Meta-analysis of the diagnostic accuracy of laparoscopic ultrasonography and intraoperative cholangiography in detection of common bile duct stones

KN Jamal¹, H Smith¹, K Ratnasingham¹, MR Siddiqui², G McLachlan³, AP Belgaumkar³

¹Epsom and St Helier University Hospitals NHS Trust, UK

²Croydon Health Services NHS Trust, UK

³Royal Surrey County Hospital NHS Foundation Trust, UK

ABSTRACT

INTRODUCTION During laparoscopic cholecystectomy, intraoperative cholangiography (IOC) is currently regarded as the gold standard in the detection of choledocholithiasis. Laparoscopic ultrasonography (LUS) is an attractive alternative with several potential advantages.

METHODS A systematic review was undertaken of the published literature comparing LUS with IOC in the assessment of common bile duct (CBD) stones.

RESULTS Twenty-one comparative studies were analysed. There were 4,566 patients in the IOC group and 5,044 in the LUS group. The combined sensitivity and specificity of IOC in the detection of CBD stones were 0.87 (95% confidence interval [CI]: 0.83–0.89) and 0.98 (95% CI: 0.98–0.98) respectively with a pooled area under the curve (AUC) of 0.985 and a diagnostic odds ratio (OR) of 260.65 (95% CI: 160.44–423.45). This compares with a sensitivity and specificity for LUS of 0.90 (95% CI: 0.87–0.92) and 0.99 (95% CI: 0.99–0.99) respectively with a pooled AUC of 0.982 and a diagnostic OR of 765.15 (95% CI: 450.78–1,298.76).

LUS appeared to be more successful in terms of coming to a clinical decision regarding CBD stones than IOC (random effects, risk ratio: 0.95, 95% CI: 0.93–0.98, df=20, $z=-3.7$, $p<0.005$). Furthermore, LUS took less time (random effects, standardised mean difference: 0.95, 95% CI: 0.93–0.98, df=20, $z=-3.7$, $p<0.005$).

CONCLUSIONS LUS is comparable with IOC in the detection of CBD stones. The main advantages of LUS are that it does not involve ionising radiation, is quicker to perform, has a lower failure rate and can be repeated during the procedure as required.

KEYWORDS

Laparoscopic ultrasonography – Intraoperative cholangiography – Laparoscopic cholecystectomy – Meta-analysis

Accepted 20 July 2015

CORRESPONDENCE TO

Karim Jamal, E: kjamal@doctors.org.uk

Common bile duct (CBD) stones occur in 10–20% of patients with symptomatic gallstones,^{1–5} and the likelihood of their presence can be estimated using a combination of clinical history, liver function tests and transabdominal ultrasonography.⁶ By stratifying patients using these criteria, those deemed to be at low risk can safely proceed directly to laparoscopic cholecystectomy. Intermediate and high risk patients for CBD stones can be investigated pre-operatively with magnetic resonance cholangiopancreatography, endoscopic retrograde cholangiopancreatography (ERCP) or endoscopic ultrasonography.⁷ Despite such stratification, the incidence of choledocholithiasis remains up

to 5% even in patients with normal CBD diameter and liver function tests.⁸ If left undetected and untreated, ductal stones can lead to biliary obstruction, cholangitis, pancreatitis and postoperative bile leak.

There are two main strategies for managing proven or suspected CBD stones. Two-stage management involves ERCP prior to cholecystectomy, allowing retrieval of CBD stones and removing the need for intraoperative imaging of the biliary tree. Alternatively, with single stage management, the biliary tree may be imaged intraoperatively and if stones are detected, the CBD may be explored, either laparoscopically, via open surgery or by on-table ERCP.

Meta-analyses of two-stage versus single stage management have found no difference in morbidity or mortality between the two strategies although single stage management was associated with a shorter hospital stay.^{9,10}

Intraoperative cholangiography (IOC) is currently the gold standard technique for intraoperative imaging of the biliary tree. Disadvantages include exposure of ionising radiation to both patient and theatre personnel, a failure rate of 3–17%^{11–15} and increased operative time with a range of 13–18 minutes.^{11,14,16,17} In contrast, laparoscopic ultrasonography (LUS) is radiation free, has a lower failure rate (0–7%)^{11,12,14,18,19} and is less time consuming, increasing operative times by 5–10 minutes.^{11,14} Despite these advantages, the use of LUS during laparoscopic cholecystectomy is not commonplace. Our aim was to perform a meta-analysis of studies comparing these two techniques with regard to correct detection of choledocholithiasis, success rate in terms of coming to a clinical decision regarding CBD stones, time taken for each procedure and ability to delineate biliary anatomy accurately.

Methods

All comparative studies investigating LUS versus IOC for detecting CBD stones published between January 1970 and December 2013 were identified. First, the MEDLINE®, Embase™ and CINAHL® (Cumulative Index to Nursing and Allied Health Literature) databases were searched. The search words ‘common bile duct stones’, ‘ductal stones’, ‘stones’, ‘laparoscopic ultrasound’ and ‘on-table cholangiogram’ were used in combination with the medical subject headings ‘gallstone disease’, ‘ultrasonography’ and ‘cholangiography’. Irrelevant articles, reviews and meta-analyses evident from the titles and abstracts were excluded. Relevant articles referenced in these publications were obtained and the ‘related article’ function was used to widen the results. No language restriction was applied. All abstracts, comparative studies, non-randomised trials and citations were searched comprehensively. A flowchart of the literature search is shown in Figure 1.

Each article was reviewed critically by two researchers using a double extraction method for eligibility in our review. This was performed independently and any conflict was resolved prior to final analysis. A third researcher confirmed the data extraction. All of the papers were accounts of cohort studies where a group of consecutive patients underwent both LUS and IOC, followed by the gold standard techniques of CBD exploration, intraoperative or post-operative ERCP, or a combination of all of these. The primary outcome variable was whether CBD stones were detected correctly. Additional variables considered were time taken for each procedure, success rate in terms of coming to a clinical decision regarding CBD stones and anatomical visualisation of the biliary tree.

If either index test (LUS and/or IOC) was positive, the patient went on to have CBD evaluation using one of the gold standard techniques outlined above. If both index tests were negative, then no evaluation of the bile duct was performed because of the unacceptable morbidity related

to this. In this case, it was assumed that the result was a true negative for both index tests. Approximately half of the studies included in our analysis followed up the patients in clinic in an attempt to prove that the true negatives were all genuine.

True positive results were defined as those cases in which a CBD stone was detected by the index test and this result was confirmed by the gold standard technique. False positive results were defined as those cases in which the index test detected a CBD stone but the gold standard did not. False negative results were defined as those cases in which the index tests did not detect a stone but the gold standard did.

Sensitivity and specificity pooling was calculated with 95% confidence intervals (CIs) using the random effects model. Forest plots were used to view the results graphically. When analysing sensitivity, 0.5 was added to each cell frequency for trials in which no event occurred, as per the recommendation by Deeks *et al.*²⁰ Interaction between sensitivity and specificity was assessed using summary receiver operating characteristic (sROC) analysis described by Littenberg and Moses.^{21–25} The diagnostic rigour of IOC and LUS was assessed using diagnostic odds ratios (DORs), the Q statistic and the area under sROC curves.

Data for sensitivity and specificity were used to calculate the DOR (frequency of true positives / frequency of false positives) / (1 – frequency of true positives / 1 – frequency of false positives). The diagnostic accuracy of the index tests is proportional to the value of the DOR. A DOR of

1 indicates that a test is unable to discern between patients with or without a specified pathology.²⁴

Heterogeneity between studies was assessed using Cochran's Q test, a type of chi-squared test instituted to establish the application of sROC meta-regression curves over this dataset. The sROC curve is used to calculate the AUC, where 0.5 implies that a test is equally likely to diagnose a positive result as either positive or negative and a value of 1.0 indicates a 'perfect' test that gives a 100% correct diagnosis regardless of patient demographics. In practical terms, tests will have a variable AUC value. This will tend towards 1.0 as the diagnostic accuracy improves. An AUC of >0.75 is considered clinically acceptable. Spearman's correlation coefficient for sensitivity and 1 – specificity was used to assess the diagnostic threshold effect. A correlation of >0.6 was deemed to indicate the absence of a diagnostic threshold effect.²²

For continuous data (time taken to perform the procedures), Hedges' g statistic was used for the calculation of standardised mean differences (SMDs). The SMDs were combined using inverse variance weights in the fixed effects model; in the random effects model, the DerSimonian and Laird method was used.²⁵ Binary data (success rate for coming to a clinical decision, anatomical visualisation of the biliary tree) were summarised as risk ratios (RRs) and combined using the Mantel-Haenszel method under the fixed effects model, and the DerSimonian and Laird method under the random effects model.

A heterogeneity test was carried out for each of the outcome variables to see whether the fixed effects model was appropriate. For studies in which the standard deviations were not reported, these were estimated either from ranges or *p*-values. Where only ranges were given, a normal distribution was assumed to calculate the mean. Forest plots were used to display the results graphically.

Statistical analyses were performed using Meta-DiSc version 1.4 (http://www.hrc.es/investigacion/metadisc_en.htm) and Comprehensive Meta-Analysis version 2 (Biostat, Englewood, NJ, US). The study was undertaken in accordance with reported guidance for diagnostic test meta-analyses.^{26,27}

The potential for publication bias was examined with Egger's test²⁸ and funnel plots were used to represent this graphically. Statistical significance was indicated by a two-sided *p*-value <0.05. The quality of studies was assessed according to the QUADAS (quality assessment for diagnostic accuracy studies) criteria.²⁹

Results

Twenty-one papers comparing LUS with IOC for CBD stones were retrieved from the electronic databases.^{12,13,15,17,30–46} There were 4,566 patients in the IOC group and 5,044 in the LUS group.

Detection of CBD stones

Twenty-one studies contributed to a summative outcome.^{12,13,15,17,30–46} The combined sensitivity and specificity of IOC in the detection of CBD stones were 0.87 (95%

CI: 0.83–0.89) and 0.98 (95% CI: 0.98–0.98) respectively with a pooled AUC of 0.985 and a DOR of 260.65 (95% CI: 160.44–423.45). There was no significant heterogeneity between studies ($Q=20.60$, $df=18$, $p=0.30$, $I^2=12.6$; Table 1).

This compared with a sensitivity and specificity for LUS of 0.90 (95% CI: 0.87–0.92) and 0.99 (95% CI: 0.99–0.99) respectively with a pooled AUC of 0.982 and a DOR of 765.15 (95% CI: 450.78–1,298.76). There was no significant heterogeneity between studies ($Q=20.22$, $df=18$, $p=0.32$, $I^2=11.0$; Table 1).

Figure 2 illustrates the sROC curves for IOC and LUS in relation to detection of CBD stones. For IOC, Spearman's correlation coefficient for diagnostic threshold was 0.17 ($p=0.48$), indicating an absence of a significant threshold effect. For LUS, the correlation coefficient for diagnostic threshold was -0.25 ($p=0.30$), again indicating an absence of a significant effect.

Success rate

Twenty-one studies reported on the success rate of the procedures (ie whether it was possible to come to a clinical decision regarding CBD stones).^{12,13,15,17,30–46} LUS appeared to be more successful than IOC (random effects, RR: 0.95, 95% CI: 0.93–0.98, $df=20$, $z=-3.7$, $p<0.005$). However, there was significant heterogeneity between studies ($Q=193.36$, $I^2=89.7$, $p<0.05$).

Time taken to perform the procedures

Fourteen studies reported on the time taken to perform the procedures.^{12,13,17,30,31,33,34,38–43,45} LUS took less time than IOC (random effects, SMD=0.95, 95% CI: 0.93–0.98, $df=20$, $z=-3.7$, $p<0.005$). However, there was significant heterogeneity between studies ($Q=193.36$, $I^2=89.7$, $p<0.05$).

Anatomical identification

Five studies assessed the ability of the procedures to identify biliary anatomy.^{12,31,33,34,39} These studies looked at the visualisation of the intrahepatic ducts, common hepatic duct, extrapancreatic CBD and intrapancreatic CBD. IOC appeared to be better at detecting the intrapancreatic CBD (random effects, RR: 1.15, 95% CI: 1.04–1.26, $p=0.007$) but there was no significant difference in identifying the extrapancreatic CBD (random effects, RR: 1.04, 95% CI: 0.95–1.12, $p=0.60$).

Quality assessment and publication bias

All of the studies included were of a reasonable standard, with a QUADAS score of >10. The results of Egger's test and the funnel plots showed no evidence of publication bias.

Discussion

IOC is the current gold standard technique for intraoperative imaging of the biliary tree. LUS is another method but is not widely available at present. The results presented demonstrate that LUS and IOC have similar accuracy in detection of CBD stones. These findings suggest that LUS can be used as an alternative to IOC for diagnosing CBD

Table 1 Sensitivity and specificity of intraoperative cholangiography and laparoscopic ultrasonography in the detection of common bile duct stones

	Intraoperative cholangiography		Laparoscopic ultrasonography	
	Sensitivity (95% CI)	Specificity (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)
Barteau, 1995 ³⁰	0.71 (0.42–0.92)	1.00 (0.97–1.00)	0.93 (0.66–1.00)	0.96 (0.91–0.99)
Birth, 1998 ³¹	0.83 (0.63–0.95)	1.00 (0.99–1.00)	1.00 (0.85–1.00)	0.99 (0.97–1.00)
Castro, 1995 ³²	0.89 (0.52–1.00)	1.00 (0.91–1.00)	0.89 (0.52–1.00)	0.93 (0.80–0.98)
Catheline, 2002 ³³	0.80 (0.68–0.89)	0.99 (0.98–1.00)	0.75 (0.62–0.85)	0.98 (0.97–0.99)
Falcone, 1999 ³⁴	1.00 (0.03–1.00)	0.98 (0.92–1.00)	1.00 (0.16–1.00)	0.97 (0.89–1.00)
Goletti, 1994 ³⁵	1.00 (0.40–1.00)	1.00 (0.87–1.00)	0.75 (0.19–0.99)	1.00 (0.86–1.00)
Greig, 1994 ³⁶	0.71 (0.29–0.96)	0.96 (0.85–0.99)	0.83 (0.36–1.00)	0.95 (0.84–0.99)
Hublet, 2009 ³⁷	1.00 (0.79–1.00)	1.00 (0.98–1.00)	0.97 (0.84–1.00)	0.99 (0.98–1.00)
Jakimowicz, 1987 ³⁸	0.94 (0.87–0.97)	0.99 (0.97–1.00)	0.86 (0.78–0.92)	0.96 (0.93–0.98)
Li, 2009 ³⁹	0.82 (0.63–0.94)	0.99 (0.93–1.00)	0.75 (0.55–0.89)	0.98 (0.92–1.00)
Machi, 1993 ⁴⁰	0.89 (0.52–1.00)	1.00 (0.96–1.00)	0.88 (0.47–1.00)	0.98 (0.92–1.00)
Machi, 1999 ⁴¹	0.92 (0.84–0.97)	0.99 (0.98–1.00)	0.84 (0.71–0.94)	0.96 (0.93–0.97)
Ohtani, 1997 ¹²	0.80 (0.28–0.99)	0.98 (0.91–1.00)	0.80 (0.28–0.99)	0.98 (0.89–1.00)
Orda, 1994 ⁴²	0.92 (0.64–1.00)	0.98 (0.93–1.00)	1.00 (0.72–1.00)	0.87 (0.74–0.95)
Pietrabissa, 1995 ¹³	1.00 (0.40–1.00)	1.00 (0.95–1.00)	1.00 (0.40–1.00)	0.99 (0.93–1.00)
Röthlin, 1996 ⁴³	0.93 (0.68–1.00)	0.99 (0.96–1.00)	0.38 (0.09–0.76)	0.99 (0.97–1.00)
Siperstein, 1999 ⁴⁴	0.96 (0.80–1.00)	1.00 (0.99–1.00)	0.96 (0.80–1.00)	1.00 (0.99–1.00)
Stiegmann, 1995 ¹⁷	0.89 (0.67–0.99)	0.95 (0.91–0.98)	0.59 (0.33–0.82)	1.00 (0.98–1.00)
Thompson, 1998 ⁴⁵	0.90 (0.78–0.97)	1.00 (0.98–1.00)	0.96 (0.86–0.99)	0.98 (0.96–0.99)
Tranter, 2001 ⁴⁶	0.92 (0.82–0.97)	1.00 (0.99–1.00)	0.93 (0.84–0.98)	0.97 (0.89–1.00)
Yamashita, 1993 ¹⁵	1.00 (0.03–1.00)	1.00 (0.92–1.00)	1.00 (0.03–1.00)	1.00 (0.91–1.00)
Pooled values	0.90 (0.87–0.92)	0.99 (0.99–0.99)	0.87 (0.83–0.89)	0.98 (0.98–0.98)
CI = confidence interval				

stones. LUS has a number of advantages in that it does not involve ionising radiation, is quicker to perform, has a lower technical failure rate and can be used safely in pregnancy and for patients with a contrast allergy. IOC requires additional theatre personnel, disposable cholangiography catheters, an image intensifier and a longer procedure time. As a result, the cost of IOC is approximately double that of LUS (\$665 vs \$362).⁵⁴

LUS has a unique benefit in assessing biliary anatomy as it can be used dynamically throughout the dissection, unlike IOC, which can usually only be performed once. The addition of colour Doppler imaging to standard LUS can also aid visualisation of important surrounding structure such as the hepatic artery and portal vein. IOC requires isolation and cannulation of a duct. As well as causing bile spillage, IOC may even lead to inadvertent biliary tract injury although this is rare and evidence from large case series suggests that IOC might reduce bile duct injury or at least that it is not associated with adverse outcomes.⁴⁷ Potential limitations of LUS include the inability

to detect bile leaks from hitherto unidentified branches and subtle biliary injuries.

The limited analysis presented here comparing LUS and IOC in the visualisation of the biliary tree indicates that evaluation of the intrapancreatic portion of the CBD is more accurate with IOC. IOC can confirm patency of the lower end of the CBD by passage of contrast into the duodenum.

At present, the main disadvantage of LUS is the surgeon's familiarity with the procedure and the cost investment required to purchase the probe. LUS is very user dependent and relies heavily on the experience of the surgeon. There is evidence that the learning curve is relatively slow, in the order of approximately 40 LUS procedures.⁴¹

Study limitations

Overall, the quality of the studies was of a good standard although the QUADAS criteria identified potential areas of bias. In all of the studies, a true negative was inferred if both index tests were negative since a ductal exploration

would not be ethical in this situation. Despite this, routine follow-up review took place in only ten studies as a means of excluding clinical events secondary to missed ductal stones.^{12,33,35–39,42,45,46} In the studies that did perform follow-up, no patients were diagnosed subsequently with ductal stones. Although the length of follow-up was limited (range: 6–30 months), these results indicate that true negatives were identified accurately at the time of intraoperative imaging.

A major limitation of this meta-analysis is the absence of any randomised controlled trials comparing these techniques. Only three studies were designed so that the IOC and LUS results were interpreted by separate individuals, and they were both blinded to each other's findings.^{33,34,39} In most of the studies, however, the same person performed and interpreted both of the index tests, which is clearly a source of potential bias. In these studies, the order in which LUS and IOC were performed in each patient may

have led to a confirmation bias on the outcome of the second test performed.

In general, the papers had very little information of the inclusion criteria. In fact, 16 studies omitted a clear description of their inclusion criteria.^{12,13,15,17,30,32,35–38,40–45} Three studies stated clearly that they had excluded patients at high risk of CBD stones.^{31,34,39} Little information was given on the experience of the surgeons performing the procedures for either LUS or IOC.

Conclusions

LUS is comparable with IOC in the detection of CBD stones and visualisation of the biliary tree. The main advantages of LUS are safety, reduced procedure time, reduced cost and unlimited use. There is a significant outlay cost and learning curve associated with LUS but there is also an undoubted long-term benefit. As probe technology continues to improve, it may be that LUS becomes superior to IOC. Further studies with modern day probes are required to investigate this further.

References

- Houdart R, Perniceni T, Darne B *et al*. Predicting common bile duct lithiasis: determination and prospective validation of a model predicting low risk. *Am J Surg* 1995; **170**: 38–43.
- Lacaine F, Corlette MB, Bismuth H. Preoperative evaluation of the risk of common bile duct stones. *Arch Surg* 1980; **115**: 1,114–1,116.
- Neuhaus H, Feussner H, Ungeheuer A *et al*. Prospective evaluation of the use of endoscopic retrograde cholangiography prior to laparoscopic cholecystectomy. *Endoscopy* 1992; **24**: 745–749.
- Saltzstein EC, Peacock JB, Thomas MD. Preoperative bilirubin, alkaline phosphatase and amylase levels as predictors of common duct stones. *Surg Gynecol Obstetr* 1982; **154**: 381–384.
- Welbourn CR, Mehta D, Armstrong CP *et al*. Selective preoperative endoscopic retrograde cholangiography with sphincterotomy avoids bile duct exploration during laparoscopic cholecystectomy. *Gut* 1995; **37**: 576–579.
- Mercer S, Singh S, Paterson I. Selective MRCP in the management of suspected common bile duct stones. *HPB* 2007; **9**: 125–130.
- Williams EJ, Green J, Beckingham I *et al*. Guidelines on the management of common bile duct stones (CBDS). *Gut* 2008; **57**: 1,004–1,021.
- Collins C, Maguire D, Ireland A *et al*. A prospective study of common bile duct calculi in patients undergoing laparoscopic cholecystectomy. *Ann Surg* 2004; **239**: 28–33.
- Cuschieri A, Lezoche E, Morino M *et al*. EAES multicenter prospective randomized trial comparing two-stage vs single-stage management of patients with gallstone disease and ductal calculi. *Surg Endosc* 1999; **13**: 952–957.
- Lu J, Cheng Y, Xiong XZ *et al*. Two-stage vs single-stage management for concomitant gallstones and common bile duct stones. *World J Gastroenterol* 2012; **18**: 3,156–3,166.
- Catheline J, Rizk N, Champault G. A comparison of laparoscopic ultrasound versus cholangiography in the evaluation of the biliary tree during laparoscopic cholecystectomy. *Eur J Ultrasound* 1999; **10**: 1–9.
- Ohtani T, Kawai C, Shirai Y *et al*. Intraoperative ultrasonography versus cholangiography during laparoscopic cholecystectomy: a prospective comparative study. *J Am Coll Surg* 1997; **185**: 274–282.
- Pietrabissa A, Di Candio G, Giulianotti PC *et al*. Comparative evaluation of contact ultrasonography and transcystic cholangiography during laparoscopic cholecystectomy: a prospective study. *Arch Surg* 1995; **130**: 1,110–1,114.
- Wu JS, Dunnegan DL, Soper NJ. The utility of intracorporeal ultrasonography for screening of the bile duct during laparoscopic cholecystectomy. *J Gastrointest Surg* 1998; **2**: 50–60.
- Yamashita Y, Kurohiji T, Hayashi J *et al*. Intraoperative ultrasonography during laparoscopic cholecystectomy. *Surg Laparosc Endosc* 1993; **3**: 167–171.
- Röthlin MA, Schlumpf R, Largiadèr F. Laparoscopic sonography. An alternative to routine intraoperative cholangiography? *Arch Surg* 1994; **129**: 694–700.

17. Stiegmann GV, Soper NJ, Filipi CJ *et al.* Laparoscopic ultrasonography as compared with static or dynamic cholangiography at laparoscopic cholecystectomy. A prospective multicenter trial. *Surg Endosc* 1995; **9**: 1,269–1,273.
18. Bezzi M, Merlino R, Orsi F *et al.* Laparoscopic ultrasonography in laparoscopic surgery and diagnosis. *Radiol Med* 1995; **89**: 82–90.
19. Santambrogio R, Bianchi P, Opocher E *et al.* Intraoperative ultrasonography (IOUS) during laparoscopic cholecystectomy. *Surg Endosc* 1996; **10**: 622–627.
20. Deeks JJ, Altman DG, Bradburn MJ. Statistical Methods for Examining Heterogeneity and Combining Results from Several Studies in Meta-analysis. In: Egger M, Davey Smith G, Altman DG. *Systematic Reviews in Health Care*. 2nd edn. London: BMJ Publishing; 2001. pp285–312.
21. Littenberg B, Moses LE. Estimating diagnostic accuracy from multiple conflicting reports: a new meta-analytic method. *Med Decis Making* 1993; **13**: 313–321.
22. Moses LE, Shapiro D, Littenberg B. Combining independent studies of a diagnostic test into a summary ROC curve: data-analytic approaches and some additional considerations. *Stat Med* 1993; **12**: 1,293–1,316.
23. Walter SD. Properties of the summary receiver operating characteristic (SROC) curve for diagnostic test data. *Stat Med* 2002; **21**: 1,237–1,256.
24. Glas AS, Lijmer JG, Prins MH *et al.* The diagnostic odds ratio: a single indicator of test performance. *J Clin Epidemiol* 2003; **56**: 1,129–1,135.
25. Egger M, Davey Smith G, Altman DG. *Systematic Reviews in Health Care*. 2nd edn. London: BMJ Publishing; 2001.
26. Irwig L, Tosteson AN, Gatsonis C *et al.* Guidelines for meta-analyses evaluating diagnostic tests. *Ann Intern Med* 1994; **120**: 667–676.
27. Jaeschke R, Guyatt G, Sackett DL. Users' guides to the medical literature. III. How to use an article about a diagnostic test. A. Are the results of the study valid? *JAMA* 1994; **271**: 389–391.
28. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ* 1997; **315**: 629–634.
29. Whiting P, Rutjes AW, Reitsma JB *et al.* The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. *BMC Med Res Methodol* 2003; **3**: 25.
30. Barteau JA, Castro D, Arregui ME, Tetik C. A comparison of intraoperative ultrasound versus cholangiography in the evaluation of the common bile duct during laparoscopic cholecystectomy. *Surg Endosc* 1995; **9**: 490–496.
31. Birth M, Ehlers KU, Delinikolas K, Weiser HF. Prospective randomized comparison of laparoscopic ultrasonography using a flexible-tip ultrasound probe and intraoperative dynamic cholangiography during laparoscopic cholecystectomy. *Surg Endosc* 1998; **12**: 30–36.
32. Castro D, Arregui ME, Brueggemann A. Laparoscopic Ultrasound: Principles and Techniques. In: Arregui ME, Fitzgibbons RJ, Katkhouda N *et al.* *Principles of Laparoscopic Surgery*. New York: Springer; 1995. pp489–506.
33. Catheline JM, Turner R, Paries J. Laparoscopic ultrasonography is a complement to cholangiography for the detection of choledocholithiasis at laparoscopic cholecystectomy. *Br J Surg* 2002; **89**: 1,235–1,239.
34. Falcone RA, Fegelman EJ, Nussbaum MS *et al.* A prospective comparison of laparoscopic ultrasound vs intraoperative cholangiogram during laparoscopic cholecystectomy. *Surg Endosc* 1999; **13**: 784–788.
35. Goletti O, Bucciatti P, Decanini L *et al.* Intraoperative sonography of biliary tree during laparoscopic cholecystectomy. *Surg Laparosc Endosc* 1994; **4**: 9–12.
36. Greig JD, John TG, Mahadaven M, Garden OJ. Laparoscopic ultrasonography in the evaluation of the biliary tree during laparoscopic cholecystectomy. *Br J Surg* 1994; **81**: 1,202–1,206.
37. Hublet A, Dili A, Lemaire J *et al.* Laparoscopic ultrasonography as a good alternative to intraoperative cholangiography (IOC) during laparoscopic cholecystectomy: results of prospective study. *Acta Chir Belg* 2009; **109**: 312–316.
38. Jakimowicz JJ, Rutten H, Jürgens PJ, Carol EJ. Comparison of operative ultrasonography and radiography in screening of the common bile duct for calculi. *World J Surg* 1987; **11**: 628–634.
39. Li JW, Feng B, Wu L *et al.* Intraoperative cholangiography in combination with laparoscopic ultrasonography for the detection of occult choledocholithiasis. *Med Sci Monit* 2009; **15**: MT126–MT130.
40. Machi J, Sigel B, Zaren HA *et al.* Technique of ultrasound examination during laparoscopic cholecystectomy. *Surg Endosc* 1993; **7**: 544–549.
41. Machi J, Tateishi T, Oishi AJ *et al.* Laparoscopic ultrasonography versus operative cholangiography during laparoscopic cholecystectomy: review of the literature and a comparison with open intraoperative ultrasonography. *J Am Coll Surg* 1999; **188**: 360–367.
42. Orda R, Sayfan J, Levy Y. Routine laparoscopic ultrasonography in biliary surgery. A preliminary experience. *Surg Endosc* 1994; **8**: 1,239–1,242.
43. Röthlin MA, Schöb O, Schlumpf R, Largiadèr F. Laparoscopic ultrasonography during cholecystectomy. *Br J Surg* 1996; **83**: 1,512–1,516.
44. Siperstein A, Pearl J, Macho J *et al.* Comparison of laparoscopic ultrasonography and fluorocholangiography in 300 patients undergoing laparoscopic cholecystectomy. *Surg Endosc* 1999; **13**: 113–117.
45. Thompson DM, Arregui ME, Tetik C *et al.* A comparison of laparoscopic ultrasound with digital fluorocholangiography for detecting choledocholithiasis during laparoscopic cholecystectomy. *Surg Endosc* 1998; **12**: 929–932.
46. Tranter SE, Thompson MH. Potential of laparoscopic ultrasonography as an alternative to operative cholangiography in the detection of bile duct stones. *Br J Surg* 2001; **88**: 65–69.
47. Slim K, Martin G. Does routine intra-operative cholangiography reduce the risk of biliary injury during laparoscopic cholecystectomy? An evidence-based approach. *J Visc Surg* 2013; **150**: 321–324.