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Review

# A review of techniques for liver resection

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***Background*: There has been a significant increase in the number of hepatic resections performed. The aim of this review was to assess available techniques for liver resection and their application.**
***Methods*: A literature review was performed based on a Medline search to identify articles on liver resection. Keywords included liver resection, liver neoplasm, cancer, colorectal metastases and hepatocellular carcinoma.**
***Results*: Improved understanding of the segmental anatomy of the liver has resulted in the evolution of liver resection. The development of new approaches to the biliovascular tree, combined with clamping to produce ischaemic demarcation, has been important in demonstrating segmental boundaries for resection. The combination of methods of vascular control such as the Pringle manoeuvre and techniques of parenchymal resection such as ultrasonic dissection allows hepatic resection with minimal blood loss and morbidity.**
***Conclusions*: Application of refined techniques for liver resection by specialised units allows liver resection to be performed on both normal and cirrhotic livers with low morbidity and mortality.**

*Key words*: Liver resection – Neoplasm – Cirrhosis

Surgical practice is intimately related to developments in surgical technique and anatomical understanding; the explosion in liver resection over the last 20 years is a prime example of this. Liver resection remains the only potentially curative treatment for primary and metastatic liver tumours. The aims of this review are to consider the anatomical and technical refinements in hepatic resection that have stimulated this expansion.

Hepatic resection can be applied to a wide range of pathologies. These include: (i) benign primary tumours such as liver cell adenoma or haemangioma; (ii) primary malignant tumours such as hepatocellular carcinoma; or (iii) hepatic trauma. The most frequent application, however, is for liver metastases, the commonest being colorectal metastases. The benefit of liver resection for colorectal metastases is proven, with Scheele demonstrating a 38% 5-year survival following hepatic resection and other studies have shown similar survival outcomes.[1–7]

The techniques used for resection are similar whatever the pathology though with some refinements. Emphasis will be placed on techniques for tumour resection as this is the commonest application of hepatic resection.

## Aims of resection

The aim is to resect the liver with minimal bleeding and leaving adequate functional liver. It is crucial that sufficient residual functioning liver remains after resection so as to avoid hepatic insufficiency postoperatively. This is of particular concern in patients with cirrhosis where liver function may be reduced anyway, and also in patients with extensive disease where the volume of liver to be resected

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is considerable. Surgeons are understandably wary of the potential for bleeding from the liver and losses of up to 10 l have been reported.[8–10] Excessive blood loss is associated with increased peri-operative morbidity[8,11,12] and, in the case of colorectal metastases, a shorter disease-free interval.[13]. A number of units, however, have produced liver resection series demonstrating very low transfusion requirements and surgical mortality of 5% or less,[14–17] and these results reflect the use of refined techniques for liver resection.

**Surgical anatomy of the liver**

Developments in the understanding of hepatic anatomy have been of vital importance in liver resection. Morphologically, as the liver lies in the abdominal cavity, it is split into a large right and a small left lobe by the falciform ligament extending from the anterior abdominal wall. The morphological description, however, does not correspond to the surgical anatomy of the liver and studies by Tung,[18] and most importantly by Couinaud,[19] on the functional anatomy of the liver have paved the way to safe hepatic resection. Division of the portal inflow divides the liver into two, a right and left hemiliver, along the principal plane (Rex-Cantlie line) that passes through the gall bladder bed towards the vena cava and through the right axis of the caudate lobe. Further subdivisions of the portal inflow divide each hemiliver into 2 subdivisions termed sectors and then each sector into 2 subdivisions termed segments. There is one exception to this, which is described below. The divisions of the portal vein are mirrored by divisions of the bile duct and hepatic artery forming a 'portal trinity', and hence the liver can be divided into segments, each of which has its own 'portal trinity' supplying it.[20] The 3 major hepatic veins (right, middle, and left) lie between the 4 sectors in the 3 main fissures or scissuras, right, main, and left, respectively, and each vein drains the sectors on either side of it. This is shown diagrammatically in Figure 1.

The functional anatomy is not visible on inspection of the liver and Figure 2 shows the liver if it were to be divided into its segments. The right hepatic vein separates the two sectors of the right hemiliver which lie anterior and posterior. The right anterior sector is subdivided into segments V (inferior) and VIII (superior) and the right posterior sector is subdivided into segments VI (inferior) and VII (superior). The left vein separates the 2 sectors of the left hemiliver which lie anterior and posterior. The left anterior sector is divided into two segments, III and IV but the left posterior sector is the one exception to the rule as it only has one segment, segment II. The caudate lobe is a distinct anatomical segment and is labelled segment I. It receives branches of the portal trinity from the right and left liver and drains independently into the vena cava.

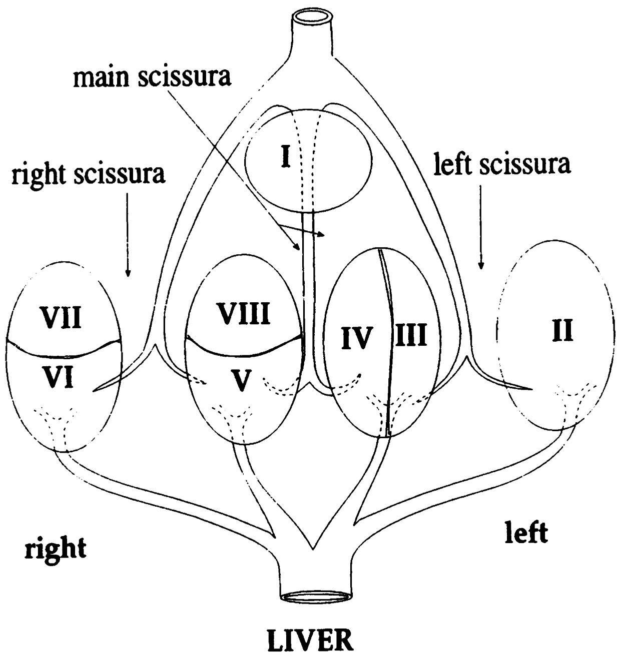


**Figure 1** Diagrammatic representation of the segmental anatomy of the liver. The right side of the liver contains segments V, VI, VII, and VIII. The left side contains segments II, III, and IV, and the caudate lobe is equivalent to segment I.

The right vein drains into the vena cava independently, but the middle and left veins usually join and drain into the vena cava as a single vein.[19] There are usually a few small veins draining into the vena cava from behind the liver. Occasionally there can be 2 or 3 inferior right hepatic

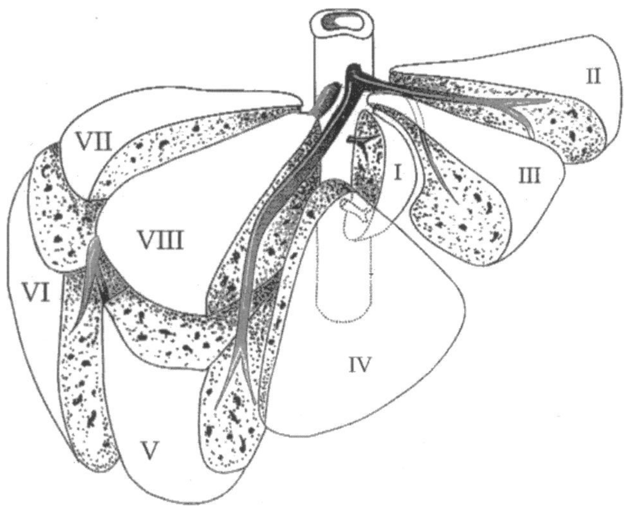


**Figure 2** Couinaud's segmental picture of liver. The representative appearance of the hepatic segments separated within the liver.

veins of moderate size and these can provide significant drainage. If these are not recognized and torn during hepatic resection, bleeding may be profuse.

As each segment of liver has its own supply from the portal trinity, independent of the other segments, they can be resected independently of other segments. In practice, it is easier to remove some segments together. Although the intersegmental planes are not visible on the surface of the liver, segments can be defined by occluding the inflow to that segment thus rendering the segment ischaemic and demonstrating the functional division on the liver surface. It has been recognised that Glisson's capsule extends as a condensation of fascia around the biliovascular branches of the portal trinity (Glissonian sheaths). Couinaud and more recently Launois and Jamieson[21] have noted that the fascia continues within the liver parenchyma up to the segmental divisions. The surgical implication is that if the supply to an individual segment is approached from within the liver, mass ligation of a sheath will devascularise the segment. This is simplified even further by the use of a stapler.[22]

The nomenclature of hepatic resection remains confusing with differing terminology used in the literature.[23] The contrast is between the American terminology of Goldsmith and Woodburn[24] and that of Couinaud.[19] It is important that precise descriptions of what part of liver is to be resected are used.

**Resection techniques**

A number of abdominal incisions can be used for liver resection. A bilateral subcostal incision provides good access and usually is made by extending an exploratory right subcostal incision to confirm there is no unexpected peritoneal disease. An upwards extension to the bottom of the sternum to form a Mercedes-Benz incision can be made to allow wider access. A costal retractor such as a Rochard (Downs Surgical, UK) may be used. A mid-line incision with a right costal extension is also practical. Following an exploratory laparotomy, the liver is mobilized from its peritoneal attachments. The falciform ligament is divided, with particular care superiorly where the hepatic veins enter the inferior vena cava. The right coronary ligament, with its anterior and posterior leaves around the bare area of the liver and its fused caudal extension as part of the triangular ligament, is divided to mobilize the right liver. The left triangular ligament is divided to mobilize the left liver, though for extensive right-sided resections, it may be preserved to prevent liver rotation and venous outflow occlusion post resection.

Following mobilization, the liver is assessed with intra-operative ultrasound. This is a standard adjunct to resections of both primary and secondary neoplasms,[25–28] and may modify the planned approach in up to 50% of cases.[25,27,28] It allows confirmation of expected sites of disease and may detect additional lesions in 10–50% of cases.[26,29,30] Intra-operative ultrasound allows confirmation of the hepatic vascular anatomy in relation to the tumour[31] and allows identification of specific segmental pedicles and the location of the hepatic veins.[32,33] This is important for segmental resections as the pedicle should be located and occluded early in parenchymal transection to identify the borders of the particular segment, as a clear parenchymal demarcation will result, and guide the extent of parenchymal transection.[33]

**Approaches to the hepatic inflow pedicles and veins**

The majority of hepatic resections involve the right or left hemiliver and the inflow of the resected hemiliver must be ligated at some point during the resection. The same is true of resections of a sector or of a segment. The appropriate technique will vary with the method of vascular inflow control used (discussed below) and segment(s) to be resected. The outflow must also be controlled and divided at some point. The different approaches are not exclusive and may be combined. Staplers are often of particular value in dividing the portal triads and hepatic veins.[22,34,35]

*Extrahepatic approach*

The main hepatic pedicle can be approached from outside or from inside the liver substance. The extrahepatic approach was first described by Lortat-Jacob and co-workers in 1952 in a report of a right hemihepatectomy.[36] The free edge of the lesser omentum is opened, the portal vein, hepatic artery, and common bile duct followed up to their divisions, and the appropriate side dissected and divided. Dissection can be time consuming and anatomy may vary. Division may be high and close to the porta hepatis. Misidentification and ligation of the wrong vessels may devascularise an area of liver that is not planned to be resected.

The hepatic veins may be dissected extrahepatically in the case of both the right vein and the middle/left vein, whether combined or prior to their joining. The veins are wide and accidental damage may result in catastrophic and uncontrollable haemorrhage.

*Intrahepatic approach*

The hepatic pedicles may be approached directly by the anterior intrahepatic approach.[8,37] This was first described by Tung[37] and involves dissection of the hepatic parenchyma along the hepatic fissures and ligation of the pedicles directly within the liver. The problems are that the fissures are not identifiable on the liver surface and, prior to pedicle ligation, there are no identifiable boundaries between the segments. There may be considerable haemorrhage as the pedicles are ligated after parenchymal dissection. This method is necessary to ligate a portal triad to an individual segment and intra-operative ultrasound can aid identification of the appropriate portal triads.[32,33,38] The hepatic veins may also be ligated within the liver substance. The advantage is that this reduces the risk of damaging the vein, but the disadvantage is that ligation of the vein tends to have to be late in the resection and hence haemorrhage may again be considerable.

The hepatic pedicles may be approached by the posterior intrahepatic approach described by Launois and Jamieson[39] which utilizes the Glissonian sheaths. Incisions of the liver capsule around the porta hepatis allow limited intrahepatic dissection. Dissection along the sheaths around the portal triads provides access to the main trunk sheaths supplying an entire hemiliver, further within to sectorial divisions, and then to segmental divisions. Clamping of these divisions may be used to confirm identification by devitalisation of the supplied segment(s) and the appropriate sheath may then be ligated. Excellent results have been reported with this method.[40–42]

## Hepatic vascular control

The potential of severe haemorrhage during liver resection[8–10] and the resulting morbidity has already been mentioned.[8,11–13] Bleeding maybe a particular problem during parenchymal transection. A number of techniques of hepatic vascular control of inflow and outflow are available and, though liver resection can be performed without vascular control,[37] the use of vascular control can result in very low blood losses.[16,43,44] Alternative techniques to reduce parenchymal bleeding such as use of a hepatic tourniquet[45] or instruments to compress the parenchyma[46,47] are not generally used.

### *No preliminary vascular occlusion*

This is the original technique described by Tung[37] with direct dissection through the liver parenchyma to the inflow and outflow of the area to be resected with no other vascular control. It has the advantage of no risk of erroneous ligation of hilar structures, but, unless performed quickly, bleeding is substantial from the transection surface, particularly if coagulation is impaired such as with cirrhosis. Identification of the hepatic fissures may also be a problematic as perfusion of the hepatic segments remains uniform during transection.

### *Pretransection ligation of hilar vessels*

The extrahepatic approach to the hilar vessels and hepatic veins described by Lortat-Jacob[36] does provide vascular control prior to transection of the liver parenchyma. The advantages are that the area to be transected is well demarcated prior to transection as it is devascularised, and that intra-operative haemorrhage is minimal. The disadvantages are that inappropriate ligation at the porta hepatis is possible and dissection of the hepatic veins may be difficult, with the risks of severe haemorrhage and air embolism. It is also not possible if resection of a segment alone is undertaken.

### *Temporary vascular occlusions of the liver*

A number of techniques of occlusion of hepatic inflow are available which may be combined with occlusion of hepatic outflow.

**Total inflow occlusion**

Pringle first described total clamping of the hepatic pedicle or the Pringle manoeuvre in 1908 to reduce hepatic haemorrhage secondary to trauma.[48] It is probably the most common method of minimizing blood loss during parenchymal resection and involves 'en masse' clamping of all the structures of the hepatic pedicle present in the free edge of the lesser omentum with a non-crushing clamp. Nagasue *et al.*[49] and Kim *et al.*[44] have compared hepatic resections of cirrhotic livers with and without the Pringle manoeuvre and have shown a significant reduction in intra-operative blood loss, postoperative complications, and mortality in the group in which the Pringle manoeuvre was used. Studies in which both cirrhotic and non-cirrhotic patients underwent hepatic resections also demonstrated a significant improvement using the Pringle manoeuvre.[50,51] Inflow occlusion does result in a haemodynamic response with an increase in systemic vascular resistance and a corresponding increase in heart rate and mean arterial pressure,[50,52] but this is usually well tolerated in both non-cirrhotic[15,53] and cirrhotic patients.[54]

Opinion on the safe duration of clamping varies. For a long time, the original description by Pringle[48] of 15–20 min of inflow occlusion was considered the limit in a normal liver.[55] Huguet *et al.*[56] reported no major complications or mortality in a series of resections with inflow occlusions times of 25–65 min with a mean of 38 min. Since then, a number of authors have reported continuous occlusion times of up to 60 min with few complications,[14,52] and this is generally considered the safe upper limit for normal livers. Continuous occlusion up to 90 min has been reported,[57] although this duration of warm ischaemia is associated with a significant number of major complications such as transient hepatic insufficiency and encephalopathy. Nagasue *et al.* have demonstrated that inflow occlusion durations of up to 30 min can be tolerated safely in cirrhotic livers,[49,58] and possibly up to

60 min in early disease,[54] though increasing duration does increase the potential to develop problems.

If prolonged occlusion is required, intermittent clamping can be used with repeated clampings of 10–20 min duration, each followed by 5 min declamping.[51,59] Intermittent occlusion with total ischaemic durations greater than 90 min has been used safely.[60] In cirrhotic livers, total occlusion times of 45 min have been shown to be safe using intermittent clamping.[61,62] Animal studies have shown better results with intermittent occlusion than with continuous occlusion, [63,64] and a recent controlled study has confirmed this in humans.[65] There are case reports of very long total ischaemic durations.[62,66]

**Lowering of the central venous pressure**

Total inflow occlusion, whether continuous or intermittent, will reduce bleeding from the liver parenchyma, but there will still be bleeding from the liver parenchyma from backflow through the hepatic veins. This backflow has been shown to be important for liver perfusion.[67] The draining hepatic vein of the hemiliver to be resected, in the case of a hemihepatectomy, can be divided prior to parenchymal transection and this will reduce bleeding from that half of the liver.[68] This dissection is, however, potentially hazardous and damage to the draining veins may produce severe haemorrhage; it may be safer to divide the vein from within the liver. There will still be back bleeding from the remaining liver, but use of techniques to lower the central venous pressure (CVP) to 0–5 cm during transection has a dramatic effect on reduction of blood loss. Lowering the CVP to below 5 cm significantly reduces blood loss,[69] and has resulted in groups demonstrating very low intra-operative blood losses.[16,17] Melendez *et al.*[17] have done this by positioning the patient head down and restricting fluid replacement until the resection is completed. Rees *et al.*[16] used a combination of epidural anaesthesia and intravenous nitroglycerine for vasodilatation. Air emboli may occur during hepatic surgery,[70] and the risk of this is increased with lowering of the CVP.

**Selective inflow occlusion**

Total inflow occlusion results in an ischaemic insult to liver that is not to be resected. Some groups have tried to limit the ischaemia to the side of liver to be resected only. Bismuth[71] described dissection of the arterial and portal elements to one side of the liver which are temporarily occluded, allowing demarcation of the parenchymal incision line. Any minor veins connecting the right liver to the retro hepatic vena cava are divided and then the parenchyma is transected down to the portal triads supplying the area of liver to be resected. These are then ligated within the liver, distal to the extra hepatic hilar clamps. The appropriate hepatic vein is ligated within the liver as the final vascular ligation. Makuuchi *et al.*[38,61] have described the use of hemi-hepatic vascular occlusion with intermittent repeated occlusion periods of 15–30 min and reported a significant reduction in blood loss compared to no occlusion. A number of groups have reported good results using this technique,[72–74] and the potential benefit is with cirrhotic patients where the liver function is already impaired. The advantages are minimal blood loss, safe ligation of vessels within the liver, demarcation of the devascularised liver parenchyma, and no ischaemic insult to the unresected liver. Alternation of the side of occlusion has been shown to allow resection across the main hepatic fissure for extended resection.[61,75] The disadvantage is the necessary dissection of the extrahepatic hilar elements that can be a particular problem in cirrhotic patients; however, with use of the posterior intrahepatic approach to the portal triad described by Launois,[39] this is reduced. Although there is a theoretical physiological advantage to reducing hepatic ischaemia, no clinical benefit has been demonstrated. Miyagawa *et al.*[76] demonstrated that serum amylase levels in cirrhotic patients were significantly more elevated following liver resection using the Pringle manoeuvre than with hemi-hepatic occlusion though elevation in serum bilirubin, aspartate aminotransferase (AST), and alanine aminotransferase (ALT) have not been shown to differ between the two techniques.[77]

An alternative technique to allow selective hepatic vascular occlusion has been the use of balloon catheters inserted into the portal vein and down its divisions, with inflation of the balloon used to produce occlusion of the appropriate area perfused by the portal vein.[78,79] Ultrasound guidance may be used to identify the intended vein within the liver and methylene blue may be injected to confirm that the vein is supplying the appropriate segment of liver. Once this has been confirmed, a balloon catheter is inserted, again under ultrasound control, the balloon inflated, and the segment inflow occluded.[78,79] Goseki *et al.*[80] have reported insertion of a double balloon through a branch of the ileocolic vein, via the portal vein, into a segmental division, allowing selective vascular occlusion of the segment in combination with intermittent occlusion of the portal vein. The advantages are again the reduction in liver ischaemia with the potential of reduced postoperative hepatic insufficiency; avoidance of hilar dissection. and prevention of portal dissemination of tumour cells which is considered to be a risk with hepatocellular carcinoma. The disadvantage is that the procedure is complicated, and there may be associated bleeding from the hepatic artery inflow which is not controlled.[81]

**Total hepatic vascular exclusion**

The aim of hepatic vascular inflow control is to reduce the blood loss associated with liver resection. The extension of this argument is to isolate completely the liver from both inflow and outflow during resection. This was described by Heaney *et al.*[82,83] and has been applied by a number of authors.[14,52,57,84–87] The suprahepatic subdiaphragmatic inferior vena cava and the infrahepatic vena cava, above the right adrenal vein, are both clamped, along with the hepatic pedicle to isolate completely the liver from blood flow. Any indirect supply to the liver including any vessels in the hepatic ligaments must also be divided.[81] Total hepatic vascular exclusion (THVE) results in a significant haemodynamic response, with a substantial reduction in cardiac output, though blood pressure is usually maintained.[88] Around 10% of patients cannot tolerate it haemodynamically.[87] Veno-venous bypass may be used to maintain inferior vena cava flow in patients who are unable to tolerate the haemodynamic effects of THVE or supracoeliac aortic clamping for similar reasons.[84,89] It is possible to perform THVE with maintenance of vena cava flow, if the inferior vena cava is not involved by the tumour.[90] THVE is associated with significant morbidity. This can be up to 50% in patients without cirrhosis, along with a mortality rates of up to 10%.[52,85,86] The ischaemic limit is 60–90 min for patients with normal liver function.[15,57,91] Although resections with THVE can be performed safely in patients with cirrhosis, the maximal ischaemic time is halved and, in addition, the residual liver function before surgery must be at the better end of the spectrum.[86] This technique allows otherwise inoperable cases, such as tumours near or involving the retrohepatic vena cava or the confluence of the hepatic veins and vena cava, to be undertaken.[14] There are problems associated with this technique; it is time-consuming, may result in haemodynamic complications, and may cause significant hepatic insufficiency, particularly in patients with cirrhosis, as the ischaemia is constant and not intermittent. There is only one controlled trial comparing THVE with the Pringle manoeuvre.[87] There was no difference in blood loss or postoperative hepatic function between the two groups, although THVE was associated with a longer hospital stay, longer operating times, and a longer period of hepatic ischaemia. In addition, 14% of patients could not tolerate THVE. Melendez *et al.*[17] argued that use of the intermittent Pringle manoeuvre along with low CVP techniques provide evidence that extended hepatic resections can be performed without THVE. The use of THVE should probably be restricted to cases discussed above such as tumours involving the retrohepatic vena cava or its confluence with the hepatic veins.[92]

THVE can be combined with hypothermic perfusion to permit an ischaemic time of over 90 min. Perfusion of the liver with cold heparinised Ringer's solution allows liver ischaemia of up to 120 min.[93,94] Further studies[95,96] have veno-venous bypass and University of Wisconsin solution as perfusate[97] with ischaemic times ranging up to over 4 h. Delriviere *et al.*[96] reported no postoperative mortality or hepatic insufficiency in 11 resections of non-cirrhotic liver. The potential use is for extensive resections that necessitate a very prolonged ischaemic time, although the available evidence to support its use and long-term outcome is very limited.

Extracorporeal liver resection with removal of the whole liver, resection of the liver outside of the patient, and re-implantation of the liver as an autograft has been reported.[95] Lodge *et al.*[98] have reported a similar procedure in 4 patients with acceptable results. This is associated with significant surgical risk and should be restricted to specialist centres, but offers potential treatment for patients with otherwise irresectable tumours.

## Resection of cirrhotic livers

Hepatic resection of the cirrhotic liver, which is usually for resection of hepatocellular carcinoma, does pose increased problems compared to normal liver, as has been mentioned above. Other than the problem of hilar dissection being more difficult with the surrounding fibrous liver and potentially deranged clotting, the major problem is estimation of residual liver function and tolerance of the cirrhotic liver to ischaemia. Normal liver has been shown to tolerate continuous inflow occlusion for over 60 min,[15] and intermittent occlusion for substantially longer.[60] Studies have shown that cirrhotic liver can tolerate ischaemic episodes of over 30 min,[49] and even longer in early disease,[54] although morbidity is increased compared to normal liver.[31] Many groups have reported good results for hepatic resection in cirrhotic livers,[31,49,99–101] and much of this is due to developments in technique. Vascular occlusion significantly reduces blood loss[49] and hemihepatic vascular occlusion has been proposed specifically for cirrhotic resection.[61] The use of segmental resection has allowed the extent of resection to be reduced, maximising the amount of residual functional liver,[31] and, in the case of hepatocellular carcinoma, addressing the problem of intraportal extension.[33] The potential for hepatic resection in cirrhotic liver has increased substantially, although morbidity and mortality are both increased

## Parenchymal transection

The hepatic fissures and segmental divisions are not visible on the liver surface. Clamping of the inflow as described above, allows ischaemic demarcation of the area of liver to be resected and indicates the appropriate line of resection. In segmental resection, segmental inflow ligation may not be possible prior to parenchymal transection and the line of resection must be estimated. The line of division needs to be 5–10 mm to the side of the line of ischaemic division along the hepatic fissures to avoid damage to the hepatic veins which usually lie within the fissures.[20] The liver capsule is divided with knife or diathermy. The aim is to divide the parenchyma and leave the hepatic veins and larger branches of the hepatic sheaths containing divisions of bile duct, portal vein and hepatic artery. Small branches less than 1 mm may be diathermied, but larger branches are clipped or ligated.[20] Segmental branches or the main hepatic veins may easily be stapled.[22,102] Meyer-May described the use of Kocher-like clamps to crush liver parenchyma in 1939[103] and haemostatic clamps such as Kelly clamps[59] are still used by some units to crush small areas of parenchyma, leaving the vessels intact. Lortat-Jacob used the handle of a scalpel[36] and Lin[46] described the use of finger fracture to remove parenchyma. Ultrasonic dissection has been developed using a CUSA (Cavitron ultrasonic aspirator).[104] This is an acoustic vibrator, perfused with saline, which disrupts the liver parenchyma by producing a cavitational force. Diathermy is also in-built into the tip. This has been shown to be very effective for division of parenchyma with low blood losses.[28,104–106] The use of other instruments such as water-jet dissection[107–109] or ultrasonic cutting[110] have also been reported.

Following division of the parenchyma, any form of vascular occlusion is released. Any residual bleeding vessel on the divided liver surface is then controlled. Use of argon beam coagulation can be valuable as it can plug vessels by creating a surface coagulum.[111] Fibrin glue has been shown to be valuable in sealing the liver surface.[112] The falciform ligament must be reconstituted if the right liver is resected to prevent torsion of the residual liver, although no ligament reconstruction is necessary for a left-sided resection.

There has been a limited application of laparoscopic hepatic resection[113] and, although the results have been satisfactory with successful resections in 20 patients, the numbers are too small to make any conclusion as to its application on a wider scale.

### Increasing resectability rates

A proportion of patients are not appropriate for resection as their tumour is too extensive and/or the residual liver is too small to provide adequate functional hepatic reserve. Techniques have been applied pre-operatively to increase the amount of residual functional liver post-operatively, thereby increasing the proportion of patients for potential resection. The technique of portal vein embolisation was first proposed almost a decade ago[114,115] with the aim of embolising the portal vein supplying the hemiliver to be resected in order to induce hypertrophy of the other hemiliver, thereby increasing the amount of functional residual liver. This has been demonstrated to result in an increase in functional residual liver.[116–118] Hypertrophy of 70–80% in the future liver remnant has been noted.[117,118] It has been reported, however, that liver metastases present within the regenerating lobe in fact grow at a faster rate than the normal parenchyma.[119] Resectability rate is improved following portal vein embolisation with resections in 24 out of 31 previously irresectable patients following portal vein embolisation.[117] Impaired liver parenchyma may hypertrophy to a lesser extent or not at all,[119] although Shoto *et al.*[120] reported improved outcome for hepatic resection for hepatocellular carcinoma following pre-operative portal vein embolisation with a reduction in negative histological recurrence factors such as involved surgical margins. Long-term outcome embolisation and resection for colorectal metastases is reasonable with a 5-year survival of 28.6% in 27 patients with previously irresectable colorectal metastases.[121] This is slightly reduced compared to that following classical hepatectomy for resectable colorectal metastases (5-year survival 34.4%), although it can be considered satisfactory in view of the size and number of colorectal metastases in the initially irresectable group.[121]

Pre-operative neo-adjuvant chemotherapy has been used to down-stage colorectal metastases that were initially unresectable due to location, size, multinodularity, or extrahepatic disease. In a unique study, Bismuth *et al.*[122] analysed a group of 330 patients classed as having irresectable colorectal hepatic metastases. By using treatment regimens based on oxaliplatin and given by a cyclical system called chronotherapy they showed that 53 patients responded sufficiently to allow resection. Treatment often involved repeated hepatectomies and extrahepatic surgery. The 5-year survival was 40% which is comparable with that reported with primary liver resection.[122]

### Conclusions

Hepatic resection has been a growth area over the last decade, particularly resection of colorectal metastases. Understanding of the segmental anatomy of the liver described by Couinaud[19] has been a vital component of this expansion and has stimulated technical developments.

Intra-operative ultrasound provides valuable information prior to commencement of resection[30,31] and either extrahepatic or intrahepatic dissection,[21] and clamping of the supply to the hemiliver of segment(s) of liver to be resected allows identification of the plane of parenchymal liver resection. Minimization of blood loss during parenchymal resection is vital and vascular control is an integral factor for this. A variety of techniques have been developed, with varying advantages and disadvantages and with increasing complexity. These allow hepatic resection to be undertaken in previously unresectable cases, although these should probably be restricted to specialised centres. Maintenance of a low CVP during resection is probably the most important development to reduce blood loss.[16,17] Techniques such as pre-operative portal vein embolisation[117,121] or pre-operative neo-adjuvant chemotherapy[122] can increase resectability of malignant cases, but the numbers to which this is applicable are limited and may be adversely influenced by availability of resources.

Liver resection has taken great strides, stimulated particularly by the proven benefits of resection of primary and metastatic hepatic malignancy. Development and application of the techniques above allow resection to be performed with minimal morbidity and mortality.

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