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REVIEW

Intra-operative ultrasound assessment of the biliary tree during robotic cholecystectomy

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Abstract

Image-guided assessment of bile ducts and associated anatomy during laparoscopic cholecystectomy can be achieved with intra-operative cholangiography (IOC) or laparoscopic ultrasound (LUS). Rates of robotically assisted cholecystectomy (RC) are increasing and herein we describe the technique of intra-corporeal biliary ultrasound during RC using the Da Vinci system. For intraoperative evaluation of the biliary tree during RC, in cases of suspected choledocholithiasis, the L51K Ultrasound Probe (Hitachi, Tokyo, Japan) is used. The extrahepatic biliary tree is scanned along its length, capitalising on the benefits of the full range of motion offered by the articulated robotic instruments and integrated ultrasonic image display using TilePro™ software. Additionally, this technique avoids the additional time and efforts required to undock and re-dock the robot that would otherwise be required for selective IOC or LUS. The average time taken to perform a comprehensive evaluation of the biliary tree, from the hepatic ducts to the ampulla of Vater, is 164.1 s. This assessment is supplemented by Doppler ultrasound, which is used to fully delineate anatomy of the porta hepatis, and accurate measurements of the biliary tree and any ductal stones can be taken, allowing for contemporaneous decision making and management of ductal pathologies. Biliary tract ultrasound has been shown to be equal to IOC in its ability to diagnose choledocholithiasis, but with the additional benefits of being quicker and having higher completion rates. We have described our practice of using biliary ultrasound during robotically assisted cholecystectomy, which is ergonomically superior to LUS, accurate and reproducible.

Keywords Gallstone disease · Cholecystectomy · Robotic surgery · Laparoscopy · Patient outcomes

Introduction

Intra-operative imaging of the biliary tree during cholecystectomy is most commonly achieved by an intra-operative cholangiogram (IOC), which is currently used in approximately 12% of UK cholecystectomies, or laparoscopic ultrasound (LUS) [1]. The common indications for intra-operative imaging are pre-operative derangement in serum liver function tests, a dilated biliary system on pre-operative imaging, the known presence of bile duct stones or to confirm biliary tree anatomy.

IOC and LUS are equally accurate for detecting common bile duct (CBD) stones, with reported sensitivities of 71–100% and 75–100%, respectively [2]. The drawbacks of IOC are the requirement of additional, bulky equipment, the use of X-rays and iodine contrast, and the need for a radiographer. LUS has none of these limitations, has a lower failure rate and can be performed quicker than IOC (5–10 min versus 13–18 min [2]). Additionally, LUS provides the operating surgeon with accurate, real-time information in addition to the presence of CBD stones that can help guide intra-operative decision making, including: cystic duct and CBD diameter, stone number and dimensions, and regional vascular anatomy. However, LUS is operator-dependent and has an established steeper learning curve of approximately 40 cases. It is also less useful at evaluating the dynamics of biliary drainage [3].

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Robotic-assisted cholecystectomy (RC) is becoming increasingly common. The robotic platform permits greater dexterity through wristed instrumentation, as well as a three-dimensional view and stable tenfold magnification. In the context of robotic surgery, IOC is more difficult to achieve due to the nature of the patient cart attached to the patient during the procedure. In order to achieve adequate X-ray exposure, the robot needs to be undocked from the patient, which is time consuming. Similarly, LUS requires de-docking of the robot to allow a scrubbed tableside surgeon to gain access to the patient with a hand-held LUS probe. With this in mind, we have developed the technique of using the L51K ultrasound probe (Hitachi, Tokyo, Japan) to assess the bile duct intra-operatively during RC (RUS). The integrated TilePro™ system permitted by the da Vinci systems gives an integrated view of the operative field and USS images. More importantly, the dexterity permitted by the wristed instrumentation allows for exceptional views of the entire bile duct from the hepatic bifurcation to the ampulla of Vater without de-docking the robot. LUS is well described in the literature but the application of RUS, to date, remains limited. Herein we describe the standard views achieved of the biliary tree during RC using the Da Vinci X/Xi system and TilePro™ inlay function.

Materials and methods

Robotically-assisted cholecystectomies have been performed at Queen Alexandra Hospital, Portsmouth Hospitals University NHS Trust, since 2021. Approximately, 1000 cholecystectomies are performed each year in our trust and 175 have been performed robotically by five consultant upper gastrointestinal surgeons [4]. All patients undergoing this procedure do so after providing informed written consent and, as this is an established surgical practice, Institutional Review Board approval was not required.

Robotically-assisted cholecystectomy is performed in the standard fashion with the Da Vinci X/Xi system; the robot is docked from the patients right side with a scrubbed tableside assistant on the patients left. In our practice, four ports are used: an 8 mm camera port, a 8 mm left arm port, a 8 mm right arm port and a 12 mm accessory/assistant port. Low pressure pneumoperitoneum (typically 8 mm Hg) is maintained and simultaneous smoke extraction is performed using AirSeal® (ConMed, New York, USA). Hepatocystic dissection proceeds in the standard fashion in order to achieve a critical view of safety. The cystic artery is then clipped and divided.

For RUS, the L51K Ultrasound Probe (Hitachi, Tokyo, Japan) is used (Fig. 1). This is a 9.4 × 9.4 × 8.5 mm probe, attached to a 3.0 m flexible cable, intended for intra-operative diagnostic ultrasound evaluation. It operates at a frequency of 8.5 MHz with a field of view of 13 mm. This probe is introduced via the accessory port, which can then be gripped on its posterior surface using an atraumatic grasper and subsequently manipulated through the full range of motion permitted by the articulated instrument. Ultrasonic images generated by the probe are visualised on the attached ultrasound machine (Hitachi, Tokyo, Japan), which is positioned at the end of the patient bed. The TilePro™ software of the Da Vinci system is then activated, which allows simultaneous visualisation of the ultrasonic images alongside the 3D surgical field as an auxiliary video input to the Da Vinci console. The operating surgeon is therefore able to see both images side-by-side within the display (Fig. 2).

Fig. 1 Hitachi L51K Ultrasound Probe used for robotically assisted biliary tract ultrasound

Biliary tract ultrasound commences in B mode at the confluence of the left and right hepatic ducts and slowly proceeds distally along the course of the extrahepatic biliary tract. The probe is placed parallel to the common hepatic duct (CHD) (Fig. 3: A, i), which can be identified as the uppermost, central compressible luminal structure without Doppler flow. The probe should only be applied with sufficient pressure to allow acoustic coupling as overzealous compression can occlude the lumen and distort the anatomy. The probe is then moved in a caudal direction (Fig. 3: B, ii), tracing the biliary tree with minor degrees of pronation and supination to allow for full visualisation of the duct until the confluence of cystic duct and CHD is reached. The common bile duct (CBD) can then be traced distally to examine the supra-pancreatic duct (Fig. 3: C, iii) and then further distally as it enters the pancreatic head (Fig. 3: D, iv). Finally, transduodenal views (Fig. 3: E) can be used to examine the distal CBD as it joins the pancreatic duct at the ampulla of Vater (Am in image v).

Adjustments to the transducer power, gain, time gain compensation, harmonics and depth may be required to acquire the best quality images, which can be manipulated easily by the operating surgeon whilst scanning is performed. As with all other forms of ultrasound imaging, the image can be frozen, in order to take accurate measurements of the ducts and any filling defects present, and the Doppler function can be used to identify and quantify the

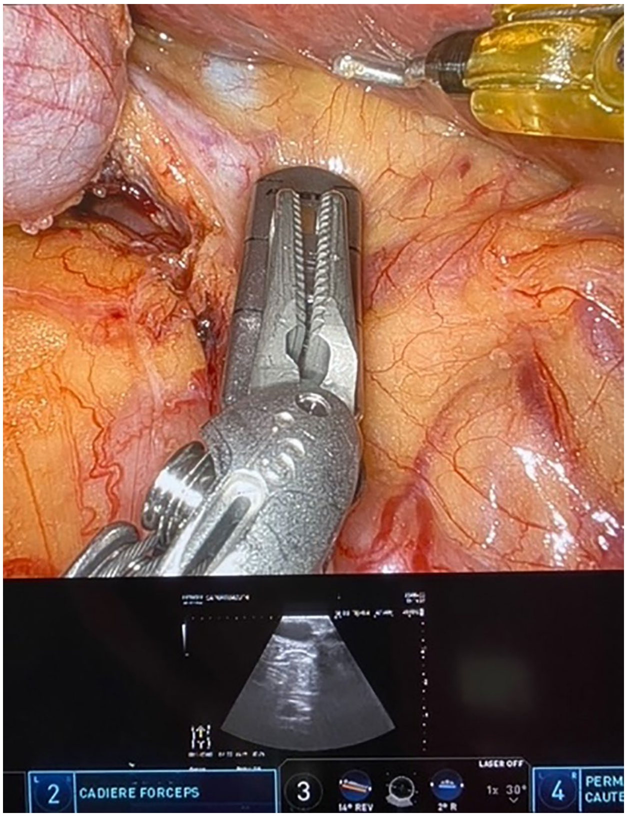

Fig. 2 Simultaneous on-screen visualisation of the 3D surgical field and ultrasound-generated images using the TilePro™ software of the Da Vinci system

regional vascular anatomy. Doppler assessment is usually utilised early to orientate the surgeon and clearly identify the structures of the porta hepatis (i.e. bile duct, hepatic artery and portal vein, Fig. 3A), which is especially important in the context of aberrant anatomy.

As is recommended for LUS, the following critical views and landmarks should be fully visualised: the extrahepatic portion of the right and left hepatic ducts, their confluence, and the common hepatic duct (CHD) (Fig. 3A); the confluence of the cystic duct and the CHD to form the CBD (Fig. 3B); the supraduodenal portion of the CBD (Fig. 3C); and the intra-pancreatic CBD as it joins with the pancreatic duct to form the ampulla of Vater and drain into the second part of the duodenum (Fig. 3D and E). In our centre, the average time taken to perform this comprehensive robotically assisted ultrasonic evaluation of the biliary tree is 164.1 s (90–285 s).

A stone can be identified within the ducts by the presence of a filling defect that casts an acoustic shadow. Any stone(s) can be accurately measured with the on-screen callipers and, alongside the measurements taken of the ducts, contemporaneous decision making can occur with regard to management of this i.e. whether transcystic duct exploration is likely to be successful or whether formal choledochotomy and duct exploration or post-operative Endoscopic Retrograde Cholangiopancreatography is required. The cholecystectomy can then be completed in the usual fashion with or without duct exploration.

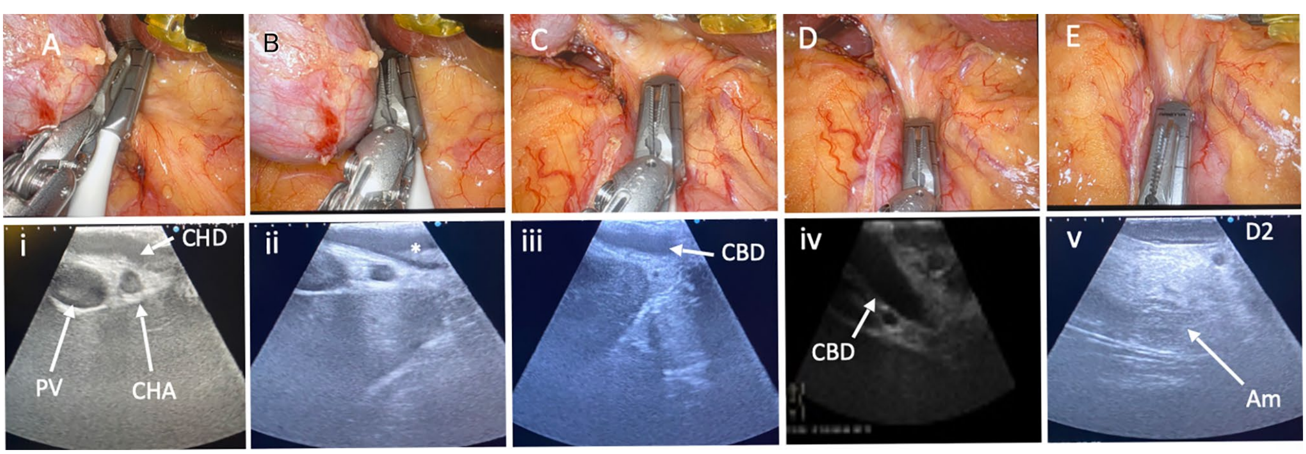

Fig. 3 Robotically assisted bile duct ultrasound using the Hitachi L51K Ultrasound Probe: probe is gripped on its spine using the Cadiere forceps. The external biliary tree is visualised by commencing proximally (**A**, **i**) with the probe orientated parallel to the common hepatic duct (CHD). The portal vein (PV) and common hepatic artery (CHA) are visualised deep to this. The probe is then moved in a caudal direction (**B**, **ii**), tracing the biliary tree until the confluence of cystic duct and CHD is reached (* in image **ii**). The common bile duct (CBD) can then be traced distally to examine the supra-pancreatic duct (**C**, **iii**) and then distally as it enters the pancreas (**D**, **iv**). Finally, transduodenal views (**E**) can be used to examine the distal CBD as it joins the pancreatic duct at the ampulla of Vater (Am in image **v**)

Discussion

Bile duct ultrasonography is an accurate and valid alternative to IOC for the assessment of the biliary tree during cholecystectomy, which can be performed quicker, with less bulky equipment and avoids unnecessary radiation exposure [2, 5, 6]. In addition, it has a higher reported completion rate of 93–100% versus 83–97% for IOC [2]. This paper is not designed to favour one technique over the other, but rather to describe the utilisation and highlight the benefits of bile duct ultrasound in the context of RC. The number of RCs being performed worldwide each year is increasing exponentially. With 12% of UK cholecystectomies requiring intraoperative biliary tree imaging and with a mean worldwide IOC rate of 38.8% [7], there is a call for an efficient and effective imaging technique.

Ultrasound assessment of the biliary tree lends itself well to RC as, in addition to the above benefits, it specifically avoids the additional time and efforts required to undock and re-dock the robot that would otherwise be required for selective IOC. RUS also presents significant advantages over LUS. In the context of laparoscopic cholecystectomy, the ultrasound probes used for intra-operative assessment of the biliary tree are typically straight or flexible-tip probes with a curvilinear array transducer. The limitations created by laparoscopic access, combined with the inherent rigidity of these laparoscopic probes, result in restricted angulation and limited views along the extrahepatic biliary tree. Furthermore, entry of the probe into the abdomen mean that LUS is performed at an oblique angle, rather than in a true anterior–posterior orientation, which can distort image interpretation. For RUS, the subcentimeter transducer can be held by the robotic grasper and manipulated within the full range of motion offered by the articulated instrument. This has inherent benefits for image acquisition, anatomy interpretation and the time required to perform the intra-operative assessment. A direct comparison between RUS, LUS and robotically assisted IOC has not taken place, but in our institution the average time to complete RUS biliary assessment is less than 3 min.

There are no current reports of the utilisation of robotically-assisted bile duct ultrasound. One study reported that less than 1% of surgeons routinely use LUS in their practice [8] and one would therefore assume that RUS has only been adopted in limited specialist robotic centres. With the increasing use of robotic surgery, however, we would recommend RUS as an efficient and accurate means of interrogating the biliary tree for choledocholithiasis. One limitation to the uptake of biliary tract US remains the significant learning curve associated with this practice but, with time, appropriately accredited training centres should exist to flatten this curve and promote best practice.

Outlay costs for ultrasound equipment has also been quoted as a limitation to the uptake of LUS/RUS. A health economics report from NICE in 2014 quoted the incremental cost of IOC to be £137.41 per case but no such evaluation has taken place for LUS or RUS [9]. Outlay costs must take account of purchasing of the ultrasound machine, the several probes that will be required to run a continuous biliary service, and the sterilisation costs. In our centre, this amounts to £158,000 (ultrasound machine, 4 probes and servicing contract). The number of cases performed per year will therefore dictate the cost-effectiveness of this, but several studies have already concluded that LUS is more cost-effective than IOC [2, 10, 11]. Rystedt et al. [11] also report that the incremental cost incurred per QALY gained using routine IOC is acceptable when analysing the costs of iatrogenic bile duct injuries, and so one can assume that this holds true for bile duct ultrasound as the 'cheaper' alternative. However, a thorough cost analysis in the context of robotic surgery is also required, but this is beyond the scope of this report. As IOC continues to be the most commonly utilised means of intraoperative biliary imaging, we can assume that cost is not prohibitive and therefore the time benefits and diagnostic accuracy of RUS should be heavily considered when it comes to making decisions around training and procurement.

In conclusion, biliary tract ultrasound has been shown to be equal to IOC in its ability to diagnose choledocholithiasis, but with the additional benefits off being quicker and having higher completion rates. We have described our practice of using biliary ultrasound during robotically-assisted cholecystectomy, which is ergonomically superior to LUS, accurate and reproducible.

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Author contributions MAG and GVB wrote the main manuscript, RB and CB provided the ultrasound images (Figs. 2 and 3), and NCC, BCK, PHP and SJM edited the manuscript. All authors have reviewed and approved the final manuscript.

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Declarations

Conflict of interest Michael A Glaysher is the recipient of a fellowship grant from LawMed. Nicholas C Carter and Stuart J Mercer are proctors for Intuitive Surgical. Gijs van Boxel is a proctor for Intuitive Surgical and recipient of a fellowship grant from LawMed. Philip Pucher receives consulting fees from Fundamental Surgery. Christopher Ball, Richard Beable and Benjamin C Knight have no financial interests or conflicts of interest to declare.

Ethical approval All patients undergoing this procedure do so after providing informed written consent and, as this is an established surgical practice, Institutional Review Board approval was not required.

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