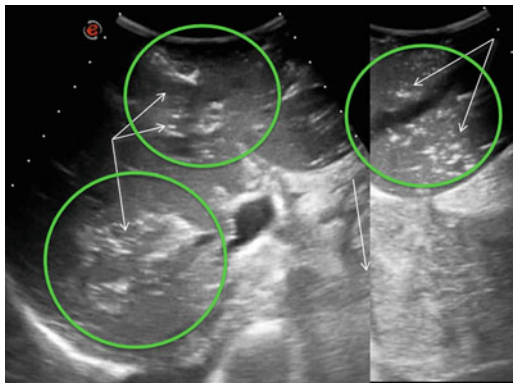


Fig. 9.12 Once enough pure air is injected strongly into the biliary tree, the effect obtained gives a parenchymatous contrast (*arrows* and *green circles*)

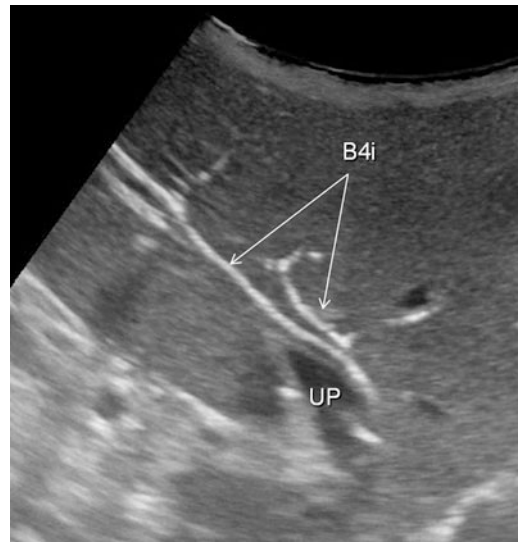


Fig. 9.13 Once air and saline are mixed and injected gently into the biliary tree, the effect obtained gives anatomical details as in this case showing the bile ducts draining the segment 4 inferior (*B4i*); umbilical portion (*UP*)

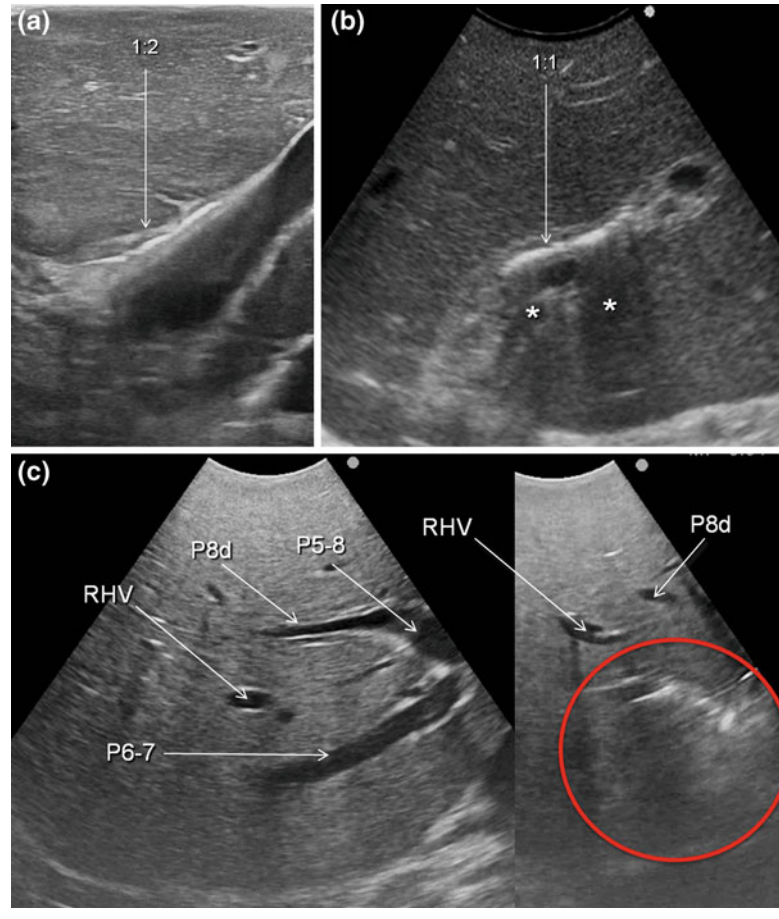


Fig. 9.14 Once air and saline are mixed and injected gently, the anatomical details vary depending on the concentration of the two components having more anatomical detail once the ratio air/saline is 1:2 (**a**), with some artifacts (*) at a ratio of 1:1 (**b**), or strong artifacts (*red circle*) if pure air is injected (**c**); portal branch to subsegment 8 dorsal (*P8d*); portal branch to the right anterior section (*P5-8*); portal branch to the right posterior section (*P6-7*); right hepatic vein (*RHV*)

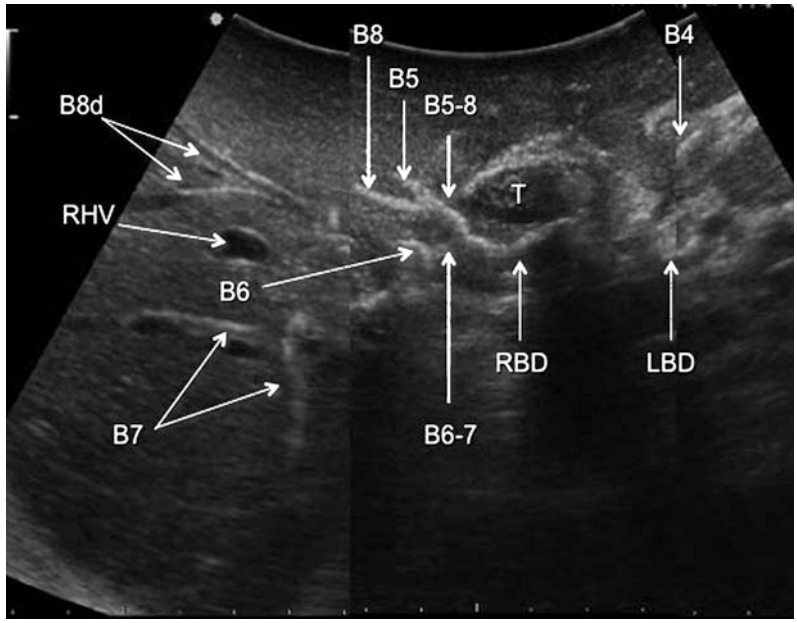


Fig. 9.15 Once pure air is injected slowly and gently allowing its mixture with the bile juice, the anatomical details can be obtained together with a panoramicity which allows visualizing most of the intrahepatic biliary tree; bile duct draining segment 4 (*B4*); bile duct draining segment 5 (*B5*); bile duct draining segment 6 (*B6*); bile ducts draining segment 7 (*B7*); bile duct draining segment 8 (*B8*); bile duct draining subsegment 8 dorsal (*B8d*); bile duct draining the right anterior section (*B5-8*); bile duct draining the right posterior section (*B6-7*); left bile duct (*LBD*); right bile duct (*RBD*); right hepatic vein (*RHV*)

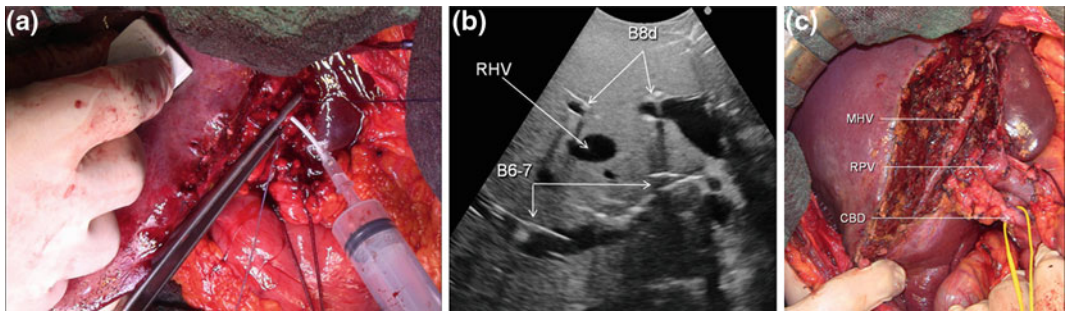


Fig. 9.16 After a left hepatectomy in which the dissection has given the impression of having approached too close to the biliary confluence, the injection of air into the biliary stump (**a**), the visualization by IOCUS of the contrast effect disclosing the bile duct draining the right posterior section (*B6-7*), and that draining the segment 8 dorsal (*B8d*) (**b**), demonstrate the preservation of the proper biliary drainage of the right hemiliver (**c**); common bile duct (*CBD*); middle hepatic vein (*MHV*); *right portal* vein (*RPV*)

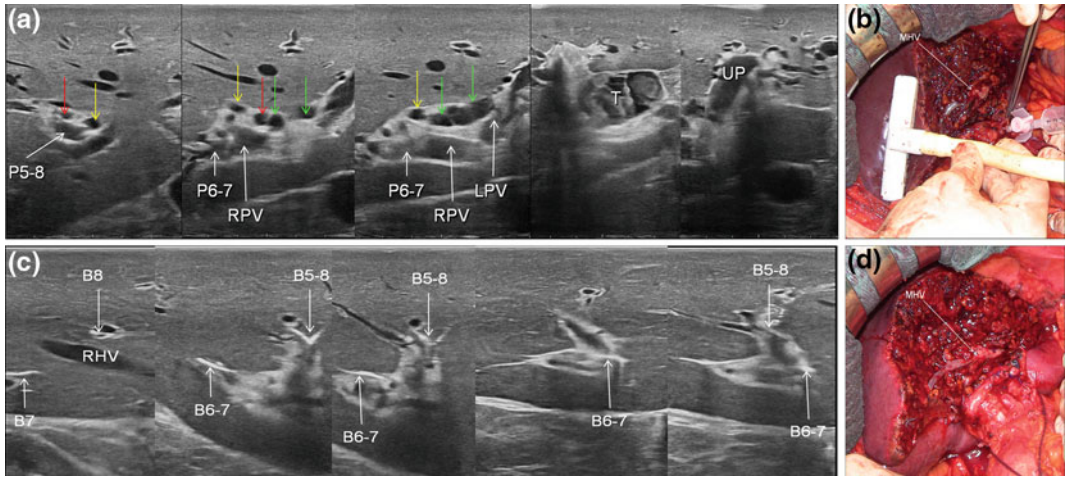
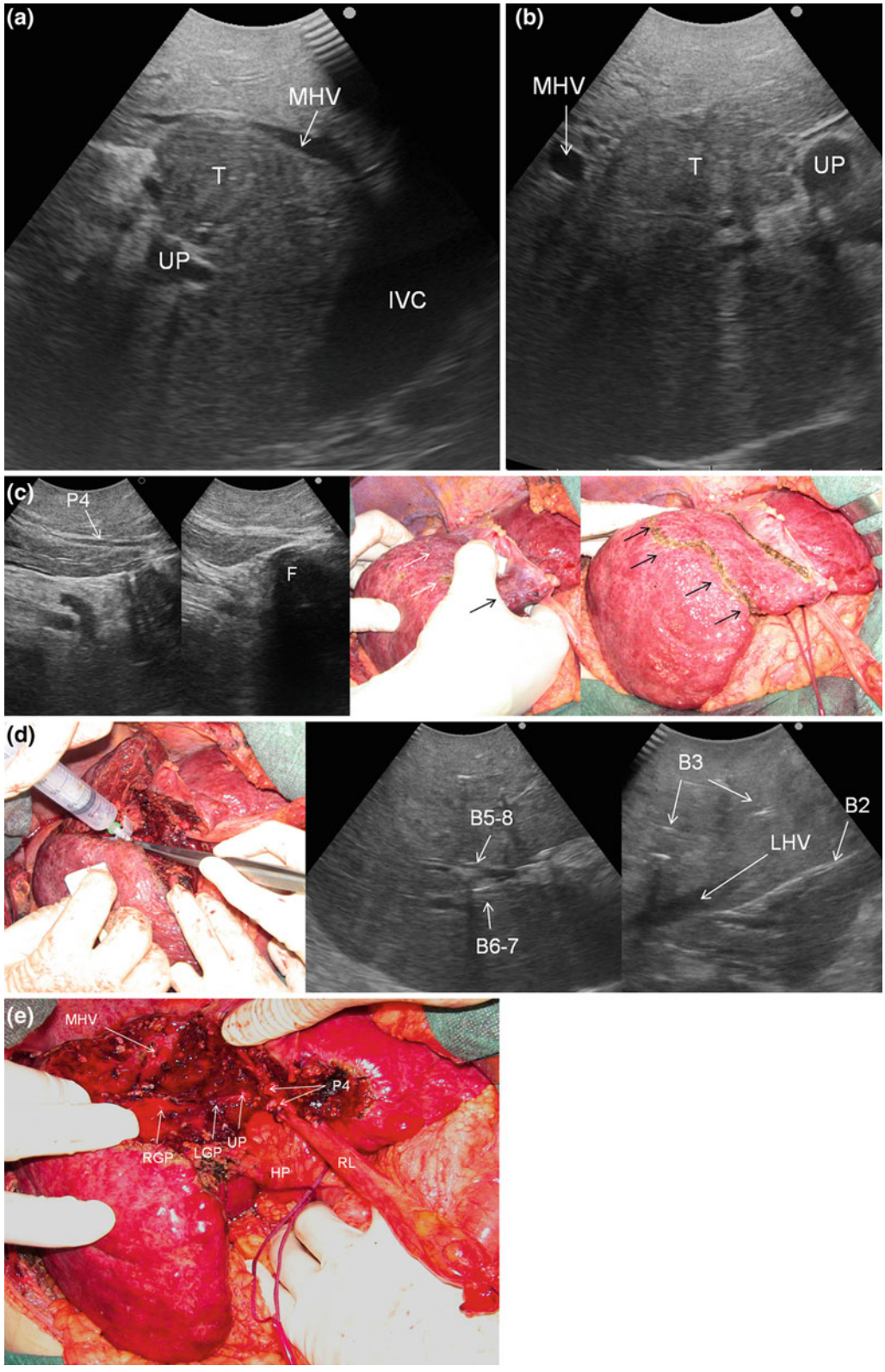


Fig. 9.17 **a** In this patient, operated for an intraductal cholangiocarcinoma (*T*), IOUS disclosed from the left to the right, the bile duct draining the right posterior section (B6-7 here indicated by *red arrow*) flowing into the left bile duct (*green arrow*), and then flowing together with the bile duct draining the right anterior section (B5-8 here indicated by *yellow arrow*) into the common bile duct; **b** once a left hepatectomy is carried out, confirmation of the proper division of the LBD is obtained by injecting slowly air into the bile duct stump; **c** B6-7 and B5-8 ducts are well followed up to those draining segments 7 (*B7*) and 8 (*B8*); **d** the left hepatectomy is then safely concluded; left portal vein (*LPV*); middle hepatic vein (*MHV*); portal branch to the right anterior section (*P5-8*); portal branch to the right posterior section (*P6-7*); right hepatic vein (*RHV*); right portal vein (*RPV*); umbilical portion (*UP*)

Fig. 9.18 **a** In this patient, IOUS shows an HCC (*T*) located between the umbilical portion (*UP*) and the middle hepatic vein (*MHV*) which it is in contact with, while the vein approaches its confluence into the inferior vena cava (*IVC*); **b** a transverse scan further details the relation between tumor, MHV, and UP; **c** finger (*F*) compression of the segment 4 pedicle (*P4*) is carried out and the segment edges are visible on the liver surface; **d** before removal of the specimen, a bile duct stump just above the left glissonian pedicle (*LGP*) is injected with air and the bile duct draining the right posterior section (*B6-7*), the right anterior section (*B5-8*), segment 3 (*B3*), and segment 2 (*B2*) are visualized confirming the preserved integrity of the remnant biliary tree; **e** a fully anatomical segmentectomy of segment 4 is then carried out; hilar pedicle (*HP*); right glissonian pedicle (*RGP*); round ligament (*RL*) ▶


(a)
MHV
T
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(b)
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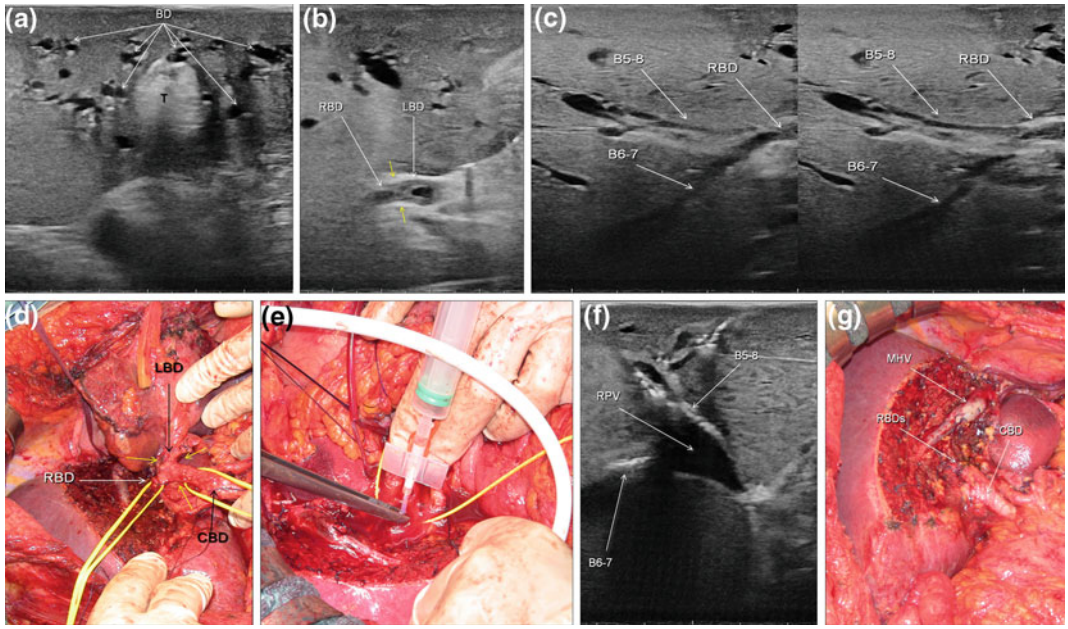

Fig. 9.19 **a–c** In this patient, IOUS shows a cholangiocarcinoma (*T*) determining bile duct (*BD*) dilation in the left liver (**a**), having associated with the wall thickening of the left bile duct (*LBD*) up to its confluence (*yellow arrows*) together with the right bile duct (*RBD*) into the common bile duct (*CBD*) (**b**); **c** on the right, apart from a wall thickening of the RBD, there are no signs of dilation of the ducts draining the right anterior (*B5-8*) and posterior (*B6-7*) sections; **d** left hepatectomy is almost concluded, remaining to be removed the biliary confluence (*yellow arrows*); **e** IOCUS with air is carried out by gentle injection from the hepatic stump after resection; **f** in IOCUS, B5-8 and B6-7 are well disclosed; **g** the operation is completed by end-to-end biliary reconstruction enabled by the negative frozen section on both sides, the wideness of the stumps, and the redundant length of the CBD; right bile duct stump (*RBDs*); right portal vein (*RPV*)

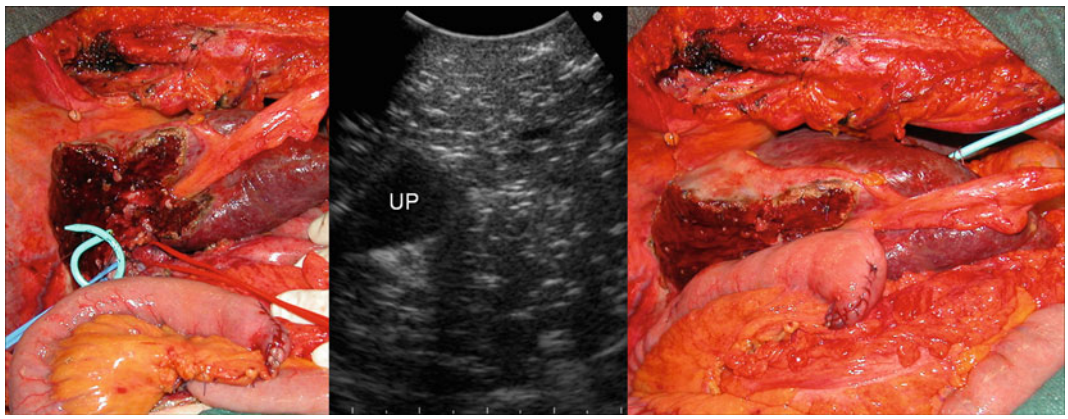

Fig. 9.20 Before hepatico-jejunostomy after right hepatectomy extended to segment 4 inferior and segment 1 for a perihilar cholangiocarcinoma (*left*), IOCUS confirms proper drainage by means of a parenchymatous phase (*center*), and then the anastomosis is carried out (*right*); umbilical portion (*UP*)

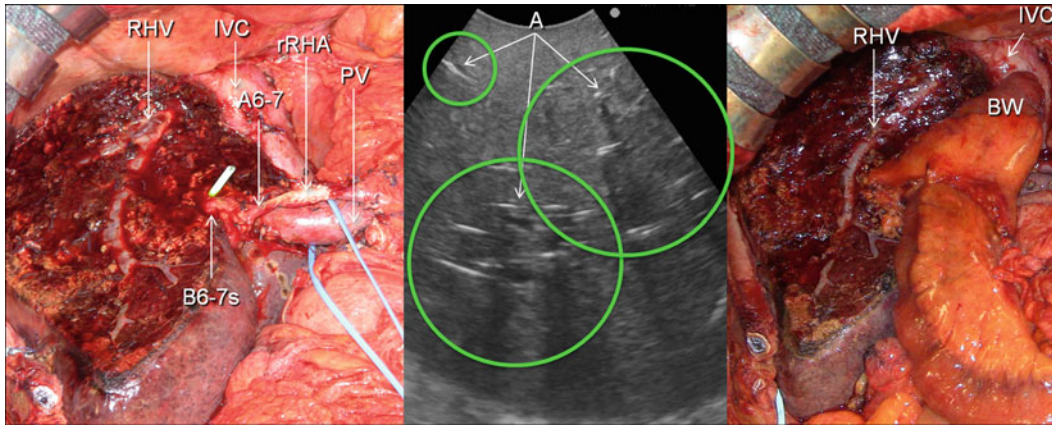

Fig. 9.21 Before hepatico-jejunostomy after left trisectionectomy extended to segment 1 for a perihilar cholangiocarcinoma (on the *left*), IOCUS confirms proper drainage by means of a parenchymatous phase (*green circles*), and then the anastomosis was carried out (on the *right*); air (**a**); hepatic artery to the right posterior section (*A6-7*); stump of the bile duct draining the right posterior section (*B6-7 s*); bowel (*BW*); inferior vena cava (*IVC*); portal vein (*PV*); reconstructed (with patch of bovine pericardium) right hepatic artery (*rRHA*); right hepatic vein (*RHV*)

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