Review Article

Laparoscopic Ultrasound during Laparoscopic Cholecystectomy- A Systematic Review

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Abstract

Purpose: The aim of this review was to verify whether laparoscopic ultrasound (LUS) could be an alternative to intraoperative cholangiography (IOC) in terms of prevention of retained common bile duct (CBD) stones and bile duct injury (BDI) during laparoscopic cholecystectomy (LC).

Method: The electronic database PUBMED and MEDLINE were searched between January 1980 and May 2017 for English language articles with regard to prevention of retained CBD stones and BDI during LC.

Result: A total of 24 studies which compared LUS with IOC during LC were found. Two meta-analyses revealed that the accuracy of LUS in detection of CBD stones was equivalent with that of IOC. Success rate of LUS was higher (91-100%), and the time for evaluation of LUS for the biliary system was shorter than IOC (5-10min. vs. 10-17min.). BDI was able to be reduced almost to 0% by routine use of LUS in a majority of reports. In comparison of the cost between LUS and IOC, LUS was much more cost-effective than IOC. Furthermore, no need for irradiation, reduced procedure time, and unlimited use were additional advantages of LUS. On the other hand, LUS required long learning curve for surgeons to be able to evaluate the biliary system properly.

Conclusion: LUS during LC was extremely effective for detecting CBD stones, thereby avoiding retained stones and for prevention of BDI. LUS was safe and effective procedure, which could potentially replace IOC particularly in the prevention of BDI.

ABBREVIATIONS

LUS: Laparoscopic Ultrasound; IOC: Intraoperative Cholangiography; LC: Laparoscopic Cholecystectomy; BDI: Bile Duct Injury; CBD: Common Bile Duct

INTRODUCTION

Laparoscopic ultrasound (LUS) was introduced in the 1990s as a novel method for detection of stones in the common bile duct (CBD) during laparoscopic cholecystectomy (LC), and subsequently its use was extended to intraoperative surveillance of biliary anatomy [1,2]. Prior to the introduction of LUS, intraoperative cholangiography (IOC) was often performed during LC, and proved to be a reliable procedure for detection of CBD stones within the biliary tract [3]. However, IOC had several disadvantages such as its complexity and the need for irradiation and specialist staff. A systematic review concluded that there was no robust evidence to indicate the effectiveness of IOC for prevention of bile duct injury (BDI) or residual CBD stones [4]. On the other hand, it has been reported that LUS is more reliable in this respect, in addition to its other advantages such as radiation-free assessment, a lower failure rate and a shorter procedure time [5-27]. Along with the recent technological advances in ultrasound techniques, LUS has become a promising modality for safer LC.

Recently, remarkable developments in surgical instrumentation have made it possible to accomplish LC even in severe cases accompanied by marked inflammation [28]. Some studies have also demonstrated that LC can be performed as an urgent procedure for acute cholecystitis without complications in most patients [29]. At the same time, however, some severe complications during and after LC have been reported. One is retention of stones in the CBD, and the other is BDI. Retained CBD stones may cause postoperative bile leakage, acute pancreatitis, cholangitis and sepsis [30,31]. Intraoperative BDI can lead to significant morbidities including bile duct stenosis, biliary or abdominal sepsis, postoperative obstructive jaundice, and liver damage [32,33]. Such complications could, in turn, trigger lethal conditions such as liver failure. Therefore, more convenient and reliable methods to prevent these complications of LC are required.

The aim of this systematic review was to verify whether LUS could be an alternative to IOC in terms of prevention of retained CBD stones and BDI during LC.

METHODS

The present review was executed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [34]. The PUBMED and MEDLINE electronic databases were searched between January 1980 and May 2017 for English language articles related to the prevention of retained CBD stones and BDI during LC. The search was performed on June 15th, 2017, utilizing the search terms “laparoscopic cholecystectomy”, “intraoperative cholangiography”, “cholangiography”, “laparoscopic ultrasonography”, “laparoscopic ultrasound”, “choledocholithiasis”, “common bile duct stone”, “bile duct injury”, and “biliary complication”. The reference lists of the selected articles were also reviewed. Irrelevant articles, reviews and meta-analyses, as concluded from the titles and abstracts, were excluded. The related articles function and reference list of each publication were used to widen the literature search.

Prospective and retrospective cohort studies had to meet the following inclusion criteria: (1) Comparison of LUS and IOC during laparoscopic cholecystectomy; (2) Sufficient data with regard to the diagnostic accuracy for CBD stones, success rate, safety, cost, and learning curve.

RESULTS

Fifty-one articles dealing with LUS during LC were identified. Eighteen of these were excluded because their titles and abstracts were outside our criteria. Two studies were excluded because the full texts were not written in English. Furthermore, seven articles in which intraoperative data on LUS and IOC were insufficient were excluded. A total of 24 studies comparing LUS with IOC during LC were found and analyzed. The data were extracted from selected studies that contained material applicable to the topic. A flow chart of the literature search is shown in Figure 1.

Diagnostic accuracy for CBD stones

LUS could clarify the presence of CBD stones accurately and quickly. As a result, it could prevent the postoperative complication of retained CBD stones. Two meta-analyses that compared the diagnostic accuracy for detecting CBD stones between IOC and LUS were reported [35,36]. Aziz et al., reported in their first meta-analysis that LUS had the equivalent diagnostic accuracy with IOC for detecting CBD stones. They concluded that LUS was a potentially useful modality to confirm the absence of CBD stones without need for puncture and cannulation of the biliary system [35]. Hakamada et al., reported that routine use of LUS during LC [37]. Machi et al., reported that LUS assessment before dissection around the gall bladder (GB) could make it easy to dissect the fundus of GB and the Calot’s triangle; as a result, it could possibly reduce BDI during LC [37]. Maki et al., reported that LUS assessment after clipping the cystic duct was useful to reduce BDI as surgeons could confirm the misidentification of the bile duct with the cystic duct [22]. Hakamada et al., reported that routine use of LUS in

Feasibility (Success rate)

Previous reports comparing LUS with IOC during LC were listed in (Table 1) [5-27]. LUS was a feasible diagnostic procedure as it was performed in higher successful rates (91-100%) than IOC. The time for assessment of LUS was reported to be 5-10min, while that of IOC was 10-17min. It meant that assessment time of LUS was about half of that of IOC. Machi et al., reviewed 12 studies including 2059 cases, in which both intraoperative ultrasound and IOC were performed simultaneously during open and LC [15]. They reported the success rate being 88-100% both in ultrasound and IOC. The time for assessment of LUS was about 7min, though the time of IOC was 14min which was twice as long. However at the same time, they recommended that during the learning period LUS should be performed concurrently with IOC as LUS had the technical difficulties in accomplishment. Li et al. reported that the detection rate of LUS for the intrapancreatic bile duct was 73.8% on the other hand, that of IOC was 97.3%. They described that LUS had some difficulty in screening intrapancreatic bile duct. They also described that LUS and IOC should be used complementary for the more accurate assessment of CBD [27].

Safety

LUS made it possible to recognize the biliary anatomy properly and potentially led to prevent BDI. There were several reports regarding prevention of BDI using LUS. In 1999, Tomonaga et al., reported that LUS assessment before dissection around the gall bladder (GB) could make it easy to dissect the fundus of GB and the Calot’s triangle; as a result, it could possibly reduce BDI during LC [37]. Machi et al., reported that LUS assessment after clipping the cystic duct was useful to reduce BDI as surgeons could confirm the misidentification of the bile duct with the cystic duct [22]. Hakamada et al., reported that routine use of LUS in

![Figure 1 Flowchart of studies included in review.](image-url)
Table 1: Reported studies comparing LUS with IOC during LC.

<table>
<thead>
<tr>
<th>No.</th>
<th>Author</th>
<th>Year</th>
<th>Study design</th>
<th>Cases</th>
<th>Time for assessment</th>
<th>Success rate</th>
<th>Rate of BDI with LUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yamashita Y(10)</td>
<td>1993</td>
<td>RCS</td>
<td>45</td>
<td>- -</td>
<td>91.1%</td>
<td>84.4%</td>
</tr>
<tr>
<td>2</td>
<td>Orda R(11)</td>
<td>1994</td>
<td>RCS</td>
<td>28</td>
<td>5-10 min</td>
<td>-</td>
<td>100.0%</td>
</tr>
<tr>
<td>3</td>
<td>Goletti O(12)</td>
<td>1994</td>
<td>RCS</td>
<td>30</td>
<td>6-10 min</td>
<td>-</td>
<td>100.0%</td>
</tr>
<tr>
<td>4</td>
<td>Bartau(13)</td>
<td>1995</td>
<td>RCS</td>
<td>117</td>
<td>6.6 min</td>
<td>10.9 min</td>
<td>90.8%</td>
</tr>
<tr>
<td>5</td>
<td>Rothlin M(14)</td>
<td>1996</td>
<td>PCS</td>
<td>200</td>
<td>- -</td>
<td>-</td>
<td>100.0%</td>
</tr>
<tr>
<td>6</td>
<td>Thompson DM(15)</td>
<td>1998</td>
<td>PS</td>
<td>360</td>
<td>6.6min</td>
<td>10.9min</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Birth M(16)</td>
<td>1998</td>
<td>PRS</td>
<td>518</td>
<td>7 min</td>
<td>16min</td>
<td>99.6%</td>
</tr>
<tr>
<td>8</td>
<td>Siperstein A(17)</td>
<td>1999</td>
<td>PNRS</td>
<td>300</td>
<td>- -</td>
<td>-</td>
<td>94.6%</td>
</tr>
<tr>
<td>9</td>
<td>Kimura T(18)</td>
<td>1999</td>
<td>RCS</td>
<td>183</td>
<td>-</td>
<td>-</td>
<td>96.0%</td>
</tr>
<tr>
<td>10</td>
<td>Cathline J(19)</td>
<td>1999</td>
<td>PS</td>
<td>600</td>
<td>10.2min</td>
<td>17.9min</td>
<td>100.0%</td>
</tr>
<tr>
<td>11</td>
<td>Machi J(20)</td>
<td>1999</td>
<td>Review of 12 studies</td>
<td>2059</td>
<td>7min</td>
<td>14min</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>Machi J(21)</td>
<td>1999</td>
<td>PCS</td>
<td>100</td>
<td>8.2min</td>
<td>15.9min</td>
<td>95.0%</td>
</tr>
<tr>
<td>13</td>
<td>Falcone RA(22)</td>
<td>1999</td>
<td>RCS</td>
<td>65</td>
<td>- -</td>
<td>92.0%</td>
<td>86.0%</td>
</tr>
<tr>
<td>14</td>
<td>Biffl WL(23)</td>
<td>2000</td>
<td>NRS</td>
<td>844</td>
<td>- -</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>Tranter SE(24)</td>
<td>2001</td>
<td>PS</td>
<td>367</td>
<td>- -</td>
<td>99.0%</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>Cathline J(25)</td>
<td>2002</td>
<td>NRS</td>
<td>900</td>
<td>-</td>
<td>-</td>
<td>97.8%</td>
</tr>
<tr>
<td>17</td>
<td>Tranter SE(26)</td>
<td>2003</td>
<td>PSCS</td>
<td>135</td>
<td>- -</td>
<td>97.8%</td>
<td>89.0%</td>
</tr>
<tr>
<td>18</td>
<td>Onders RP(27)</td>
<td>2005</td>
<td>RCS</td>
<td>255</td>
<td>- -</td>
<td>-</td>
<td>95.0%</td>
</tr>
<tr>
<td>19</td>
<td>Machi J(28)</td>
<td>2007</td>
<td>RCS</td>
<td>200</td>
<td>- -</td>
<td>96.5%</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>Perry RA(29)</td>
<td>2008</td>
<td>RCS</td>
<td>236</td>
<td>- -</td>
<td>95.3%</td>
<td>-</td>
</tr>
<tr>
<td>21</td>
<td>Hakamada K(30)</td>
<td>2008</td>
<td>RCS</td>
<td>644</td>
<td>- -</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>Hublet A(31)</td>
<td>2009</td>
<td>PS</td>
<td>269</td>
<td>- -</td>
<td>99.0%</td>
<td>94.9%</td>
</tr>
<tr>
<td>23</td>
<td>Machi J(32)</td>
<td>2009</td>
<td>MRCS</td>
<td>1381</td>
<td>-</td>
<td>98.0%</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>Li JW(33)</td>
<td>2009</td>
<td>PS</td>
<td>103</td>
<td>8.5min</td>
<td>13.8min</td>
<td>100%</td>
</tr>
</tbody>
</table>

Abbreviations: LUS: Laparoscopic ultrasound; IOC: Intraoperative cholangiography; LC: Laparoscopic cholecystectomy; RCS: Retrospective cohort study; PCS: Prospective controlled study; PS: Prospective study; PRS: Prospective randomized study; PNRS: Prospective non-randomized study; NRS: Non-randomized study; PSCS: Prospective single-blinded controlled study; MRCS: Multicenter retrospective cohort study; BDI: Bile duct injury

LC could reduce BDI to 0% despite the fact that 72% of LC was performed less-skilled junior surgeons [24]. They described that routine use of LUS in LC was extremely effective in educational program for junior surgeons as it would clarify the accurate biliary anatomy in the short time. Biffl et al. reported that routine use of LUS decreased the rate of BDI (CBD injury, bile leak and retained CBD stone from 2.5% to 0% [17]. They described that the misidentification of the biliary anatomy caused BDI. Therefore, they concluded that particularly in patients with acute cholecystitis in which recognition of the biliary anatomy was difficult, LUS should be more effective to prevent BDI. Machi et al., conducted a multicenter study which included 1381 cases in five centers [26]. They reported that LUS could clarify the biliary anatomy in 98% of cases, resulting in, no BDI. In their report, the following five points were cited as the reasons for reducing BDI: 1, LUS can be performed immediately after laparoscopic exploration with no or little tissue dissection; 2, LUS is repeatable because of safety and no need for biliary cannulation; 3, As LUS images and laparoscopic view are visualized simultaneously, the precise location of cystic duct and CBD can be readily understood; 4, the blood vessels can be identified using color or power Doppler imaging of LUS; as a result, the risk of vascular injury which might increase risk of BDI is decreased; 5, LUS can be repeated after application of clips of the cystic duct to confirm that the bile duct is intact. However at the same time, they described that LUS could not completely replace IOC because there were certain cases in which IOC was important to accomplish LC.

Cost

The cost of LUS and IOC was reported to be $53-$362 [16,40] and $77-738, respectively [38,39]. Falcone et al., conducted the prospective comparing study with regard to LUS and IOC in LC [16]. They reported that there was a significant difference in the cost of LUS and IOC [LUS vs. IOC, 362$ vs. 665$; p<0.05]. The cost for disposable catheters for cholangiography and the cost of real-time fluoroscopy in the operation room considered to be the difference of the cost between LUS and IOC. Furthermore, LUS could save the operating room cost because the time for...
assessment of LUS is shorter than that of IOC. They also described that the cost to purchase the ultrasound probe was $28,500, given the $300 per patient saving over the cost of IOC, the expense of the probe would be recaptured after 95 exams. Machi et al., reported that the cost of routine LUS plus highly selective IOC, routine IOC, and selective IOC were $131.28/operation, $408.0/operation, and $157.08/operation, respectively. Therefore, it appeared that LUS significantly reduced the cost of operation including intraoperative imaging examination [26].

**Learning curve**

In spite of beneficial advantages of LUS, several disadvantages were also reported. One of them was a long learning curve. Machi et al., reported that 50-100 operations were necessary for a surgeon to be able to assess the biliary system properly using LUS [26]. Falcone et al., described in their prospective study that the learning curve of LUS was generally long for proper assessment of the biliary system during LC [16]. They divided surgeons into two groups, one was surgeons who had performed >10 LUS [EXP], and the other was surgeons who had performed ≤10 LUS [NOV]. They made surgeons assess the LUS difficulty in three stages: Easy; Difficult; Impossible, and compared between EXP and NOV groups. According to their study, EXP surgeons evaluated 71% cases as Easy despite the fact that NOV surgeons evaluated only 24% of cases as Easy. Hakamada et al. compared the operation time between senior surgeons who had performed LUS more than 100 times and junior surgeons who had performed LUS less than 30 times [24]. They described that the operation time of junior surgeons were significantly longer than that of senior surgeons. The difference of the operation time was caused by the difference of the time for LUS. Initial demonstration by the senior surgeon to understand the proper biliary anatomy during LUS was necessary for less-skillsful surgeon to be able to use LUS appropriately. Consequently, the operation time was significantly extended when the junior surgeons performed LC. They described that educational program with a certain learning period was necessary to master LUS and to prevent BDI. As a potential limitation of LUS, inability to detect BDI should be noted. If the BDI occurred intraoperatively, LUS probably may not be able to identify the exact location and extent of injury. At this point, IOC was much more reliable to detect where BDI occurred.

**DISCUSSION**

In comparing LUS with IOC, the accuracy of LUS in detection of CBD stones is equivalent to that of IOC. Success rate of LUS is higher, and the time for evaluation of the biliary system is shorter than IOC. IOC requires the dissection around the cystic duct and the cannulation to bile duct. Such procedures cause the excessive operation time and to misunderstanding the biliary system. As a result, BDI could occur before performing IOC. On the other hand, LUS can be performed before dissecting the tissue around GB and cystic duct, and can clarify the details of the biliary system. Therefore, LUS has remarkable advantages of accuracy and safety, comparing with IOC. Furthermore, no need for irradiation, the cost effectiveness, reduced procedure time, and unlimited use are additional advantages of LUS. At the same time, it should be noted that there are certain disadvantages. One of them is a long learning curve. However, once it is mastered, LUS can become the promising diagnostic tool during LC. Another disadvantage is inability to accurately detect intraoperative BDI once it occurs. If it is suspected, IOC should be performed.

Recently, fluorescent cholangiography (FC) has been investigated as a novel method for preventing BDI during LC [41]. The effectiveness of intraoperative FC was first reported by Ishizawa et al. in 2010 [42,43]. The indocyanine green (ICG) administrated intravenously was excreted into the bile. The excreted ICG emitted the fluorescent light reacting the near-infrared light, which could visualize the biliary system intraoperatively. Therefore, misidentification of the biliary system was reduced, which consequently prevented intraoperative BDI. Further investigation should be performed to verify the effectiveness of FC for prevention of BDI.

The present systematic review revealed the value of LUS. On the other hand, this study had several limitations. One is that information of LUS for prevention of BDI was still relatively small. The other is that meta-analysis was not conducted in this study. These limitations remain to be addressed in a future study.

In conclusion, LUS during LC was extremely effective for detecting CBD stones and for prevention of BDI. LUS was safe and cost-effective procedure, which could potentially replace IOC particularly in the prevention of complications during LC.

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**REFERENCES**


