Photodiagnosis and Photodynamic Therapy 28 (2019) 346–353

Contents lists available at ScienceDirect

Photodiagnosis and Photodynamic Therapy

journal homepage: www.elsevier.com/locate/pdpdt

Effectiveness and safety of indocyanine green fluorescence imaging-guided hepatectomy for liver tumors: A systematic review and first meta-analysis

Chi Qi[b,d,1], Hao Zhang[a,1], Yue Chen[b,d], Song Su[a], XiaoFeng Wang[f], XinQiao Huang[f], Cheng Fang[a], Bo Li[a], XianMing Xia[a,c,*], Pan He[a,c,e,*,1]

[a] Department of Hepatobiliary Surgery, Affiliated Hospital, Southwest Medical University, Luzhou, 646000, China
[b] Department of Nuclear Medicine, Affiliated Hospital, Southwest Medical University, Luzhou, 646000, China
[c] Academician(Expert)Workstation of Sichuan Province, Luzhou, 646000, China
[d] Nuclear Medicine and Molecular Imaging Key Laboratory of Sichuan Province, Luzhou, 646000, China
[e] Department of Anesthesiology, Affiliated Hospital, Southwest Medical University, Luzhou, 646000, China
[f] Department of Radiology, Affiliated Hospital, Southwest Medical University, Luzhou, 646000, China

ARTICLE INFO

Keywords:
Indocyanine green
Fluorescence imaging
Hepatectomy
Liver tumor
Meta-analysis

ABSTRACT

Background: This meta-analysis was conducted to evaluate the effectiveness and safety of indocyanine green fluorescence imaging-guided hepatectomy(FIGH) for liver tumors.

Methods: Clinical studies were retrieved from the PubMed, Embase, Cochrane Library, Medline and Web of Science electronic databases. Primary outcomes included operative time, blood loss, blood transfusion, hospital stay, R0 resection, postoperative complications, postoperative mortality and 1-year recurrence rate. Study-specific effect sizes and their 95% confidence intervals (CIs) were combined to calculate the pooled value using a fixed-effects or random-effects model.

Results: Six studies comprising 587 patients were included. Major operative time (mean difference [MD] = -55.45; 95% CI = -78.85– -32.05), blood loss (MD = 12.99; 95% CI = 12.00–13.97), hospital stay (rate difference [RD] = -12.61; 95% CI = -15.06– -10.17), and postoperative complications (RD = -0.07; 95% CI = -0.12– -0.01) were all less in the FIGH group than in the traditional hepatectomy(TH) group. No differences were found in blood transfusion, R0 resection or 1-year recurrence rate. No perioperative mortality was observed in either group.

Conclusion: Based on current evidence, applying indocyanine green fluorescence imaging technology to accurately diagnose and treat liver tumors can effectively reduce operative time, blood loss, hospital stay and postoperative complications.

1. Introduction

Liver resection is the mainstay curative treatment for liver tumors [1,2], with anatomic hepatectomy being recommended to treat hepatocellular carcinoma (HCC) and some metastatic liver cancers [3]. However, even after curative resection, 70–80% of patients with HCC experience tumor recurrence within 5 years postoperation [4–6]. This high early recurrence rate may be due to the presence of small metastatic and residual cancerous lesions that are missed using current preoperative and intraoperative detection methods [7]. Accordingly, using intraoperative detection technology during liver cancer resection to avoid residual small metastatic lesions can help prevent tumor recurrence and improve cure rates.

Indocyanine green (ICG) is a water-soluble compound that has been clinically approved in many countries for over 50 years for use in medical diagnostic imaging, including determining cardiac output and hepatic function. To date, ICG fluorescence with infrared light methods has been developed for various targets, including cancer cell agents [8,9], sentinel lymph nodes [10,11], neurological diseases [12,13], cardiovascular disease [14,15], and hepatically cleared agents for bile duct imaging [16]. Recent studies have described the application of fusion ICG fluorescence imaging in liver surgery, reporting that it showed great potential for real-time navigation during hepatectomies for liver tumors [17,18]. ICG can be used to detect microscopic lesions and for anatomic hepatectomy navigation because it emits fluorescence upon illumination with near-infrared light.

* Corresponding authors at: Department of Hepatobiliary Surgery, Affiliated Hospital, Southwest Medical University, Luzhou, 646000, China.
E-mail addresses: xxm6202@126.com (X. Xia), 18783096517@163.com (P. He).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.pdpdt.2019.10.007
Received 6 August 2019; Received in revised form 29 September 2019; Accepted 4 October 2019
Available online 07 October 2019

However, high-quality evidence to determine whether ICG fluorescence imaging can improve the effectiveness of liver tumor surgery is lacking. Therefore, whether the fluorescence technique is beneficial and safe for patients remains undetermined. Until recently, no meta-analyses have evaluated the effectiveness and safety of ICG fluorescence imaging-guided hepatectomy for liver tumors. Therefore, the present meta-analysis was conducted to systematically review the published literature and evaluate the effectiveness and safety of ICG fluorescence imaging-guided hepatectomies for liver tumors. The results could serve as a reference for clinical practice.

2. Methods

2.1. Literature search

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [19]. Three authors (P.H., C.Q., and H.Z.) independently searched the PubMed, Embase, Cochrane Library, Medline and Web of Science databases for the literature that compared fluorescence imaging-guided hepatectomy with traditional hepatectomy of no-fluorescence imaging-guided hepatectomy for liver tumors. The following terms were searched: indocyanine green fluorescence, ICG fluorescence, hepatectomy, hepatectomies, liver neoplasm, liver neoplasms, hepatic neoplasm, hepatic neoplasms, hepatic cancer, hepatic cancers, liver cancer, liver cancers, hepatocellular cancer, hepatocellular cancers, hepatocellular carcinoma, cancer of liver, cancer of the liver, and liver tumor. The reference lists of the included articles were also reviewed for additional information. The literature search was limited to articles published in English and dated through 20 June 2019.

2.2. Inclusion and exclusion criteria

Inclusion criteria were as follows: (1) patients of any sex, age, race or nationality who underwent hepatectomies for liver tumors; (2) the experimental group underwent liver tumor resection via ICG fluorescence-imaging technology, while the traditional control group did not; (3) studies reporting at least one of the following outcomes: operative time, blood loss, blood transfusion, R0 resection, hospital stay, postoperative complications (including biliary leakage, postoperative infection, pleural effusion, liver failure, and others), mortality and 1-year recurrence rate; and (4) studies were either randomized controlled trials (RCTs), cohort studies, or comparative studies. Exclusion criteria were as follows: (1) studies with no control group; (2) case reports, abstracts, conference reports, or experiments; and (3) studies in which the full text was unavailable, and information from the abstract was insufficient.

2.3. Study selection and data extraction

Three reviewers (P.H., C.Q., and H.Z.) independently read the full texts and extracted the following data: first author, year, country, study design, maximum tumor diameter, R15, age, sample size and outcomes. The authors of the studies were contacted via e-mail to obtain any missing information. For quantitative data without means or standard deviation (SD), if the missing information was unavailable from the authors, an alternate method [20,21] was used to estimate the mean and SD based on the median, range, and sample size.

2.4. Methodological quality assessment

The methodological quality of the included studies was assessed independently by three researchers (P.H., C.Q., and H.Z.) using the Newcastle-Ottawa Scale (NOS), which is widely used to assess the quality of nonrandomized studies in meta-analyses [22]. Based on the study population selection, comparability of the groups under study, and outcome assessment, this scale was used to rate the quality of the included studies. The maximum score on the scale was 9, and studies with scores > 5 were considered to have high methodological quality. Disagreements were resolved by common consensus.

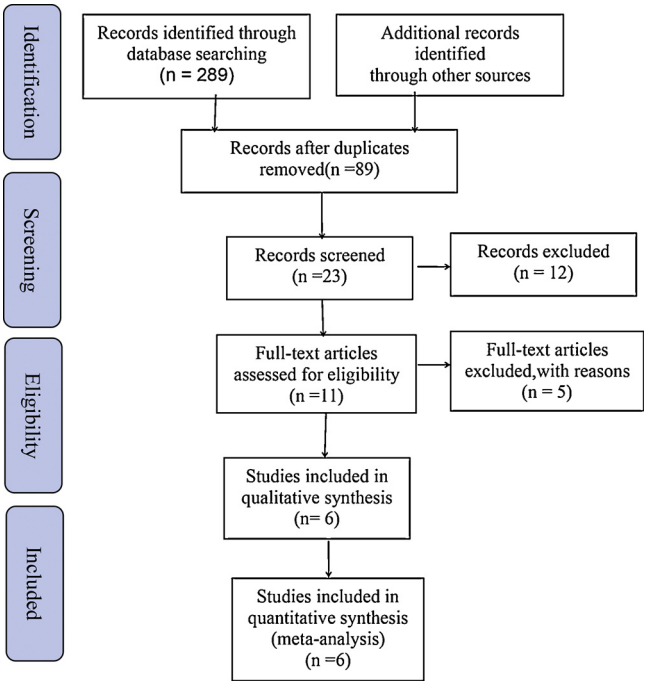

Fig. 1. Flow diagram of the literature selection. PubMed, Embase, Cochrane Library, Medline and Web of Science were searched for the literature with designed searching terms. After screening the titles, abstracts, and then the full text for relevance step by step, seven studies were considered suitable to conduct the said meta-analysis in the end.

2.5. Statistical analysis

The study-specific rate difference (RD) for categorical variables, mean difference (MD) for continuous variables, and the 95% confidence intervals (CIs) were combined to calculate the pooled value of each study using Cochrane Review Manager software (RevMan; version 5.1). Heterogeneity was investigated using the χ^2 test and I^2 statistics. Heterogeneity was considered unimportant when the I^2 value was 0–35%, moderate when the I^2 value was 35–75%, and considerable when the I^2 value was 75–100%. If heterogeneity existed (> 75%), the data were analyzed using a random-effects model. If heterogeneity was considered unimportant or moderate, a fixed-effects model was used. Sensitivity analysis was performed by removing one study at a time and repeating the meta-analysis to assess whether at least one study significantly affected the pooled estimates. Potential publication bias was assessed by visually inspecting the funnel plots based on primary outcomes. A study was considered to have no publication bias when the figure presented good symmetry. When possible, subgroup analyses of cancer staging, surgery type, type of primary tumor and resection, comorbidities, pre- and postoperative liver function, fibrosis grade, and imaging system used were performed to determine whether these factors affected the conclusion. $P < 0.05$ (two-sided) was considered statistically significant.

3. Results

3.1. Search results, characteristics, and quality of included studies

Literature was selected using the designed strategy, and 89 relevant citations were identified after removing duplicates. Twenty-three

Table 1
Characteristics of Included Studies.

References	Year	Country	Study Design	Maximum Tumor Diameter(cm)[a]	R15[a]	Age(years)[a]	Sample Size			NOS
							Total	FIGH	TH	
Nishion et al	2017	Japan	Retrospective cohort	NA	13.3 ± 5.8/ 13.1 ± 7.7	66.9(39-82)/ 65.1(33-82)	52	23	29	9
Handgraaf et al	2017	Netherlands	Retrospective cohort	NA	NA	62.0 ± 9.2/ 63.0 ± 9.4	154	67	87	9
Kaiborl et al	2011	Japan	Retrospective cohort	(5.3 ± 4.9) / (5.0 ± 4.6)	11.8 (5.7)/ 15.3 (7.6)	70.4 ± 5.5/ 68.2 ± 11.0	102	52	50	8
Aoki et al	2018	Japan	Retrospective cohort	2.9(0.8-5.7) / 2.5(0.7-4.8)	13 (4–17)/ 16 (3–32)	63(34-84)/ 69(35-86)	97	25	72	8
Zhou et al	2019	China	Retrospective cohort	3.1(1.8-5.5) / 3.2(1.2-5.5)	NA	NA	42	21	21	8
Cheung et al	2018	China	Retrospective cohort	2.75(1.2-6.5) / 3.45(1.0-9.5)	NA	60.5(47.0-73.0)/ 61.5(25.0-86.0)	140	20	120	8

[a] Experimental group/control group.NOS: Newcastlee-Ottawa Scale. NA: Not available.R15:Indocyanine green ratio after 15 min.FIGH :Fluorescence imaging-guided hepatectomy.TH: Traditional hepatectomy.

Table 2
Raw data of the included studies.

Studies	Group	Operative time(min)	Blood loss(ml)	Blood Transfusion	Hospital Ttay(d)	R0 Resection	Postoperative complication	1-year recurrence rate
Nishion et al	FIGH	483.1 ± 152.5	1025.5 ± 987.9	5	NA	NA	NA	6
	TH	483.7 ± 195.5	1062.3 ± 1434.9	9	NA	NA	NA	12
Handgraaf et al	FIGH	183 ± 56	416 ± 3.3	NA	25.75 ± 20.75	NA	10	NA
	TH	180 ± 53	403 ± 2.8	NA	15.25 ± 7.8	NA	11	NA
Kaiborl et al	FIGH	328 ± 124	886 ± 1402	10	10.4 ± 3.8	NA	2	NA
	TH	337 ± 126	992 ± 1504	13	18.2 ± 15.9	NA	8	NA
Aoki et al	FIGH	179.75 ± 76.25	NA	NA	NA	30	1	NA
	TH	232.5 ± 68.3	NA	NA	NA	77	7	NA
Zhou et al	FIGH	210 ± 45	175 ± 100	0	NA	21	4	NA
	TH	232.5 ± 60	225 ± 150	0	NA	21	4	NA
Cheung et al	FIGH	238.5 ± 101.5	NA	0	6.25 ± 2.75	20	0	2
	TH	373.25 ± 105.3	NA	8	32 ± 18.3	116	18	8

NA: Not available.FIGH :Fluorescence imaging guided hepatectomy.TH: Traditional hepatectomy.

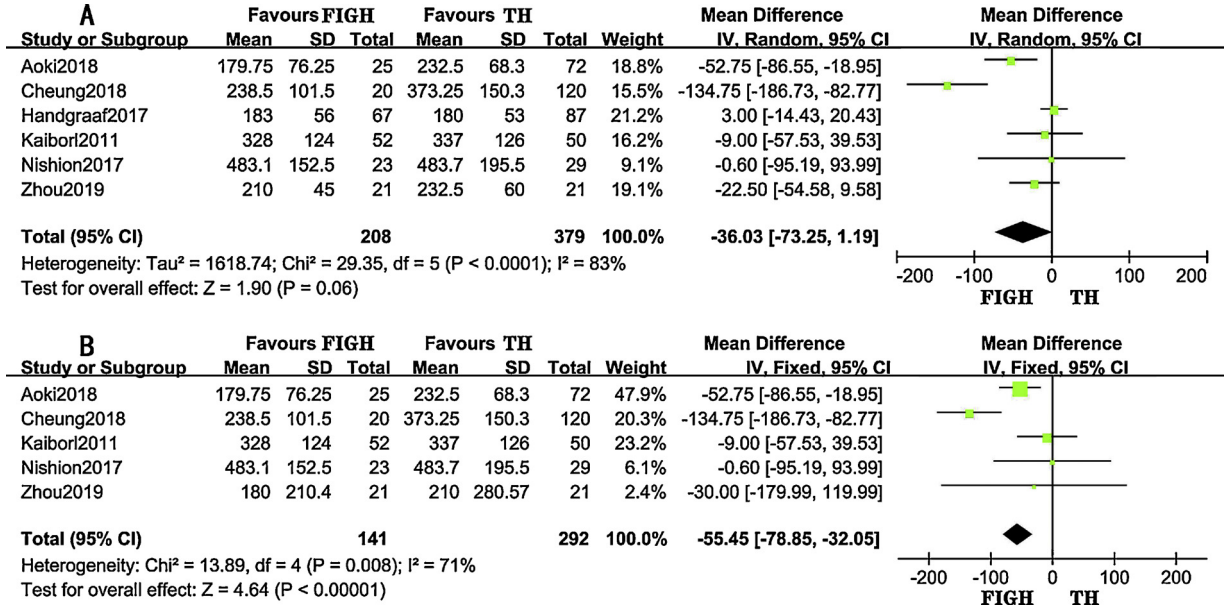

Fig. 2. Forest plot of the meta-analysis on operative time.

citations were excluded after reviewing the titles and abstracts. The remaining 11 citations were assessed for eligibility by reviewing the full text, and 5 were excluded. Finally, 6 retrospective cohort studies [17,23–27] were selected into this meta-analysis. Fig. 1 shows the details of the literature selection process. Five hundred eight-seven patients who underwent indocyanine green fluorescence imaging-guided or not for hepatectomies for liver tumors were enrolled. Table 1 lists the characteristics and quality assessment outcomes of each included study. Table 2 summarizes the raw data from the included studies. The methodological quality of the included studies was

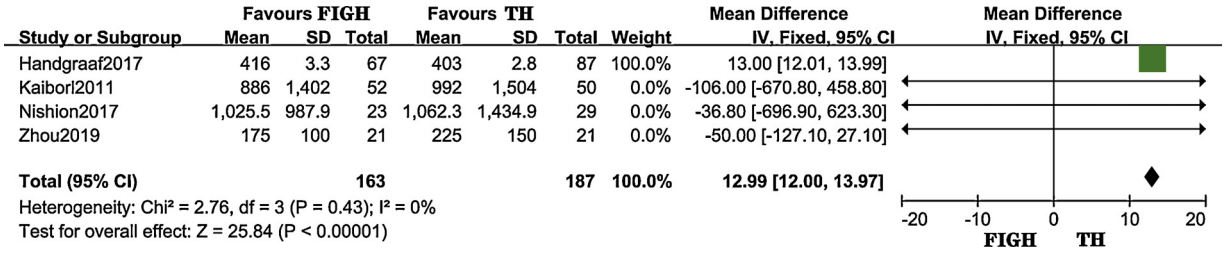

Fig. 3. Forest plot of the meta-analysis on blood loss.

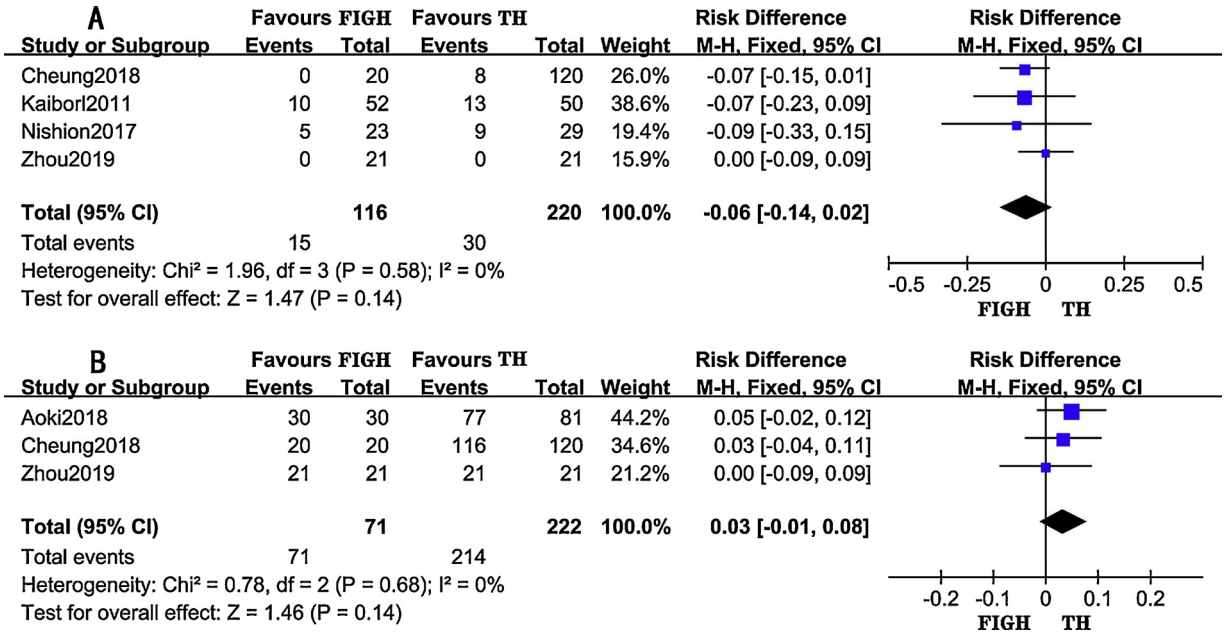

Fig. 4. Forest plot of the meta-analysis on blood transfusion and R0 resection.

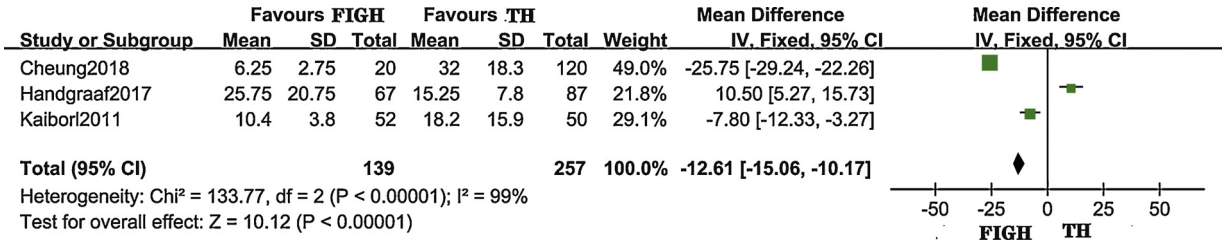

Fig. 5. Forest plot of the meta-analysis on hospital stay.

moderate to high.

3.2. Meta-analysis of the operative time

Six studies [17,23–27] investigated the operative time (in minutes). No significant difference was observed between the two groups (MD = -36.03; 95% CI = -73.25–1.19). Considerable heterogeneity was found (P < 0.01; I^2 = 83%; Fig. 2A). A less homogenous result (P = 0.008; I^2 = 71%)was obtained, the pooled estimate changed, and the operative time was significantly lower in the FIGH group(MD = —55.45; 95% CI = -78.85– -32.05) in the sensitivity analysis when one trial [23] was excluded (Fig. 2B).

3.3. Meta-analysis of blood loss

Four studies [17,23,24,26] explored the blood loss (in milliliters). Less blood loss occurred in the FIGH group (MD = 12.99; 95% CI = 12.00–13.97). Unimportant heterogeneity was found among the trial results (P = 0.43; I^2 = 0%; Fig. 3). The robustness of the result was confirmed via sensitivity analysis.

3.4. Meta-analysis of blood transfusion

Four studies [17,24,26,27] explored the blood transfusion rate. No significant difference was observed between the groups (RD = -0.06; 95% CI, -0.14–0.02). Unimportant heterogeneity was found (P = 0.58; I^2 = 0%; Fig. 4A). The robustness of the result was confirmed via sensitivity analysis.

3.5. Meta-analysis of R0 resection

Three studies [25–27] explored the R0 resection rate. No significant difference was observed between the two groups (RD = 0.03; 95% CI, -0.01–0.08). Unimportant heterogeneity was found (P = 0.68; I^2 = 0%; Fig. 4B). The robustness of the result was confirmed via sensitivity analysis.

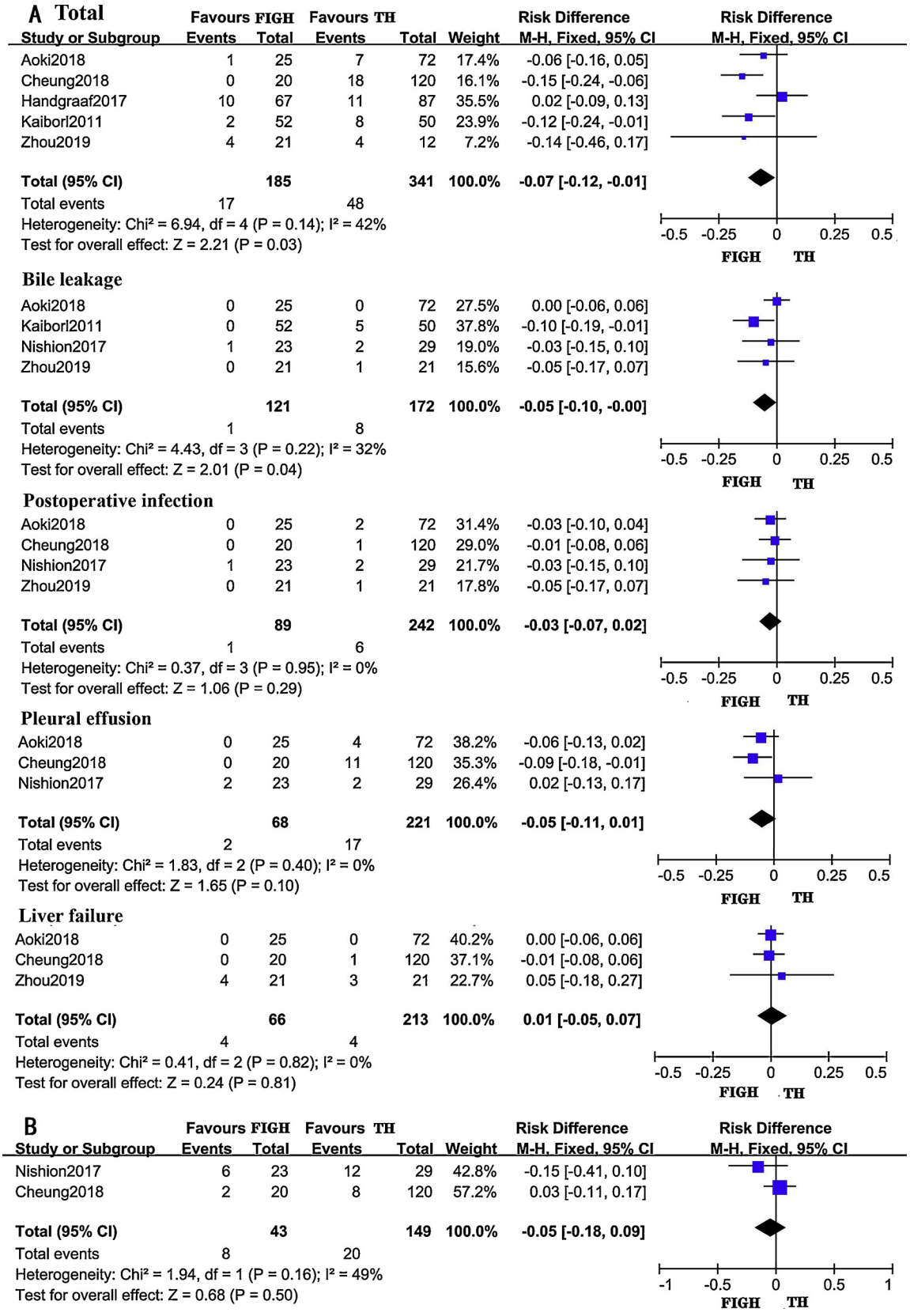

Fig. 6. Forest plot of the meta-analysis on postoperative complication and 1-year recurrence rate.

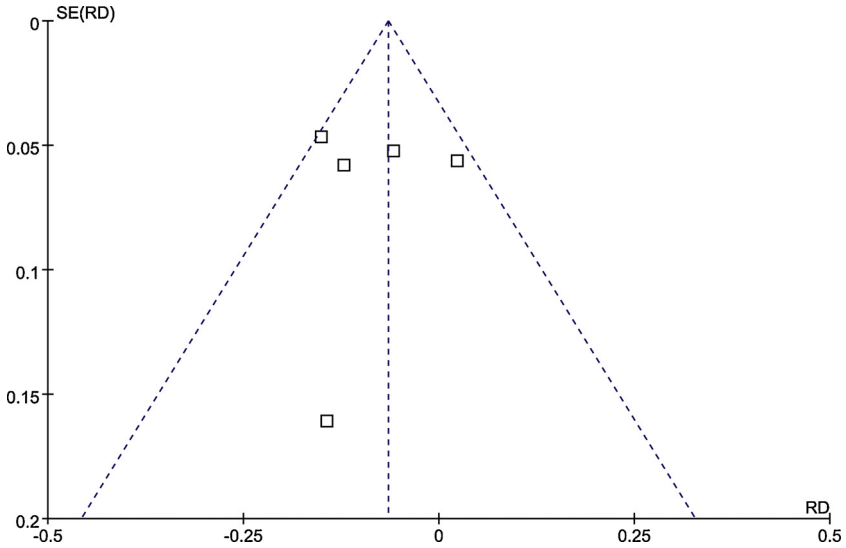

Fig. 7. Funnel plot showing no publication bias.

3.6. Meta-analysis of hospital stay length

Three studies [23,24,27] explored the hospital stay length (in days). The FIGH group had shorter hospital stays (MD = -12.61; 95% CI = -15.06– -10.17). Substantial heterogeneity occurred among the trial results (P < 0.01; I^2 = 99%; Fig. 5). The robustness of the result was confirmed via sensitivity analysis.

3.7. Meta-analysis of postoperative complications, mortality and 1-year recurrence rates

Five studies [23–27] included the postoperative complication rates, four studies [17,24–26] explored bile leakage, four studies [17,25,24–27] explored postoperative infections, three studies [17,25,27] explored pleural effusion, and three studies [25,24–27] explored liver failure. Fewer overall complications occurred in the FIGH groups (RD = -0.07; 95% CI = -0.12– -0.01). Unimportant heterogeneity was found (P = 0.14; I^2 = 42%). The incidence of biliary leakage was significantly reduced in the FIGH group (RD = -0.05; 95% CI = -0.10–0.00). No significant differences were found for other individual complications (Fig. 6A). The robustness of the results was confirmed via sensitivity analysis. No perioperative mortality occurred in either group.

Two studies [17,27] explored the 1-year recurrence rates. No significant difference was observed between the two groups (RD = -0.05; 95% CI, -0.18–0.09). Moderate heterogeneity was found (P = 0.16; I^2 = 49%; Fig. 6B). The robustness of the result was confirmed via sensitivity analysis

3.8. Publication bias and subgroup analysis

Fig. 7 shows the funnel plot for overall postoperative complications. All studies were inside the limits of the 95% CIs and were evenly vertically distributed, showing no evidence of publication bias.

Owing to limitations in the existing data, six studies were included in our subgroup analysis by surgery type (laparoscopic vs open) [17,23–27], and five studies were included in our subgroup analysis by imaging system type (MIPS vs PINPOINT) [17,24,24,25,26,27]. Our subgroup analysis results showed no obvious change in the direction or statistical significance of the OR or MD for any parameters considered or the level of heterogeneity (Table 3).

4. Discussion

ICG is a water-soluble compound, which, when injected into human tissues, immediately binds tightly to blood plasma and fluoresces under excitation at 760–820 nm [28]. ICG fluorescence imaging has recently been used to detect lymph nodes via the lymphatic duct in breast and digestive tract surgery [29,30] as well as to detect vascular flow in other surgical fields [31,32]. The tumor can be visualized with only 200 tumor cells under near-infrared light, and surgeons can observe the tumor foci with a minimum of 1 mm [33]. Within the field of liver surgery, Ishizawa et al. [34] reported the first use of ICG molecular fluorescence imaging-guided hepatectomy in 2009. Subsequent clinical studies have shown that ICG fluorescence molecular imaging technology can be used to qualitatively and quantitatively analyze pathological changes at the cellular and molecular levels in vivo, objectively display liver tumor boundary information, define liver tumor boundaries [35], detect residual lesions, and achieve three-dimensional staining and real-time intraoperative navigation of the liver parenchyma in the target area [36,37]. However, previous studies were either case reports or small studies [38,26]. Therefore, the efficacy and safety of ICG fluorescence imaging technology remain uncertain. Some have even questioned whether the technology will increase the operative time and cost of hospital stays. Because evidence for the effectiveness of this technique is lacking, this meta-analysis was conducted to compare the effectiveness and safety of ICG fluorescence imaging-guided hepatectomy for liver tumors.

To our knowledge, this was the first meta-analysis of indocyanine green fluorescence imaging-guided hepatectomies for liver tumors. In this meta-analysis, only six studies involving 587 patients were feasibly included. To date, this represents the most information available to assess the effectiveness and safety of FIGHfor liver tumors. According to the NOS used for assessing study quality, articles included in this meta-analysis were graded with a score of 9 [17,23], and a score of 8 [24–27] represented high-quality patient selection, comparability, and exposure measurements. The results of the present meta-analysis showed that FIGH has some advantages for hepatectomies for liver tumors. First, using indocyanine green fluorescence imaging technology did not increase the operative time; the FIGH group had shorter operative times than those of the control group. This may be because fluorescence imaging rapidly shows the locations of tumor lesions and allows real-time navigation for surgical resection, which compensates for surgeons spending substantial time deciding which tissues to remove and which should be preserved via the naked eye and palpation [39]. Second, the

Table 3
Subgroup analyses based on type of surgery and imaging system.

Variables	S/P	operative time			S/P	blood loss			S/P	blood transfusion		
		Statistical method	Efect estimate	P value		Statistical method	Efect estimate	P value		Statistical method	Efect estimate	P value
type of surgery												
Laparoscopic	4/433	MD(IV,Fixed,95% CI)	−19.16(-33.09-6.14)	0.004	2/196	MD(IV,Fixed,95% CI)	12.99(12-13.97)	< 0.01	2/182	OR(M–H,Fixed,95% CI)	0.32(0.02,5.81)	0.44
open	2/154	MD(IV,Fixed,95% CI)	−7.25(-50.43,35.93)	0.74	2/154	MD(IV,Fixed,95% CI)	−76.75(-525.9,352.4)	0.73	2/154	OR(M–H,Fixed,95% CI)	0.66(0.31,1.39)	0.27
type of imaging system												
MIPS	2/154	MD(IV,Fixed,95% CI)	−7.25(-50.43,35.93)	0.74	NA	NA	NA	NA	2/154	OR(M–H,Fixed,95% CI)	0.66(0.31,1.39)	0.27
PINPOINT	3/279	MD(IV,Fixed,95% CI)	−53.18(-74.41,-31.94)	< 0.01	NA	NA	NA	NA	2/182	OR(M–H,Fixed,95% CI)	0.32(0.02,5.81)	0.44

S Study, P patients, OR odds ratio,MD Mean difference, M–H Mantel–Haenszel, IV Inverse variance, Fixed Fixed-efect model, CI confdence interval, NA Not available.MIPS is a imaging system (Osaka, Japan).PINPOINT is a imaging system (NOVADAQ,Toronto, Canada).

FIGH was associated with significantly less blood loss. Bleeding is difficult to control during hepatectomies, and unexpected bleeding may obscure the surgeon's vision. The favorable outcomes of FIGH may be because fluorescence imaging enables visualizing tumor lesions and blood vessels [39]. The operative time is also reduced, thus reducing the overall bleeding. Third, one study showed that fluorescence imaging increased hospital stay lengths [23]. However, our analysis showed that using FIGH did not increase the hospital stay length. Our conclusion was consistent with the results of other published studies [24,27].

Furthermore, the rates of major complications and bile leakage were lower in the FIGH group. The main advantages of FIGH are real-time display of the surgical area, reduced manipulation of intra-abdominal organs and detection of bile leakage. Thus, FIGH should reduce procedure-related complications during hepatectomies [24]. Another main advantage of ICG fluorescence imaging is the accurate excision of liver tumors to prevent residual tumor lesions and reduce postoperative recurrence. Although the relevant literature shows that ICG fluorescence imaging can achieve a high R0 cutting edge rate [25,27] and reduce postoperative recurrence rates [17,27], no significant difference was found in R0 resection, 1-year recurrence rates, or blood transfusion complications. More research is needed to confirm these results.

Because the studies yielded heterogeneous outcomes, we used the random-effects model in our analysis. Sensitivity analysis was performed by removing one study at a time and repeating the meta-analysis to assess whether at least one study significantly affected the pooled estimates. The outcome estimates for blood loss, blood transfusions, R0 resection, hospital stay length, postoperative complications and 1-year recurrence rates changed slightly after the sensitivity analysis. Moreover, the funnel plot symmetry showed no publication bias, and the subgroup analysis results were generally consistent with those of the overall analysis, thus strengthening the results of this meta-analysis. The operative time estimates changed markedly. However, heterogeneity was lowered when Handgraaf's [23] study was excluded, indicating that this study might have been the source of the heterogeneity. A possible explanation for this heterogeneity is that Handgraaf's study evaluated different disease types, specifically colorectal liver metastases.

This systematic review has some limitations. First, the number of included studies was small, and the methodological quality was generally low, mainly because ICG molecular fluorescence imaging technology is not being currently applied in RCTs of liver tumors; most are retrospective cohort studies. Second, most studies had a small sample size, and few reports have been published on the long-term prognoses, which should be compared in future studies. Third, some outcome indicators showed significant heterogeneity at the time of combination, which may affect the reliability of the results owing to the lack of multifactor subgroup analyses. Fourth, most of the literature was from studies conducted in Asia, which may influence extrapolation of the results.

In conclusion, this systematic review showed that using ICG fluorescence imaging technology to accurately diagnose and treat liver tumors can effectively reduce the operative time, blood loss, hospital stay length and postoperative complication incidence. However, considering the clinical and methodological heterogeneity among studies, high-quality, consistent intervention, large-sample, multicenter randomized controlled studies are required.

Declaration of Competing Interest

The authors declares that they have no conflict of interest.

Acknowledgments

This work was supported by grants from the Scientific and Technological Strategic Cooperation Foundation, the People's

Government of Luzhou City, China (no. 2017LZXNYD-J07), the Fourth Batch of Provincial Science and Technology Plans in 2017-key R&D Projects (no. 2017SZYZF0015), and the Funded Project of Sichuan Provincial Science and Technology Department Joint Research Special Fund (no. Z1428).

References

[1] A.B. Benson 3rd, T.A. Abrams, E. Ben-Josef, et al., NCCN clinical practice guidelines in oncology: hepatobiliary cancers, J. Natl. Compr. Cancer Netw. 7 (2009) 350–391.
[2] A.B. Benson 3rd, T. Bekaii-Saab, E. Chan, et al., Metastatic colon cancer, version 3. 2013: featured updates to the NCCN guidelines, J. Natl. Compr. Cancer Netw. 11 (2013) 141–152.
[3] K. Hasegawa, N. Kokudo, H. Imamura, et al., Prognostic Impact of anatomic resection for hepatocellular carcinoma, Ann. Surg. 242 (2005) 252–259.
[4] J.M. Llovet, J. Fuster, J. Bruix, Intention-to-treat analysis of surgical treatment for early hepatocellular carcinoma: resection versus transplantation, Hepatology 30 (1999) 1434–1440.
[5] Y. Sasaki, T. Yamada, H. Tanaka, H. Ohigashi, H. Eguchi, M. Yano, et al., Risk of recurrence in a long-term follow-up after surgery in 417 patients with hepatitis B- or hepatitis C-related hepatocellular carcinoma, Ann. Surg. 244 (2006) 771–780.
[6] S.C. Katz, J. Shia, K.H. Liau, M. Gonen, L. Ruo, W.R. Jarnagin, et al., Operative blood loss independently predicts recurrence and survival after resection of hepatocellular carcinoma, Ann. Surg. 249 (2009) 617–623.
[7] M. Shimada, K. Takenaka, K. Taguchi, Y. Fujiwara, T. Gion, K. Kajiyama, et al., Prognostic factors after repeat hepatectomy for recurrent hepatocellular carcinoma, Ann. Surg. 227 (1998) 80–85.
[8] Z. Hu, Y. Qu, K. Wang, et al., In vivo nanoparticle-mediated radiopharmaceutical-excited fluorescence molecular imaging, Nat. Commun. 6 (2015) 7560.
[9] T. Song, X. Liu, Y. Qu, et al., A novel endoscopic Cerenkov luminescence imaging system for intraoperative surgical navigation, Mol. Imaging 14 (2015) 443–449.
[10] S. Ohnishi, S.J. Lomnes, R.G. Laurence, et al., Organic alternatives to quantum dots for intraoperative near-infrared fluorescent sentinel lymph node mapping, Mol. Imaging 4 (2005) 172–181.
[11] D.K. Emerson, K.K. Limmer, D.J. Hall, et al., A receptor-targeted fluorescent radiopharmaceutical for multireporter sentinel lymph node imaging, Radiology 265 (2012) 186–193.
[12] D. Hyde, R. de Kleine, S.A. MacLaurin, et al., Hybrid FMT-CT imaging of amyloid-beta plaques in a murine Alzheimer's disease model, Neuroimage 44 (2009) 1304–1311.
[13] W. Pham, B.Q. Zhao, E.H. Lo, et al., Crossing the blood-brain barrier: a potential application of myristoylated polyarginine for in vivo neuroimaging, Neuroimage 28 (2005) 287–292.
[14] J.O. Deguchi, M. Aikawa, C.H. Tung, et al., Inflammation in atherosclerosis: visualizing matrix metalloproteinase action in macrophages in vivo, Circulation 114 (2006) 55–62.
[15] D.E. Sosnovik, M. Nahrendorf, N. Deliolanis, et al., Fluorescence tomography and magnetic resonance imaging of myocardial macrophage infiltration in infarcted myocardium in vivo, Circulation 115 (2007) 1384–1391.
[16] J.L. Figueiredo, C. Siegel, M. Nahrendorf, et al., Intraoperative near-infrared fluorescent cholangiography (NIRFC) in mouse models of bile duct injury, World J. Surg. 34 (2010) 336–343.
[17] H. Nishino, E. Hatano, S. Seo, et al., Real-time navigation for liver surgery using projection mapping with indocyanine green fluorescence: development of the novel medical imaging projection system, Ann. Surg. 267 (6) (2018) 1134–1140.
[18] M. Terasawa, T. Ishizawa, Applications of fusion-fluorescence imaging using indocyanine green in laparoscopic hepatectomy, Surg. Endosc. 31 (12) (2017) 5111–5118.
[19] A. Liberati, D.G. Altman, J. Tetzlaf, et al., The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration, Ann. Intern. Med. 151 (2009) W65–W94.
[20] X.W. Hou, J.P. Shi, X. Chen, How to estimate the mean and standard deviation based on the median, range and sample size when conducting meta-analysis, Chin. J. Evid. Based Med. 15 (2015) 484–487.
[21] S.P. Hozo, B. Djubegovic, I. Hozo, Estimating the mean and variance from the median, range and the size of a simple, BMC Med. Res. Methodol. 5 (2005) 13.
[22] A. Stang, Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses, Eur. J. Epidemiol. 25 (9) (2010) 603e605.
[23] H.J.M. Handgraaf, L.S.F. Boogerd, D.J. Hoppener, et al., Long-term follow-up after near-infrared fluorescence-guided resection of colorectal liver metastases: a retrospective multicenter analysis, Eur. J. Surg. Oncol. 43 (8) (2017) 1463–1471.
[24] M. Kaibori, M. Ishizaki, K. Matsui, et al., Intraoperative indocyanine green fluorescent imaging for prevention of bile leakage after hepatic resection, Surgery 150 (1) (2011) 91–98.
[25] T. Aoki, M. Murakami, T. Koizumi, et al., Determination of the surgical margin in laparoscopic liver resections using infrared indocyanine green fluorescence, Langenbecks Arch. Surg. 403 (5) (2018) 671–680.
[26] Z. Yu, L. Ye, H. Jin, et al., Real-time navigation guidance using fusion indocyanine green fluorescence imaging in laparoscopic non-anatomical hepatectomy of hepatocellular carcinomas at segments 6, 7, or 8 (with videos), Med. Sci. Monit. 25 (2019) 1512–1517.
[27] T.T. Cheung, K.W. Ma, W.H. She, et al., Pure laparoscopic hepatectomy with augmented reality-assisted indocyanine green fluorescence versus open hepatectomy for hepatocellular carcinoma with liver cirrhosis: a propensity analysis at a single center, Asian J. Endosc. Surg. 11 (2) (2018) 104–111.
[28] E. Tanaka, H.S. Choi, H. Fujii, M.G. Bawendi, J.V. Frangioni, Image-guided oncologic surgery using invisible light: completed pre-clinical development for sentinel lymph node mapping, Ann. Surg. Oncol. 13 (2006) 1671–1681.
[29] S. Noura, M. Ohue, Y. Seki, et al., Feasibility of a lateral region sentinel node biopsy of lower rectal cancer guided by indocyanine green using a near-infrared camera system, Ann. Surg. Oncol. 17 (2010) 144–151.
[30] I. Miyashiro, M. Hiratsuka, K. Kishi, et al., Intraoperative diagnosis using sentinel node biopsy with indocyanine green dye in gastric cancer surgery: an institutional trial by experienced surgeons, Ann. Surg. Oncol. 20 (2013) 542–546.
[31] O.T. Okusanya, B. Madajewski, E. Segal, et al., Small portable interchangeable imager of fluorescence for fluorescence guided surgery and research, Technol. Cancer Res. Treat. 14 (2) (2015) 213–220.
[32] K.J. Buretta, G.A. Brat, J.M. Christensen, et al., Near-infrared lymphography as a minimally invasive modality for imaging lymphatic reconstitution in a rat orthotopic hind limb transplantation model, Transpl. Int. 26 (2013) 928–937.
[33] T. Ishizawa, K. Masuda, Y. Urano, et al., Mechanistic background and clinical applications of indocyanine green fluorescence imaging of hepatocellular carcinoma, Ann. Surg. Oncol. 21 (2) (2014) 440–448.
[34] T. Ishizawa, N. Fukushima, J. Shibahara, K. Masuda, S. Tamura, T. Aoki, et al., Real-time identification of liver cancers by using indocyanine green fluorescent imaging, Cancer 115 (2009) 2491–2504.
[35] Y.M. Zhang, R. Shi, J.C. Hou, et al., Liver tumor boundaries identified intraoperatively using real-time indocyanine green fluorescence imaging, J. Cancer Res. Clin. Oncol. 143 (1) (2017) 51–58.
[36] K. Gotoh, T. Yamada, O. Ishikawa, et al., A novel image-guided surgery of hepatocellular carcinoma by indocyanine green fluorescence imaging navigation, J. Surg. Oncol. 100 (1) (2009) 75–79.
[37] Y. Inoue, J. Arita, T. Sakamoto, et al., Anatomical liver resections guided by 3-Dimensional parenchymal staining using fusion indocyanine green fluorescence imaging, Ann. Surg. 262 (1) (2015) 105–111.
[38] P. He, T. Huang, C. Fang, et al., Identification of extrahepatic metastasis of hepatocellular carcinoma using indocyanine green fluorescence imaging, Photodiagn. Photodyn. Ther. 25 (2019) 417–420.
[39] T. Ishizawa, A. Saiura, N. Kokudo, et al., Clinical application of indocyanine green-fluorescence imaging during hepatectomy, Hepatobiliary Surg. Nutr. 5 (4) (2016) 322–328.