ORIGINAL ARTICLE

Analysis of caudate lobe biliary anatomy and its implications in living donor liver transplantation – a single centre prospective study

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SUMMARY

Biliary complications are a significant cause of morbidity after living donor liver transplant (LDLT). Bile leak may occur from bile duct (anastomotic site in recipient and repaired bile duct stump in donor), cystic duct stump, cut surface pedicles or from divided caudate ducts. The first three sites are amenable to post-operative endoscopic stenting as they are in continuation with biliary ductal system. However, leaks from divided isolated caudate ducts can be stubborn. To minimize caudate duct bile leaks, it is important to understand the anatomy of hilum with attention to the caudate lobe biliary drainage. This single-centre prospective study of 500 consecutive LDLTs between December 2011 and December 2016 aims to define the biliary anatomy of the caudate lobe in liver donors based on intraoperative cholangiograms (IOCs) with special attention to crossover caudate ducts and to study their implications in LDLT. Caudate ducts were identified in 468 of the 500 IOCs. Incidence of left-to-right crossover drainage was 61.37% and right to left was 21.45%. Incidence of bile leak in donors was 0.8% and in recipients was 2.2%. Proper intraoperative identification and closure of divided isolated caudate ducts can prevent bile leak in donors as well as recipients.

Transplant International 2018; 31: 1041–1049

Key words
bile-leak postliver transplant, caudate lobe biliary anatomy, crossover caudate ducts, living donor liver transplant

Received: 7 March 2018; Revision requested: 3 April 2018; Accepted: 23 April 2018; Published online: 21 May 2018

Introduction

Living donor liver transplant is an established surgical procedure for treatment of end-stage liver disease. Refinements in surgical techniques have significantly reduced the incidence of post-operative morbidity in both donor as well as recipient. Biliary complications are one of the most dreaded complications in both donor as well as recipient after living donor liver transplant (LDLT) as they lead to significant post-operative morbidity and rarely mortality [1]. Bile leak may occur from the bile duct (anastomotic site in recipient and repaired bile duct stump in donor), cystic duct stump, cut surface pedicles or from divided caudate ducts in hilar plate. The first three sites are amenable to post-operative endoscopic stenting as they are in continuation with the ductal system. Bile leaks from ends of isolated divided caudate ducts can be difficult to manage. To minimize caudate duct bile leaks, it is important to understand the anatomy of hilum with attention to the caudate lobe biliary anatomy.

doi:10.1111/tri.13272

Caudate lobe is embryologically separate from the rest of the liver. This is reflected in the vascular as well as biliary drainage pattern of the caudate lobe [2]. Anatomically caudate lobe is divided into three parts, caudate process, paracaval portion and Spiegel's lobe [3]. For most hepatectomies with midline transection plane, caudate lobe can be divided into right (paracaval and caudate process portion) and left (Spiegel's) lobes for all practical purposes. Caudate lobe biliary drainage has been studied from cast specimens and cholangiographies (direct/endoscopic/drip infusion and 3D computed tomography) in patients undergoing treatment for various bile duct problems [4,5]. In contrast, donors for living donor liver transplant are healthy individuals without any pathology. They routinely undergo intraoperative cholangiography as part of donor hepatectomy. Intraoperative cholangiogram (IOC) in donors offers an excellent method to study the normal caudate duct anatomy.

Aim

This study aims to define the biliary anatomy of the caudate lobe in liver donors based on intraoperative cholangiography and to study their implications in living donor liver transplant.

Materials and methods

Study design

This is a single-centre prospective analysis of 500 consecutive living donor liver transplants between December 2011 and December 2016.

Technique

Intraoperative cholangiogram of donors undergoing donor hepatectomy is carried out intraoperatively to assess biliary anatomy. IOC is performed by cannulating the cystic duct with 6 Fr infant feeding tube following cholecystectomy. Atraumatic bulldog clamp is placed if possible, on the common bile duct (CBD) just above the duodenum to ensure complete filling of the biliary system and to prevent unnecessary pancreatic duct filling. Three to five millilitres of radio-opaque dye is injected, and cholangiographic images are obtained from multiple angles till the biliary anatomy is properly delineated. An IOC is deemed adequate when opacification of every second-order intrahepatic duct can be identified [6]. Cholangiogram is repeated after transection plane reaches below the plane of middle hepatic vein (MHV). We use the biliary anatomy classification proposed by Choi *et al.* [6] for interpretation of IOC.

Our technique for bile duct division in donors has been previously described in detail [7]. Hilar plate is sharply divided and a careful watch is kept to identify any caudate duct openings correlating with the IOCs. Sharp division of hilar plate not only helps to preserve vascularity of the ducts, but also helps in identifying divided caudate ducts which can be sutured close on both donor and graft sides with 6-0 polypropylene sutures. En masse ligation of thick hilar tissue should be avoided as it can result in slippage of ligature leading to biliary leak in donor as well as recipient. In addition to this, the hilar plate is continuously sutured with 6-0 polypropylene sutures in the donor as well as the graft (during back table preparation of graft) after removing blood clots if any, to account for any small or missed-out caudate ducts on IOC. Saline or methylene blue dye leak test is used to assess any leak from communicating caudate ducts (or the cut surface pedicles) after closure of the divided bile duct stump in donors. In all cases, intraoperative cholangiogram is carried out after taking out the graft. Any leak detected intraoperatively is sutured close.

Intraoperative cholangiograms were analysed to identify the number of caudate ducts and their drainage patterns. Right and left caudate ducts were defined relative to the midline transection plane.

Right caudate ducts are defined as ducts draining paracaval portion and the caudate process. Left caudate ducts are those which drain the Spiegel's lobe. These caudate ducts either can drain into bile ducts on their respective sides or cross over to the other side draining into the opposite bile duct. According to crossover pattern, we define the types of crossover of caudate ducts. Left-to-right crossover is defined as any left caudate duct draining into the right ductal system, whereas right-to-left crossover is defined as any right caudate duct draining into the left ductal system (Fig. 1).

Technique of bile duct reconstruction: Our technique for biliary reconstruction has been described in detail elsewhere [7]. Duct-to-duct anastomosis is preferred if possible. For two ducts which are less than 3 mm apart, ductoplasty is carried out, and this is then anastomosed as a single duct. Hepaticojejunostomy is carried out in case of multiple ducts or when recipient duct is of poor quality or inadequate size. As a routine, we do not use T tubes/internal stents during biliary anastomosis.

Post-operative incidence of bile leak in donors as well as recipients was analysed. Post-operative bile leak was defined as bilirubin concentration in the drain fluid at

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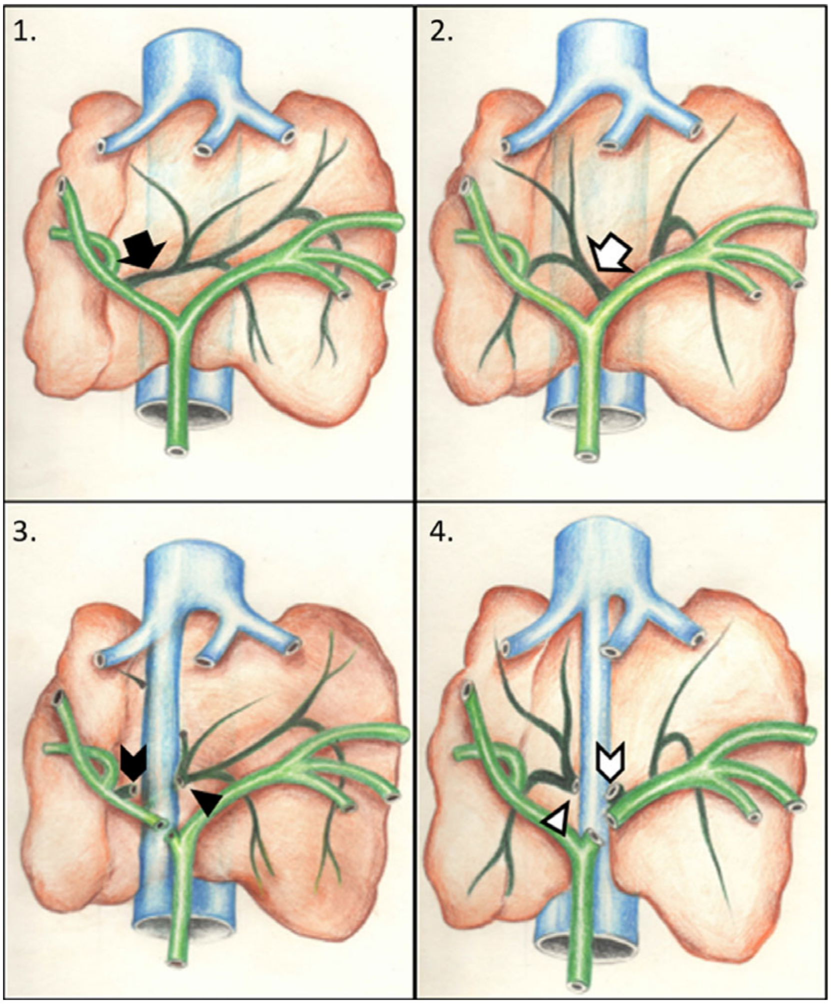

Figure 1 Image 1 shows left-to-right crossover drainage pattern of left caudate duct (black arrow), image 2 shows a right-to-left crossover drainage pattern of caudate duct (hollow arrow), image 3 shows the site of division of left-to-right crossover duct in case of right donor hepatectomy (Black arrow head shows divided isolated left caudate duct; black chevron arrow shows left-to-right crossover caudate duct in continuity with right ductal system), and image 4 shows the site of division of right-to-left crossover duct in case of left donor hepatectomy (Hollow arrow head shows divided isolated right caudate duct; hollow chevron arrow shows right-to-left crossover caudate duct in continuity with left ductal system).

least three times the serum bilirubin concentration on or after post-operative day 3 or as the need for radiologic or operative intervention resulting from biliary collections or biliary peritonitis [8].

Statistical analysis

Data were analysed using SPSS 17.0.

Results

Demographic details are mentioned in Table 1.

Caudate duct data on IOC

Identification and incidence of caudate ducts

At least one caudate duct was identified in 468 of 500 IOCs (93.6%) (Table 1). A total of 1494 ducts were identified in 500 IOCs (Average of 2.98 ducts per IOC).

Crossover drainage patterns of caudate ducts

Drainage of left caudate ducts: At least one left caudate duct was identified in 466 of 500 IOCs (Tables 1 and 2). A total of 286 of these 466 IOCs (61.37%) showed left-to-right crossover. Most common pattern of drainage of such ducts was into right posterior sectoral duct (RPSD) (75.17%), followed by right hepatic duct (RHD) (16.13%) and right anterior sectoral duct (RASD) (10.13%).

Drainage of right caudate ducts: At least one right caudate duct was identified in 429 of 500 IOCs. Ninety-two of these 429 IOCs (21.45%) showed right-to-left crossover. All these ducts drained into left ductal system. In rest of the 337 IOCs, right caudate ducts drained into the right ductal system.

Based on drainage pattern of caudate ducts, we propose a classification of caudate ducts (Fig. 2). Type 1 caudate duct drainage pattern shows presence of only a left-to-right crossover drainage. This is further subtyped into 1a, 1b and 1c when the crossover duct is draining

Table 1. Demographic and caudate duct data on intraoperative cholangiogram.

Data	Number	Percentage
Male:female	362:138	
Age (mean; years)	28.63	
Graft type		
Right lobe	468	
Left lobe	21	
Left lateral segment	9	
Right posterior sector	2	
IOC with demonstrable caudate ducts	468/500	93.6%
IOC with demonstrable left caudate ducts	466/500	93.2%
IOC with demonstrable right caudate ducts	429/500	85.8%
Average caudate ducts/IOC		2.98/IOC
Number of left-to-right crossover caudate ducts/IOC	400/500	0.8 cd/IOC
Number of right-to-left crossover caudate ducts/IOC	102/500	0.204 cd/IOC
Number of total crossover caudate ducts/IOC	502/500	1.004 cd/IOC

into right posterior sectoral duct, right hepatic duct and right anterior sectoral duct respectively. Type 2 drainage pattern shows only a right-to-left crossover. Type 3 pattern shows presence of both, left-to-right and right-to-left crossovers, whereas in Type 4 pattern, no crossover duct can be identified.

Intraoperative identification of crossover caudate ducts

Visualization for presence caudate duct during transection of hepatic parenchyma and hilar plate division was routinely performed and correlated with IOCs. All the donors in whom crossover caudate duct/s were identified in IOC, the crossover duct/s were also identified in the hilar plate or during parenchymal transection below plane of MHV (Fig. 3). A total of 502 crossover caudate ducts were identified in 500 donors (1.004 crossover ducts/donor IOC). Of these, 400 were left-to-right crossovers and 102 were right-to-left crossovers. However, on division of hilar plate we have identified an average of 1.36 divided caudate ducts/donor. The increased number of divided caudate ducts in hilar plate was due to missing of very small ducts on IOC due to inadequate filling.

All divided caudate ducts in the hilar plate were individually sutured close followed by continuous suturing of the hilar plate. Although in literature reconstruction of caudate lobe bile duct has been described in case of left lobe with caudate lobe grafts to increase the functioning graft volume [9], we have not reconstructed any caudate duct in our series.

Table 2. Caudate ducts in our study as per our classification.

Type	Subtype	Percentage
Type 1 (L–R crossover)		47.63
	1a (RPSD)	
	1b (RHD)	
	1c (RASD)	
Type 2 (R–L crossover)		6.52
Type 3 (Both crossovers)		13.67
Type 4 (No crossover)		37.8

Bile leaks after living donor liver transplant

Four of our 500 (0.8%) liver donors developed bile leak in post-operative period. Two donors were managed with prolonged drainage, one with insertion of percutaneous drain for collection and one donor required laparotomy with drain insertion.

Bile leak was identified in 11 of the 500 (2.2%) recipients post-operatively.

Discussion

Biliary anatomy of the caudate lobe has important implications in major liver surgeries involving the hilum. Caudate duct leaks are an important cause of nonanastomotic bile leak in recipients and cut surface leaks in donors [10,11]. Caudate duct leaks tend to be refractory. This emphasizes the need for detailed understanding of biliary anatomy of the caudate lobe [11]. This study highlights the importance of crossover caudate ducts in LDLT setting. Majority of studies on caudate lobe biliary anatomy have been described in a small number of patients with biliary disease. To our knowledge, this is the first and largest study analysing and classifying the IOCs of 500 healthy voluntary liver donors.

As described, the technique of IOC and its proper interpretation is very important. Application of a bulldog clamp to lower end of CBD ensures complete filling of the biliary system with minimal use of dye preventing complications such as dye-related pancreatitis [12]. Tethering can be caused by the caudate ducts at their site of insertion into the biliary ductal system, leading to overlapping and crowding of the bile ducts. This can lead to difficulty in interpreting the biliary anatomy.

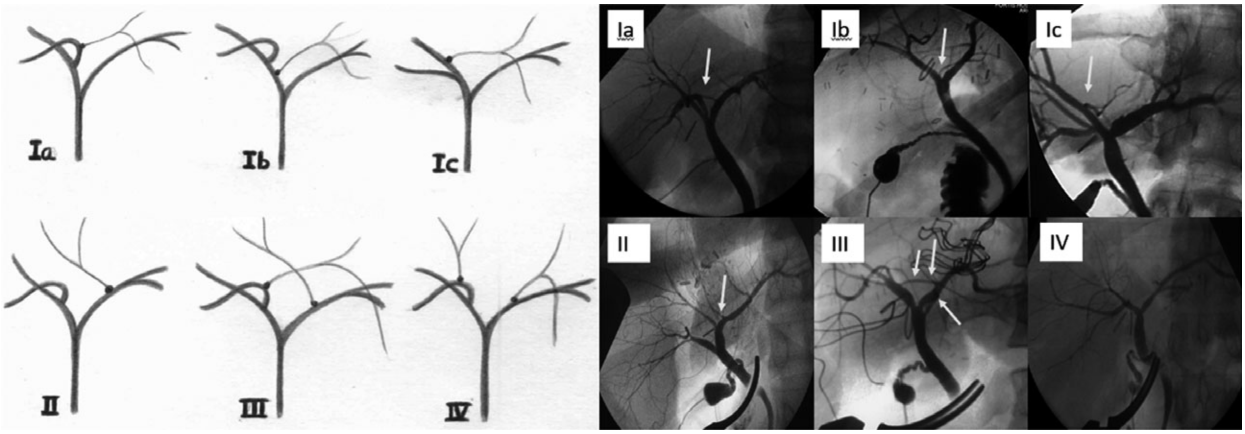

Figure 2 Classification of caudate lobe bile duct anatomy: Type I—only a left-to-right crossover drainage present. Subtyped into Ia, Ib and Ic when the crossover duct is draining into right posterior sectoral duct, right hepatic duct and right anterior sectoral duct, respectively. Type II—only a right-to-left crossover. Type III—both, left-to-right and right-to-left crossovers. Type IV—no crossover duct.

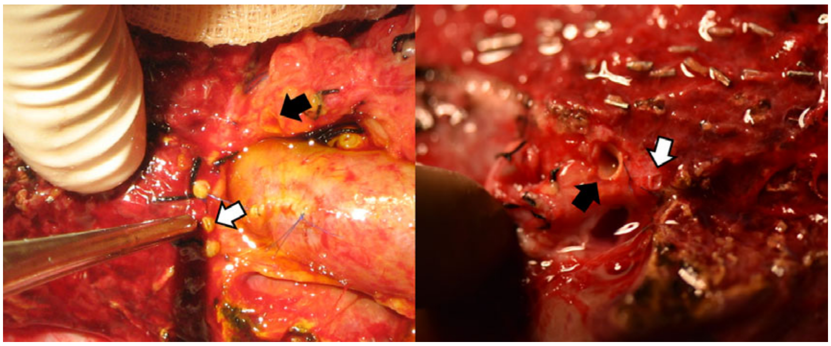

Figure 3 Divided caudate duct opening in the hilar plate in donor and graft (hollow arrow) (Black arrow represents divided right hepatic duct).

Multiple angles of cholangiogram help us to clearly delineate biliary anatomy including that of the caudate lobe (Fig. 4). We repeat IOC before dividing the duct once majority of transection is completed. This helps to differentiate between caudate ducts and segment 4 duct, should there be any confusion. This practice of repeating IOC before duct division is also advocated by Fan *et al.* [13] and Tamura *et al.* [14].

Using our technique of IOC, we could identify at least one caudate duct in 468/500 IOCs (93.6%). We could identify an average of 2.98 ducts/IOC which is similar to other studies [4,5,15]. We could not identify any caudate duct in only 6.4% of IOCs. Kitami *et al.* using noninvasive Drip-infusion cholangiography–computed tomography could similarly identify drainage ducts from each portion of caudate lobe in 96% cases [5]. Furukawa *et al.* [4] using 3D CT cholangiography were able to identify caudate ducts in 100% of their cases. Inability to identify caudate ducts in our study could be due to various reasons. Firstly, there can be inadequate filling of smaller caudate ducts. Secondly, caudate ducts are located behind the hepatic hilum and using intraoperative cholangiography, and it is sometimes difficult to eliminate the overlap of caudate ducts with other segmental ducts leading to missed caudate ducts.

Incidence of left-to-right crossover caudate ducts in our study was 61.37%. A total of 400 left-to-right crossover caudate ducts were identified (0.8 left-to-right crossover caudate duct/IOC). This is much higher as compared to other studies which give incidence of left-to-right crossover drainage ranging from 25% to 35% [4,5,11,15]. Our study was conducted in donors with normal anatomical details without any ductal dilatation. As Spiegel's lobe ducts drain from left to right with fewer left-sided overlapping ducts, left-sided caudate ducts are easy to identify on intraoperative cholangiogram increasing the accuracy of detecting left-to-right crossovers. The higher incidence of left-to-right crossovers in our study was confirmed by identifying divided crossover duct during parenchymal transection or hilar plate division intraoperatively. Anatomically, left-to-right crossover caudate ducts generally run from left to right in their initial course and then from posterior to anterior in hilar plate before insertion into the

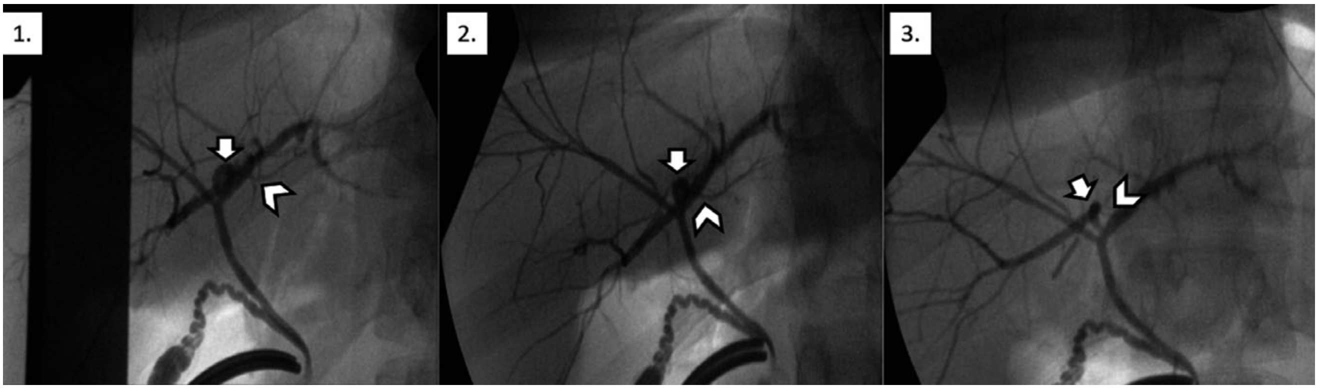

Figure 4 Right posterior sectoral duct (hollow arrow) is tethered by the left-to-right crossover caudate ducts (chevron arrow), and overlap of the bile ducts makes it difficult to interpret the images 1 and 2. However, with changing the angles, we can eliminate this overlap and better identify ductal pattern as seen in image 3.

right ductal system most commonly into RPSD. These ducts hence travel through the hilar plate over a longer distance and are most commonly divided during hilar plate division.

Incidence of right-to-left crossover caudate ducts in our study was 21.45%. Kitami *et al.* had a 36.6% incidence of right-to-left crossover, whereas Furukawa *et al.* identified no right-to-left crossover ducts [4,5]. Takamatsu had a 17% incidence of right-to-left crossover drainage [15]. The right caudate ducts have a comparatively shorter and straighter course before insertion into left hepatic ducts. These ducts are hence most commonly divided as pedicles behind the ductal confluence during parenchymal transection.

Classifying the caudate duct biliary anatomy is important in LDLT, split liver transplant and in major hepatectomies for various reasons. First, understanding of drainage of caudate ducts helps in correct interpretation of biliary anatomy and precise division of right or left hepatic duct during donor hepatectomy. Secondly, knowing the type of caudate duct and its intraoperative management helps to prevent complications such as bile leak. If any such complications should arise, the type of caudate duct is also a guide to proper management of same. Thirdly, it also has implications in left lobe graft with caudate lobe where caudate lobe ducts can be separately anastomosed to yield a higher functional volume of liver graft [9].

Pattern of bile leak in different types of liver resection and its management can be predicted from the proposed caudate duct classification.

Right lobe grafts (right donor hepatectomy)

In type I caudate duct drainage pattern, there is presence of left-to-right crossover caudate ducts. These ducts get divided during division of hilar plate. On the donor side, the divided left caudate duct is isolated from rest of the biliary ductal system and cannot be detected intraoperatively on saline or methylene blue dye test. It leads to bile leak post-operatively if not secured properly. Also, as Spiegel's lobe remains intact in the donor with its preserved vascularity and function, the amount of bile leak in the donor can be significant. As the divided left caudate duct is isolated, such leaks are not amenable to endoscopic retrograde cholangiographic stenting. Management of such bile leaks is usually conservative requiring long-term drainage to avoid intra-abdominal collections. Recalcitrant bile leaks can be managed with injecting a sclerosant such as absolute alcohol into the isolated caudate duct. As these ducts are isolated from rest of biliary tree, there is no risk of sclerosant leaking into the bile ducts of the donor. In the recipient of right lobe graft, the divided end of crossover left caudate duct is in communication with the biliary system and bile leak from these ducts generally present as side leaks. These bile leaks are benign and amenable to stenting or endoscopic papillotomy (Fig. 1).

In type 2 caudate ductal anatomy, these crossover right caudate ducts will be divided during transection and may lead to bile leak if not secured well. However, as this crossover right duct is communicating with the left biliary system in the donor, this leak can be detected on saline or methylene blue testing and is amenable to endoscopic papillotomy/stenting. In recipient of the right lobe graft, the leak from the isolated divided crossover paracaval duct is usually minor as amount of caudate tissue retrieved along with the right lobe is very small [16].

In type 3 anatomy where both right-to-left and left-to-right crossovers exist, any or both above patterns of bile leak can occur in donor as well as the recipient after right/left donor hepatectomy.

In type 4 anatomy, crossover ducts are absent and hence not divided. Right caudate ducts draining into right ductal system may be divided depending on their point of insertion and site of duct division. In the donor, this divided duct will be communicating with the biliary system and hence present as side leak. In recipient of such a right lobe graft, although the divided duct is isolated, the amount of bile leak is minimal as only a small portion of paracaval caudate is retrieved with the graft.

Left lobe grafts with caudate lobe

The pattern of bile leak and its management will be converse to that in case of right lobe grafts (Fig. 1).

Left lobe graft without caudate lobe/left lateral segment graft

In type 1 caudate anatomy, the left-to-right crossover caudate ducts usually do not get divided as transection plane below middle hepatic vein is shifted horizontally to exclude the caudate lobe. However, injury to a crossover duct in this case will result in a clinically significant bile leak as entire caudate lobe is retained with the donor.

In type 2 caudate duct drainage pattern, divided crossover paracaval ducts can result in a significant leak with characteristics like that of left lobe graft with caudate lobe (Fig. 1).

Irrespective of type of crossover caudate ducts, some left caudate ducts drain directly into the left ductal system at various distances from the confluence. These may get divided depending on the site of left hepatic duct division in retrieval of left lobe graft without caudate lobe. In a left lateral segment graft, left duct is generally divided near the umbilical fissure. Generally, only an occasional caudate duct drains directly at this point and might get transected. However, the incidence of this is quite low and in left lateral segment grafts, caudate ducts are generally not divided.

Right posterior sector graft

This is a technically difficult graft to retrieve. Attention to caudate ductal anatomy helps in safe ductal division for right posterior sector graft (RPSG). In type 1a caudate anatomy, where left caudate ducts drain into RPSD, the site of division of RPSD determines the pattern of postoperative bile leaks. Generally, the RPSD is divided lateral to the insertion point of caudate duct as it is difficult to reach up to confluence of RPSD with RASD or left hepatic duct. In these cases, the crossover caudate ducts will not be divided. However, if the right posterior sectoral duct gets divided medial to the insertion into RPSD, the pattern of bile leak will be like that seen in right lobe graft. In type 1b and 1c, the left-to-right crossover caudate ducts do not come into picture. In case of right caudate ducts draining into the right ductal system, the ducts run parallel to transection plane. They generally get divided as pedicles during parenchymal transection during retrieval of RPSG.

Table 3. Donor bile-leak rates in various studies.

Reference	Year	*N*	Bile leak (%)
Dar *et al.* [22]	2016	100	3
Sultan *et al.* [23]	2014	216	11.1
Kamel *et al.* [24]	2012	145	18.2
El-Meteini *et al.* [1]	2010	207	22
Iida *et al.* [25]	2010	500 RG 762 LG	10.6 leak in RG, 4.7 leak in LG
Ghobrial *et al.* [18]	2008	393	9.2
Taketomi *et al.* [26]	2009	206	2.43
Shio *et al.* [27]	2008	731	6.57
Gruttadauria *et al.* [28]	2008	75	9.3
Chan *et al.* [29]	2007	200	0

Donor morbidity and mortality remains the most important ethical dilemma of living donor liver transplantation. Biliary complications after living donor hepatectomy are the most common cause of donor morbidity [17–21]. Various studies have reported donor bile-leak rates of up to 30% including one incidence of donor mortality following biliary peritonitis [1,18,22–29] (Table 3). Overall incidence of donor bile leak at our centre is very low at 0.8%. Other studies have also reported a similar low incidence of donor bile leaks [29]. The major reason for minimal donor bile-leak rates in our study is careful identification and suturing of divided caudate ducts intraoperatively. Technique of continuous suture of the hilar plate has been described by Broering *et al.* [17] to reduce the incidence of bile leaks in donors. Other reasons include keeping the plane of transection strictly along the middle hepatic vein to ensure minimum crossover pedicles. It is important to ligate/clip pedicles securely before dividing them to reduce chance of bile leak from the cut surface. When a donor develops bile leak, we carefully study the IOC again to look for caudate duct anatomy and any crossover caudate ducts. A low-output bile leak without any features of systemic sepsis is managed by prolonged drainage. ERCP has its own complications in form of cholangitis and pancreatitis. Only in cases where bile leak persists for more than 4 weeks or IOC shows presence of caudate duct which is in communication with the biliary ductal system do we resort to ERCP/tubogram for localization and management of bile leak. In the four donors at our centre with bile leak, bile leak resolved with drainage in all cases within 4 weeks, so none of our donors required ERCP or tubogram. Hence it is difficult to pinpoint the exact site of bile leak in our cases.

For living donor liver transplant recipients, bile-leak rate was 2.2% at our centre. Eleven of 500 recipients suffered from bile leak. We ascribe this low rate of bile leak to our corner-sparing technique of biliary anastomosis with careful identification and meticulous closure of divided crossover caudate ducts [7]. Although it is not possible to pinpoint the site of bile leak in recipients, proper suturing of open caudate ducts allows for significant reduction in nonanastomotic bile leaks.

Conclusion

Intraoperative cholangiogram provides an excellent method to study the normal caudate duct biliary anatomy. Classifying caudate ducts has many implications in living donor liver transplant which can also be extrapolated to split liver transplant and hepatectomies for other indications. It helps in minimizing and managing postoperative bile leaks in living donor liver transplant. Also, proper knowledge of caudate duct anatomy may be used for reconstruction of relevant caudate ducts in recipient of left lobe graft with caudate lobe, thus increasing the functional liver volume. We have found a significantly higher incidence of crossover caudate ducts as compared to other studies. This serves to make us more vigilant in tackling the divided caudate ducts to prevent stubborn bile leaks in donors as well as recipients.

Authorship

Conception and design of study: KM, VV and VC. Acquisition of data: KM and AAK. Analysis and/or interpretation of data: KM, VV, ASr and ASi. Drafting the manuscript: KM, VC and AAK. Revising the manuscript critically for important intellectual content: KM, VV, ASr and ASi. Approval of the version of the manuscript to be published: KM, VC, ASr, ASi, AAK and VV.

Funding

The authors have declared no funding.

Conflicts of interest

The authors have declared no conflicts of interest.

Acknowledgements

We have received no financial or material support for our paper.

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