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Laparoscopic versus open liver segmentectomy: prospective, case-matched, intention-to-treat analysis of clinical outcomes and cost effectiveness

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Abstract

Introduction Reduction in hospital stay, blood loss, postoperative pain and complications are common findings after laparoscopic liver resection, suggesting that the laparoscopic approach may be a suitable alternative to open surgery. Some concerns have been raised regarding cost effectiveness of this procedure and potential implications of its large-scale application. Our aim has been to determine cost effectiveness of laparoscopic liver surgery by a case-matched, case–control, intention-to-treat analysis of its costs and short-term clinical outcomes compared with open surgery.

Methods Laparoscopic liver segmentectomies and bisegmentectomies performed at Ninewells Hospital and Medical School between 2005 and 2007 were considered. Resections involving more than two Couinaud segments, or involving any synchronous procedure, were excluded. An operation-magnitude-matched control group was identified amongst open liver resections performed between 2004 and 2007. Hospital costs were obtained from the *Scottish Health Service Costs Book* (ISD Scotland) and average national costs were calculated. Cost of theatre time, disposable surgical devices, hospital stay, and high-dependency unit (HDU) and intensive care unit (ICU) usage were the main endpoints for comparison. Secondary endpoints were morbidity and mortality. Statistical analysis was performed with Student's *t*-test, χ^2 and Fisher exact test as most appropriate.

Results Twenty-five laparoscopic liver resections were considered, including atypical resection, segmentectomy and bisegmentectomy, and they were compared to 25 matching open resections. The two groups were homogeneous by age, sex, coexistent morbidity, magnitude of resection, prevalence of liver cirrhosis and indications. Operative time ($p < 0.03$), blood loss ($p < 0.0001$), Pringle manoeuvre ($p < 0.03$), hospital stay ($p < 0.003$) and postoperative complications ($p < 0.002$) were significantly reduced in the laparoscopic group. Overall hospital cost was significantly lower in the laparoscopic group by an average of £2,571 ($p < 0.04$).

Conclusions Laparoscopic liver segmentectomy and bisegmentectomy are feasible, safe and cost effective compared to similar open resections. Large-scale application of laparoscopic liver surgery could translate into significant savings to hospitals and health care programmes.

Keywords Cancer · Hepato < Cancer · Costs < Technical · Surgical < Technical · Hepato (Liver)

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Since the introduction of laparoscopic cholecystectomy in 1987, the laparoscopic approach has been applied to the full spectrum of abdominal procedures. However, liver resections have remained resistant to the onslaught of laparoscopic surgery, despite a first report as early as 1992. Concerns regarding the difficult mobilisation and transection of the liver and the risks of major haemorrhage, gas embolism and dissemination of malignant tumours have been responsible for this initial slow development [1–4].

More recently, however, increased experience in laparoscopic cancer surgery and the contribution of improved technology have fuelled the enthusiasm for laparoscopic liver surgery. Increasing numbers of reports have now established that, despite occasional longer operating times, laparoscopic liver surgery is associated with reduced blood loss, reduced postoperative morbidity and shorter hospital stay [5–23]. This has culminated in the recent acclamation of the laparoscopic approach as a gold standard, at least for selected procedures such as left lateral sectionectomy [14, 24].

One last concern persists regarding the possible increased costs of the laparoscopic approach to liver surgery and the potential implications of its large-scale application [25]. In this study, we address this issue by prospectively comparing elective laparoscopic and open liver resection in a case-matched, case–control, intention-to-treat study, aiming to determine the cost effectiveness of laparoscopic liver segmental resection and to report on short-term clinical outcomes.

Materials and methods

All laparoscopic liver resections performed at the Hepato-Pancreatic-Biliary (HPB) Unit of Ninewells Hospital and Medical School between January 2005 and December 2007 were reviewed. This time period covered the evolutionary stages of the laparoscopic liver service development that saw staged introduction of the various laparoscopic resections. As such, both laparoscopic and open resections were routinely performed by two surgeons with extensive experience in both advanced laparoscopic and open liver surgery. Initially, the easier laparoscopic left lateral liver sectionectomy was introduced and performed in all patients from then on. The atypical resections and then isolated resections of the other antero-inferior segments (IV, V, VI) commenced in 2006, and all operations of this kind were also attempted laparoscopically from this time on. Finally, in 2007 the more challenging bisegmentectomies (V + VI and VI + VII) were introduced and again always attempted laparoscopically from then on. By 2007, the laparoscopic approach accounted for nearly all of the segmental resections performed that year, and only one isolated anatomical segment VIII resection was not attempted laparoscopically as it was considered technically prohibitive (this patient was excluded from this analysis).

Since April 2004, data have been prospectively entered in an HPB database in our unit, including indication to surgery, American Society of Anaesthesiologists (ASA) score, tumour location and size, presence of cirrhosis or other significant comorbidity, type of resection and of other associated surgical procedure if any, length of Pringle manoeuvre, duration of surgery (timed from patient placement on the operating table to completion of skin closure), total time in operating suite (from the time the patient entered the anaesthetic room to the time the patient entered the theatre recovery area), operative equipment used, intraoperative blood loss, blood transfusion requirement, duration of high-dependency unit (HDU) or intensive care unit (ICU) stay, overall hospital stay, complications, readmission rate, mortality and pathology.

Anatomical or nonanatomical (wedge/atypical) resections of one or two liver segments were considered while resections involving more than two Couinaud segments were excluded. Resections where any additional synchronous procedure other than cholecystectomy had been performed were also excluded from analysis. An age-, sex- and operation-matched control group was identified amongst the open resection group.

Unit costs were obtained from the *Scottish Health Service Costs Book* published by ISD Scotland with the explicit aim of assisting in comparison across heath care providers to ensure efficiency and to benchmark costs. From the cost book, we calculated the average unit costs for the five largest university/teaching hospitals in Scotland (Ninewells Hospital in Dundee, Edinburgh Royal Infirmary, Glasgow Royal Infirmary and the Western in Glasgow, and Aberdeen Royal Infirmary) and these were used to obtain results less dependent on local reality and more reproducible nationally. These unit costs were as follows: theatre usage £1,090/h, HDU £681/full day, ICU £1,695/full day and ward stay £484/full day. The cost applied to each unit of blood transfused was £101, and £57 to each unit of fresh frozen plasma. The cost of a computed tomography (CT) scan was £300. Costs of disposable instruments used were as follows: TissueLink dissecting sealer £620 each, ACE Ultracision £443 each, Ligasure £352 each, Autosuture EndoGIA £111 (reload cartridge £130), Ethicon ETS stapler £240 (reload cartridge £82), endoclip £136 and 10–12 mm trocar £53 each.

Unit and overall operating costs were the main endpoints for comparison; secondary endpoints were hospital stay, morbidity, mortality, blood loss, Pringle manoeuvre and positive resection margins.

The groups were matched for magnitude of resection and for tumour location and size. After selection of the case-matched controls, the intention-to-treat principle was applied and patients who underwent a laparoscopic converted to open liver resection were considered within the laparoscopic group.

Statistical analysis was performed with SPSS version 12.0. Data were expressed as mean ± standard deviation (SD). Student's *t*-test, chi-square and Fisher exact test were used for comparison as most appropriate. A p value of <0.05 was considered statistically significant.

Surgical technique

The open resections were performed via a right subcostal or a J-shaped laparotomy. In the laparoscopic group, the patient was in the supine French position and access was by transumbilical open laparoscopy. For resections of segments 6 and 7, a moderate left lateral decubitus was obtained by raising the right hemithorax with a small sand bag. Pneumoperitoneum was kept at 10–13 mmHg; three or four additional 12-mm trocars were added in good triangulation depending on tumour position and type of resection and a 30° laparoscope was used routinely. Intraoperative ultrasound was performed routinely both in the laparoscopic and open group for restaging and guiding the resection.

Transparenchymal approach with no prior vascular control was favoured in both groups; the limits and lines of the resection were defined by ultrasound and marked on the liver surface with electrocautery before transection of the parenchyma. Both in the laparoscopic and open procedures a tourniquet was prepared around the hepatoduodenal ligament, but a Pringle manoeuvre was performed only if and when necessary to control problematic haemorrhages, and was released as soon as control had been achieved.

In both the open and laparoscopic resections, the parenchymal transection was performed with a mixture of saline-enhanced radiofrequency TissueLink dissecting sealer (DS3.0 dissecting sealer or EndoSH2.0 sealing hook, TissueLink Medical, Dover, NH, USA), Harmonic Scalpel (Ultracision ACE, Ethicon Endo-Surgery, Cincinnati, OH, USA) and ultrasonic dissector (CUSA Excel ultrasonic surgical aspirator, Integra Radionics, Burlington, MA, USA), in various combinations. Intraparenchymal control of the main segmental pedicles was achieved with Endo GIA Roticulators staplers (Tyco Healthcare, Elancourt, France); subsegmental vessels were mostly addressed with TissueLink or ACE and only occasionally divided between titanium clips. Argon plasma coagulation (APC 300, ERBE, Marietta, GA, USA) of the raw liver surface was performed routinely after open resections and occasionally after laparoscopic ones.

The resected specimen was placed in a plastic bag and retrieved unfragmented through a 5–7-cm transverse suprapubic service minilaparotomy.

Results

In the selected period, 35 resections were performed laparoscopically. Twenty-five of these were included in the study after exclusion of cases where a synchronous colectomy (six), adrenalectomy (two), or reversal of colostomy/ileostomy (two) had been performed. A group of 25 open resections of matching magnitude, performed between 2004 and 2007, was selected, and the two groups were confirmed to be homogeneous by age, sex, coexistent morbidity (ASA), type of resection and prevalence of liver cirrhosis.

Mean age was 66.2 years (± 13.6 SD) in the laparoscopic group and 63.7 years (± 9.3 SD) in the open one [p = not significant (n.s.)]. Male-to-female ratio was 1.27 vs. 1.08 (p = n.s.), respectively. ASA grades were not statistically different in the two groups (laparoscopic: ASA 1–2 = 19 patients, ASA 3 = 6 patients, ASA 4–5 = 0 patients; open group ASA 1–2 = 18 patients, ASA 3 = 7 patients, ASA 4–5 = 0 patients; p = n.s.). The number of previous abdominal, nongynaecological operations was also similar in the two groups (laparoscopic: 18 vs. open 21, p = n.s.); all patients operated on for colorectal cancer metastasis had already had the primary tumour removed. Number of tumour nodules resected (29 vs. 31, p = n.s.), number of segments resected (41 vs. 39, p = n.s.), mean size of tumour resected (3.8 ± 1.6 vs. 4.0 ± 1.4, p = n.s.) and prevalence of liver cirrhosis (4 vs. 2, p = n.s.) were also not significantly different in the two groups; therefore, the two groups were considered homogeneous and well matched.

Forty-four (88%) patients had a malignant tumour and six had benign lesions (Caroli's disease, focal nodular hyperplasia, chronic granulomatous disease). Amongst the malignant tumours, the indications were colorectal cancer metastasis (36), hepatocellular carcinoma (6) and gallbladder cancer (2). Again no significant difference was observed between the two groups (Table 1).

The type of resections performed is shown in Table 1. There were 16 bisegmentectomies in the laparoscopic group versus 14 in the open group (p = n.s.), 4 vs. 5 unisegmentectomies (p = n.s.) and 5 vs. 6 nonanatomical resections respectively (p = n.s.). Two (8%) patients required conversion to open surgery. Both were undergoing

Table 1 Indication and resections performed

	Laparoscopic (n = 25)	Open (n = 25)	p-value
Left lateral sectionectomy	10	9	n.s.
Two segments	6	5	
One segment	4	5	
Atypical	5	6	
Colorectal cancer metastasis	16	20	n.s.
HCC	4	2	
Gallbladder cancer	1	1	
Other	4	2	

HCC = hepatocellular carcinoma

resection of segment VI and were considered in the laparoscopic surgery group according to the intention-to-treat principle.

The mean theatre time (surgery + anaesthetic) was 362 ± 113 min in the laparoscopic group vs. 366 ± 73 min in the open group (p = n.s.). Blood loss was 135 ± 84 ml vs. 420 ± 225 ml ($p < 0.0001$). A Pringle manoeuvre was necessary in 12% vs. 32% (two-sided $p = 0.03$) respectively. Overall morbidity was 12% vs. 40% ($p = 0.002$), as 3 vs. 10 patients experienced minor complications. No postoperative collection or bile leaks were observed in the laparoscopic group versus one bile leak in the open one. There was one postoperative pneumonia in the laparoscopic group versus three in the open group. There was one cardiac arrhythmia in the laparoscopic group versus two in the open group. There were no wound infections in the laparoscopic group versus four in the open group. Patients who underwent laparoscopic resection were not routinely admitted to HDU postoperatively and only 10 (40%) required a short HDU stay for close follow-up of coexistent medical conditions. All of 25 open resections were admitted to HDU for monitoring and epidural analgesia. Patients that underwent a laparoscopic resection had a shorter overall hospital stay with significantly reduced stay in both HDU (1.2 ± 1.6 vs. 3.4 ± 1.5 days, $p = 0.0003$) and standard surgical ward (6.2 ± 3.0 vs. 9.7 ± 6.5 days, $p = 0.01$) (Table 2).

Results of the operating-costs analysis are shown in Table 3. Cost of theatre usage was not statistically different in the two groups (£6,525 ± 2,143 laparoscopic vs. £6,647 ± 1,331 open, p = n.s.). Cost of disposable instruments and other devices was an average £713 per case higher for laparoscopic surgery than for open surgery (£1,302 ± 435 vs. 589 ± 378, $p < 0.0001$). HDU stay was £1,482 less expensive in the laparoscopic group (£881 ± 1,097 vs. £2,363 ± 1,052, $p < 0.0003$) and additional stay in the general surgical ward was £1,679 per case less expensive in the laparoscopic group (£3,017 ± 1,457 vs. £4,607 ± 3,149, $p = 0.05$). Overall operating costs were an average £2,571 per case less in the laparoscopic group (£11,727 ± 3,288 vs. £14,298 ± 3,817, $p = 0.04$) (Table 3).

Table 2 Comparison of laparoscopic and open operative results

	Laparoscopic	Open	p-value
Hospital stay, days	7.4	13.1	0.003
HDU (mean ± SD)	1.2 ± 1.6	3.4 ± 1.5	0.0003
Ward (mean ± SD)	6.2 ± 3.0	9.7 ± 6.5	0.01
Theatre time (mean ± SD), min	362 ± 113	366 ± 73	n.s.
Overall morbidity	12%	40%	0.002
Blood loss (mean ± SD), ml	135 ± 84	420 ± 225	<0.0001
Pringle manoeuvre	12%	32%	0.03
Resection margin	8%	4%	n.s.

HDU = high-dependency unit

Discussion

It is our opinion that surgeons should be empowered to offer the best treatment to their patients regardless of what its cost may be. However, in recent times it has become increasingly clear that surgeons are requested by hospital managers to look at cost effectiveness of surgical procedures prior to their implementation in clinical practice [25]. Our study demonstrates that, in the case of laparoscopic liver surgery, better surgery also proved to be significantly less expensive.

A recent meta-analysis suggested that the laparoscopic approach to the antero-inferior segments of the liver is a suitable alternative to open surgery, being as safe as open surgery and allowing better overall results [6]. Lower intraoperative blood loss, reduced need for a Pringle manoeuvre, lower overall and liver-related morbidity and reduced hospital stay are widely reported advantages of laparoscopic liver surgery and are also confirmed in our analysis, which, to the best of our knowledge, is the first one focusing primarily on cost effectiveness of laparoscopic liver surgery.

In our experience, laparoscopic liver surgery allowed a net saving of more than £2,500 per case compared with open surgery of matching magnitude. Theatre occupancy time was similar, with a total theatre usage time including time of anaesthesia and surgery of 362 min vs. 366 min, respectively. Theatre usage time is considered to be a better indicator than duration of surgery (although the latter appeals better to surgeons) when studying cost effectiveness and productivity, being a reflection of both the time spent by the patient in the anaesthetic room and the duration of surgery, and therefore better reflecting the actual usage of theatre as a hospital resource [26, 27]. In our department, as is best practice in the UK, patients undergoing major open surgery routinely undergo an epidural anaesthetic for postoperative pain control and are therefore routinely admitted to a high-dependency unit for postoperative care. Benefits of an epidural anaesthetic are widely known and wear off after 48–72 h, after which patients are discharged from the HDU to a general surgical ward, unless of course a medical reason or surgical complication has occurred, justifying their prolonged stay in the HDU [28]. Although undoubtedly beneficial to open-surgery patients, this practice significantly increases the theatre usage time and the hospital cost when compared with the laparoscopic group, where epidural analgesia is not

Table 3 Cost analysis

	Laparoscopic	Open	Difference	p-value
Theatre time (mean ± SD)	£6,525 ± 2143	£6,647 ± 1331	–£122	n.s.
Disposable instruments (mean ± SD)	£1,302 ± 435	£589 ± 378	+£713	<0.0001
HDU stay (mean ± SD)	£881 ± 1097	£2,363 ± 1062	–£1,482	<0.0003
Ward stay (mean ± SD)	£3,017 ± 1457	£4,697 ± 3148	–£1,679	<0.05
Total (mean ± SD)	£11,727 ± 3288	£14,298 ± 3817	–£2,571	<0.04

routinely used. As a consequence, anaesthetic time was shorter and admission to the HDU was unnecessary in the laparoscopic group, with the additional benefit of lower overall and liver-specific morbidity.

Further to savings determined by unnecessary HDU care, overall hospital stay on a general surgical ward was also significantly reduced in the laparoscopic group, confirming a quicker recovery and resumption of physiological functions. A significant contribution to this may also have come from the overall lower complications rate of laparoscopic surgery, particularly wound, respiratory and cardiovascular complications. Interestingly, the cost of diagnosing and treating these complications was not accounted for in our study, as most of these treatments continued after discharge of the patient in the community (i.e. rehabilitation, physiotherapy, antibiotics and wound care) and therefore are very difficult to quantify in our setting. It is, however, reasonable to assume that, if these costs had been considered, they would clearly have increased further the cost effectiveness of laparoscopic surgery [26]. Furthermore, indirect costs (the societal and individual costs relating to patients' absence from work or normal activities) were also ignored, being again difficult to quantify. There is, however, very good evidence that patients undergoing laparoscopic procedures return to work or to their usual activities significantly faster than patients undergoing open surgery [29–32] and, once again, it is reasonable to assume that, if accounted for, this would have again increased the cost effectiveness of laparoscopic surgery, strengthening the economic case for a routine minimally invasive approach to liver surgery.

The economic impact of laparoscopic liver surgery could be further improved by reducing its equipment cost. At present, a major drawback of laparoscopic surgery is the use of highly specialised surgical equipment and this has burdened the technique with high operating costs [27, 31, 33–35]. In our experience the average per-patient cost for operating instruments and devices was, indeed, significantly higher in the laparoscopic group (£1,302 vs. £589, $p < 0.0001$). Savings determined by shorter hospital stay, unnecessary HDU care, and lower morbidity, however, more than offset this. Our opinion is that laparoscopic liver surgery, although it has already been welcomed as a new gold standard, is still in a development phase that incurs higher costs. This has also been our own experience; in the attempt to identify the optimal transection technique, a combination of devices for division of the liver parenchyma was used in 80% of our laparoscopic cases. With standardization of operative techniques, particularly for isolated resections of segments V and VI and for the bisegmentectomies V/VI and VI/VII, the use of more than one device during the hepatotomy will become unusual, with direct implications on equipment cost. In the most recent of our cases, by using reusable ports and a single device for the transection of the liver parenchyma, the typical cost of disposable instruments for a laparoscopic left lateral sectionectomy has been reduced to £996 or £786 depending on whether the TissueLink or the Ace Ultracision was used in isolation. Similarly the typical cost of an isolated segment VI resection has also been reduced to £786 or £576 (using TissueLink or Ace Ultracision, respectively). This represents a reduction of 23%, 39% and 55% on the average per-patient cost of the study. Laparoscopic liver surgery can therefore be made even less expensive and will naturally evolve to become cheaper with the end of its development phase and wider adoption.

A marked reduction in hospital stay was a significant finding in our study and determinant of cost effectiveness. Although our study is not randomised, the two groups are very homogeneous and well matched for operation magnitude, coexistent morbidity (ASA) and indications, as shown in Table 1. Furthermore, we believe that our staged introduction of the various laparoscopic liver resections, dictated by our increasing confidence and skills, prevented any active selection bias. Once each new laparoscopic resection was introduced, all operations of that type from then on were attempted laparoscopically.

Length of hospital stay is influenced by social factors, need for rehabilitation, occupational and physical therapy, and employment status. We acknowledge that our results may somewhat depend on social and other local circumstances and we advocate further similar studies in different settings to confirm our findings. In our setting in Dundee, laparoscopic surgery has allowed an average 43% reduction in overall hospital stay (average of more than 5 days per patient). These figures may vary in different settings and shorter hospital stays for open surgery have been reported than that observed by us. We are confident that a significant reduction in hospital stay can be achieved in any setting by laparoscopic surgery compared with open surgery in case-matched groups.

Reduced hospital stay after open surgery is achievable by implementation of an enhanced recovery programme (ERP), as shown in colon and liver surgery [32, 36]. Enhanced recovery programmes aim to reduce the physiological and psychological stress of surgery and to improve patients' reaction by optimising perioperative factors and by manipulating patients expectations after surgery. It has been suggested that adoption of such programmes after open surgery, leading to reduction in hospital stay with assumed reduction in cost, may negate some of the benefits of laparoscopic surgery [32, 36]. Although we are fully supportive of the widest implementation of ERPs or any other measure to improve patients' acceptability and outcome after open surgery, we feel that the most valuable advantages of laparoscopic surgery are certainly not its shorter hospital stay and lower hospital cost. Characteristically, these are related to the minimal invasiveness of the technique with smaller surgical wounds, significant reduction in postoperative pain and quicker patient mobilization that translate to significant reduction in wound infection rates, incisional hernias, and respiratory and thromboembolic complications. The psychological benefit obtained by manipulating patients' expectations typical of ERPs is however not to be neglected and for this reason we look forward to the natural extension of enhanced recovery protocols to laparoscopic liver surgery, to further maximize its advantages to patients and benefits to hospital finances. With appropriate preparation and in the appropriate settings, as demonstrated by Koffron et al. [16] in the largest published series of laparoscopic liver resections to date, the average hospital stay can be as low as 1.9 days. Although this may appear an overambitious target to achieve in a UK or European setting, it would suggest that length of stay in the West is set to drop with increasing surgeon and patient confidence in the technique.

Conclusions

Laparoscopic surgery for liver segmentectomy and bisegmentectomy when compared with open surgery of matched magnitude is cost effective. It also proved safe and was associated with lower morbidity than open surgery. Large-scale application of this technique could therefore translate to significant savings to hospitals and reduction of health care expenditure.

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