



**Universiteit
Leiden**
The Netherlands

Nationwide oncological networks for resection of colorectal liver metastases in the Netherlands: differences and postoperative outcomes

Elfrink, A.K.E.; Kok, N.F.M.; Swijnenburg, R.J.; Dulk, M. den; Boezem, P.B. van den; Hartgrink, H.H.; ... ; Dutch Hepato Biliary Audit Grp

Citation

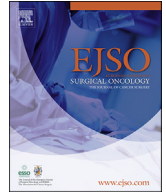
Elfrink, A. K. E., Kok, N. F. M., Swijnenburg, R. J., Dulk, M. den, Boezem, P. B. van den, Hartgrink, H. H., ... Klaase, J. M. (2022). Nationwide oncological networks for resection of colorectal liver metastases in the Netherlands: differences and postoperative outcomes. *European Journal Of Surgical Oncology*, 48(2), 435-448. doi:10.1016/j.ejso.2021.09.004

Version: Publisher's Version

License: [Creative Commons CC BY 4.0 license](https://creativecommons.org/licenses/by/4.0/)

Downloaded from: <https://hdl.handle.net/1887/3564001>

Note: To cite this publication please use the final published version (if applicable).



Nationwide oncological networks for resection of colorectal liver metastases in the Netherlands: Differences and postoperative outcomes



Arthur K.E. Elfrink, MD ^{a, b, *}, Niels F.M. Kok, MD PhD ^m,
 Rutger-Jan Swijnenburg, MD PhD ^c, Marcel den Dulk, MD PhD ^d,
 Peter B. van den Boezem, MD PhD ^e, Henk H. Hartgrink, MD PhD ^f,
 Wouter W. te Riele, MD PhD ^{g, w}, Gijs A. Patijn, MD PhD ^h, Wouter K.G. Leclercq, MD PhD ⁱ,
 Daan J. Lips, MD PhD ^j, Ninos Ayez, MD PhD ^k, Cornelis Verhoef, MD PhD ^l,
 Koert F.D. Kuhlmann, MD PhD ^m, Carlijn I. Buis, MD PhD ^b, Koop Bosscha, MD PhD ⁿ,
 Eric J.T. Belt, MD PhD ^o, Maarten Vermaas, MD PhD ^p, N.Tjarda van Heek, MD PhD ^q,
 Steven J. Oosterling, MD PhD ^r, Hans Torrengea, MD PhD ^s, Hasan H. Eker, MD PhD ^t,
 Esther C.J. Consten, MD PhD ^u, Hendrik A. Marsman, MD PhD ^v, Geert Kazemier, MD PhD ^x,
 Michel W.J.M. Wouters, MD PhD ^{a, y}, Dirk J. Grünhagen, MD PhD ^{m, 2},
 Joost M. Klaase, MD PhD ^{b, 2}, Dutch Hepato Biliary Audit Group¹

^a Dutch Institute for Clinical Auditing, Scientific Bureau, Leiden, the Netherlands

^b Department of Surgery, University Medical Center Groningen, Groningen, the Netherlands

^c Department of Surgery, Cancer Center Amsterdam, Amsterdam UMC, University of Amsterdam, Amsterdam, the Netherlands

^d Department of Surgery, Maastricht University Medical Center, Maastricht, the Netherlands

^e Department of Surgery, Leiden University Medical Center, Leiden, the Netherlands

^f Department of Surgery, Radboud Medical Center, Nijmegen, the Netherlands

^g Department of Surgery, University Medical Center Utrecht, Utrecht, the Netherlands

^h Department of Surgery, Isala, Zwolle, the Netherlands

ⁱ Department of Surgery, Máxima Medical Center, Veldhoven, the Netherlands

^j Department of Surgery, Medisch Spectrum Twente, Enschede, the Netherlands

^k Department of Surgery, Amphia Medical Center, Breda, the Netherlands

^l Department of Surgical Oncology, Erasmus MC Cancer Institute, Rotterdam, the Netherlands

^m Department of Surgery, Antoni van Leeuwenhoek – Dutch Cancer Institute, Amsterdam, the Netherlands

ⁿ Department of Surgery, Jeroen Bosch Ziekenhuis, 's Hertogenbosch, the Netherlands

^o Department of Surgery, Albert Schweitzer Hospital, Dordrecht, the Netherlands

^p Department of Surgery, IJsselland Hospital, Capelle a/d IJssel, the Netherlands

^q Department of Surgery, Gelderse Vallei, Ede, the Netherlands

^r Department of Surgery, Spaarne Gasthuis, Hoofddorp, the Netherlands

^s Department of Surgery, Deventer Hospital, Deventer, the Netherlands

^t Department of Surgery, Medical Centre Leeuwarden, Leeuwarden, the Netherlands

^u Department of Surgery, Meander Medical Centre, Amersfoort, the Netherlands

^v Department of Surgery, OLVG, Amsterdam, the Netherlands

^w Department of Surgery, St. Antonius Hospital, Nieuwegein, the Netherlands

^x Department of Surgery, Cancer Center Amsterdam, Amsterdam UMC, Vrije Universiteit, Amsterdam, the Netherlands

^y Department of Biomedical Data Sciences, Leiden University Medical Centre, Leiden, the Netherlands

ARTICLE INFO

Article history:

Received 9 April 2021

Received in revised form

29 August 2021

ABSTRACT

Introduction: Widespread differences in patient demographics and disease burden between hospitals for resection of colorectal liver metastases (CRLM) have been described. In the Netherlands, networks consisting of at least one tertiary referral centre and several regional hospitals have been established to

* Corresponding author. Scientific Bureau, Dutch Institute of Clinical Auditing, 2333 AA, Leiden, the Netherlands.

E-mail address: elfrinkake@gmail.com (A.K.E. Elfrink).

¹ Members of the Dutch Hepato Biliary Audit Group are co-authors of this study and should be listed as collaborators on Pubmed.

² Shared senior author contributions.

Accepted 2 September 2021
Available online 9 September 2021

Keywords:
Oncological networks
Variation
Colorectal liver metastases
Outcomes

optimize treatment and outcomes. The aim of this study was to assess variation in case-mix, and outcomes between these networks.

Methods: This was a population-based study including all patients who underwent CRLM resection in the Netherlands between 2014 and 2019. Variation in case-mix and outcomes between seven networks covering the whole country was evaluated. Differences in case-mix, expected 30-day major morbidity (Clavien-Dindo $\geq 3a$) and 30-day mortality between networks were assessed.

Results: In total 5383 patients were included. Thirty-day major morbidity was 5.7% and 30-day mortality was 1.5%. Significant differences between networks were observed for Charlson Comorbidity Index, ASA 3+, previous liver resection, liver disease, preoperative MRI, preoperative chemotherapy, ≥ 3 CRLM, diameter of largest CRLM ≥ 55 mm, major resection, combined resection and ablation, rectal primary tumour, bilobar and extrahepatic disease. Uncorrected 30-day major morbidity ranged between 3.3% and 13.1% for hospitals, 30-day mortality ranged between 0.0% and 4.5%. Uncorrected 30-day major morbidity ranged between 4.4% and 6.0% for networks, 30-day mortality ranged between 0.0% and 2.5%. No negative outliers were observed after case-mix correction.

Conclusion: Variation in case-mix and outcomes are considerably smaller on a network level as compared to a hospital level. Therefore, auditing is more meaningful at a network level and collaboration of hospitals within networks should be pursued.

© 2021 Published by Elsevier Ltd.

1. Introduction

Resection of colorectal liver metastases (CRLM) is performed in 20–50% of all patients with CRLM and is the cornerstone of curative treatment [1,2]. Postoperative morbidity and mortality rates are still considerable in the Netherlands [3].

In the Netherlands, centralization of surgery was nationwide initiated and led by tumour specific committees on the basis of the standardisation report of the Dutch Federation of Oncologic Societies (SONCOS) [5]. During this process, liver surgery was centralized in 28 of 69 Dutch hospitals and seven oncological networks were formed for all oncological conditions [4,5]. The intention of these oncological networks was to optimize referral patterns between hospitals and to decrease hospital variation in preoperative and operative care [6]. As a result, quality of care for patients should be comparable in each oncological network.

Oncological networks for liver surgery consist of at least one tertiary referral centre performing liver surgery, several regional hospitals performing liver surgery and several regional hospitals not performing liver surgery [7]. Within oncological networks, tumour-specific multidisciplinary (MDT) meetings are attended by hepatobiliary physicians and surgeons according to the Dutch Guideline and the standardisation report of SONCOS with balanced patient-centered treatment plans developed by these teams [5,8]. Several oncological networks have specific agreements on preoperative workup, multidisciplinary team meetings, and criteria for referral of patients to more specialized care centres within the network. These oncological networks have synchronized guidelines and protocols between all hospitals in the oncological network. Other oncological networks have agreements on which hospitals perform which type of (tertiary) liver surgery, while preoperative workup and treatment can be hospital-specific [6,9].

The main objective of these oncological networks is to decrease variation in preoperative workup and treatment for CRLM which has been described in the Netherlands on a hospital level [7,10,11]. This variation is attributed to differences in patient demographics and disease burden (i.e. case-mix) of a hospital and translates to variation in treatment patterns and postoperative outcomes [12]. Due to oncological network formation, variation in case-mix on a hospital level has increased. Assessing quality of care on a hospital level could therefore pose problems. However, variation in case-mix might be comparable among oncological networks as each network serves the population of a region and has at least one tertiary care centre in the network to which complex cases are

referred. Comparable workup and treatment in every oncological network might positively effect outcomes as patients receive standardised best-practice treatment independent of oncological network where treatment takes place. For these reasons, assessing quality of care on an oncological network level as well as auditing could be preferred.

The aim of this study was to assess variation in patient demographics and disease burden between oncological networks performing liver surgery and to compare differences in 30-day major morbidity and 30-day mortality between oncological networks.

2. Methods

This was a nationwide, population-based retrospective study performed in the Netherlands. The Netherlands is a country with approximately 17 million inhabitants. Health care is arranged in 69 hospitals including 8 university hospitals and 1 comprehensive cancer centre. Structural requirements for performing oncological care are established by SONCOS, endorsed by the Dutch Government and insurance companies [5]. These structural requirements for liver surgery include 24/7 availability of a skilled interventional radiologist, at least two skilled hepatobiliary surgeons, minimal procedural hospital volume requirements for liver resection (at least 20 liver resections per centre have to be performed annually for any indication) and participation in the Dutch Hepato Biliary Audit (DHBA); the mandatory audit in which all hospitals in the Netherlands performing liver surgery register all liver resections [13].

The 7 oncological networks in the Netherlands are based on topographical location and on agreements between hospitals (Fig. 1). All Dutch hospitals are included in an oncological network. Within oncological networks, agreements exist regarding hospitals with a tertiary referral status and the type of care that is delivered in the other hospitals. Variation exists between oncological networks regarding collaboration agreements. In several oncological networks, agreements concerning guidelines and referral criteria between hospitals have been established while in others every hospital performs care for hepatobiliary patients according to their own protocols. These collaboration agreements regarding preoperative workup and treatment of CRLM between oncological networks were assessed using a questionnaire.

Data for this study were collected from the DHBA. Data verification of the audit provided insight in completeness of 97% and



Fig. 1. Overview of the Dutch Oncological Networks. Only hospitals performing liver surgery are shown. Hospitals not performing liver surgery refer patients to regional hospitals. Tertiary referral centres perform more specialized and difficult types of care and often treat patients referred from regional hospitals.

accuracy of 96% in the DHBA when compared to the Dutch Cancer Registry [14]. No ethical approval was needed under Dutch law for this study.

2.1. Patient selection

All patients who underwent liver resection for CRLM between the 1st of January 2014 and 31st of December 2019 in the Netherlands and who were registered in the DHBA before 22nd of March 2020 were included in the study. Patients were excluded if information on date of surgery, type of tumour, or data regarding 30-day morbidity or 30-day mortality was missing. All patients who underwent thermal ablation without resection for CRLM were excluded.

2.2. Main outcomes

Main outcomes were variation in patient demographics, disease burden, 30-day major morbidity and 30-day mortality after liver resection. Major morbidity was defined as a complication Grade 3a

or higher according to Clavien-Dindo classification, within 30 days after liver resection [15]. Mortality was defined as death during hospitalization or within 30 days after liver resection.

2.3. Variables

The case-mix of an oncological network can be explained by several factors: patient demographics, disease burden and treatment characteristics. Patient demographics included sex, age, American Society of Anesthesiologist (ASA) classification, Body Mass Index (BMI), comorbidity scores classified in the Charlson Comorbidity Index (CCI), histopathological classification of liver parenchyma adjacent to tumour tissue and previous liver surgery. Disease burden included number of CRLM, diameter of the largest CRLM before the initiation of tumour-specific treatment and synchronous (within 6 months of detection of the primary tumour) or metachronous diagnosis of the CRLM. Differences in treatment characteristics were assessed. These variables included use of preoperative MRI, use of preoperative chemotherapy, minor or major liver resection, combined liver resection and thermal

Table 1
Baseline characteristics of patients diagnosed with colorectal liver metastases (CRLM) between 2014 and 2019 in the Netherlands stratified for oncological network.

Factor	Network A	Network B	Network C	Network D	Network E	Network F	Network G	p-value
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	
Total	1098	1189	1135	732	585	226	418	
Patient characteristics								
Sex								0.390
Male	710 (65)	738 (62)	727 (65)	477 (65)	354 (61)	144 (64)	255 (61)	
Female	387 (35)	449 (38)	401 (35)	252 (35)	231 (39)	82 (36)	161 (39)	
Missing ^a	1	2	7	3	0	0	2	
Age in years								0.050
<50	63 (6)	99 (8)	89 (8)	53 (7)	41 (7)	11 (5)	30 (7)	
50–64	374 (34)	426 (36)	380 (33)	261 (36)	192 (33)	79 (35)	159 (38)	
65–79	592 (54)	567 (48)	573 (51)	365 (50)	306 (52)	128 (57)	191 (46)	
≥80	66 (6)	95 (8)	92 (8)	53 (7)	45 (8)	8 (4)	36 (9)	
Missing ^a	3	2	1	0	1	0	2	
Charlson Comorbidity Index (CCI)								<0.001
0/1	836 (76)	926 (78)	871 (77)	546 (75)	428 (73)	170 (75)	239 (57)	
≥2	262 (24)	263 (22)	264 (23)	186 (25)	157 (27)	56 (25)	179 (43)	
Body Mass Index (BMI)								<0.001
Mean (sd)	26.7 (4.5)	25.9 (4.4)	26.3 (4.5)	26.3 (4.5)	26.1 (4.2)	26.4 (4.4)	26.4 (4.1)	<0.001
American Society of Anesthesiology (ASA) classification								<0.001
ASA I/II	882 (80)	924 (81)	790 (74)	565 (77)	459 (78)	186 (86)	346 (84)	
ASA III+	216 (20)	216 (19)	284 (26)	167 (23)	126 (22)	30 (14)	68 (16)	
Missing ^a	0	49	61	0	0	10	4	
History of liver resection								<0.001
No	873 (80)	956 (84)	913 (82)	544 (75)	467 (81)	192 (87)	354 (86)	
Yes	213 (20)	182 (16)	205 (18)	180 (25)	108 (19)	30 (14)	57 (14)	
Missing ^a	12	51	17	8	10	4	7	
Histopathology liver parenchyma^b								<0.001
Normal liver	727 (66)	872 (73)	747 (66)	329 (45)	354 (61)	120 (53)	318 (76)	
Steatosis	170 (16)	162 (14)	189 (17)	160 (22)	69 (12)	38 (17)	68 (16)	
Steato-hepatitis	20 (2)	19 (2)	4 (0)	28 (4)	6 (1)	7 (3)	2 (1)	
Cirrhosis	5 (1)	10 (1)	5 (0)	6 (1)	2 (1)	2 (1)	10 (2)	
Sinusoidal dilatation	8 (1)	30 (3)	7 (1)	8 (1)	4 (1)	0 (0)	0 (0)	
Missing ^a	168	96	183	201	149	59	20	
Preoperative MRI								<0.001
No	324 (30)	343 (31)	498 (44)	155 (26)	211 (37)	41 (20)	198 (49)	
Yes	759 (70)	757 (69)	623 (56)	437 (74)	361 (63)	168 (80)	208 (51)	
Missing ^a	15	89	14	140	13	17	12	
Preoperative chemotherapy								<0.001
No	740 (71)	765 (71)	712 (66)	388 (57)	423 (77)	154 (77)	298 (75)	
Yes	308 (29)	316 (29)	373 (34)	290 (43)	124 (23)	124 (23)	101 (25)	
Tumour characteristics								
Number of lesions								<0.001
1	496 (46)	462 (41)	471 (42)	285 (42)	305 (53)	115 (53)	168 (44)	
2	242 (22)	266 (24)	238 (22)	126 (19)	126 (19)	47 (22)	87 (23)	
3	107 (10)	123 (11)	137 (12)	73 (11)	73 (11)	24 (11)	50 (13)	
4	70 (7)	90 (8)	72 (7)	62 (9)	62 (9)	12 (6)	21 (6)	
≥5	167 (15)	179 (16)	189 (17)	135 (20)	135 (20)	19 (9)	54 (14)	
Missing ^a	16	69	28	51	7	9	38	
Maximum diameter of largest CRLM (mm³)								0.050
<20	339 (33)	313 (30)	310 (31)	138 (26)	172 (36)	74 (36)	99 (30)	
20–34	408 (39)	372 (36)	357 (36)	209 (39)	175 (36)	71 (35)	135 (40)	
35–54	191 (18)	215 (21)	199 (20)	118 (22)	83 (17)	36 (18)	57 (17)	
≥55	100 (10)	131 (13)	123 (12)	75 (14)	52 (11)	24 (12)	44 (13)	
Missing ^a	60	158	146	192	103	21	83	
Combined resection and ablation								<0.001
No	909 (83)	887 (75)	811 (72)	647 (88)	516 (88)	185 (82)	318 (76)	
Yes	189 (17)	302 (25)	324 (29)	85 (12)	69 (12)	41 (18)	100 (24)	
Major liver resection								<0.001
No	831 (76)	951 (80)	926 (82)	593 (81)	418 (72)	191 (85)	294 (70)	
Yes	267 (24)	238 (20)	209 (18)	139 (19)	157 (29)	35 (15)	124 (30)	
Location primary tumour								<0.001
Colon	700 (64)	779 (66)	724 (64)	434 (59)	415 (71)	145 (66)	273 (65)	
Rectal	397 (36)	308 (34)	407 (36)	298 (41)	169 (29)	74 (34)	145 (35)	
Missing ^a	1	2	4	0	1	7	0	
Bilobar disease								<0.001
No	651 (59)	610 (51)	636 (57)	315 (52)	358 (62)	143 (64)	250 (60)	
Yes	447 (41)	578 (49)	473 (43)	295 (48)	219 (38)	81 (36)	166 (40)	
Missing ^a	0	1	26	122	8	2	2	
Timing of metastases								0.090
Metachronous	423 (47)	466 (49)	491 (52)	240 (50)	237 (49)	111 (59)	177 (39)	
Synchronous	480 (53)	487 (51)	461 (48)	244 (50)	244 (51)	78 (41)	188 (52)	

Table 1 (continued)

Factor		Network A	Network B	Network C	Network D	Network E	Network F	Network G	p-value
		N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	
Total		1098	1189	1135	732	585	226	418	
Extrahepatic disease	Missing ^a	195	236	183	248	104	37	53	<0.001
	No	964 (89)	951 (84)	996 (89)	530 (87)	440 (83)	197 (92)	345 (87)	
	Yes	115 (11)	177 (16)	122 (11)	82 (13)	92 (17)	18 (18)	52 (13)	
Surgical approach	Missing ^a	19	61	17	120	53	11	21	<0.001
	Open	830 (76)	917 (78)	765 (68)	542 (75)	384 (66)	179 (80)	309 (75)	
	Laparoscopy	268 (24)	263 (22)	365 (32)	183 (25)	201 (34)	45 (20)	106 (25)	
Type of hospital^c	Missing ^a	0	9	5	7	0	2	3	<0.001
	Regional hospitals	836 (76)	353 (30)	759 (67)	313 (43)	449 (77)	58 (26)	184 (44)	
	Tertiary referral centres	262 (24)	836 (70)	376 (33)	419 (57)	136 (23)	168 (74)	234 (56)	
Year of surgery	2014	147 (13)	188 (16)	218 (19)	120 (16)	78 (13)	29 (13)	79 (19)	<0.001
	2015	216 (20)	201 (17)	130 (12)	115 (16)	100 (17)	46 (20)	86 (21)	
	2016	213 (19)	244 (21)	194 (17)	159 (22)	100 (17)	43 (19)	23 (6)	
	2017	172 (16)	207 (17)	218 (19)	114 (16)	108 (19)	56 (25)	103 (25)	
	2018	176 (16)	206 (17)	187 (17)	127 (17)	100 (17)	33 (15)	72 (17)	
	2019	174 (16)	143 (12)	188 (17)	97 (13)	99 (17)	19 (8)	55 (13)	

Bold font represents significant p-value.

Mm = millimeter.

\$Unclear why percentage missing is so high.

^a Missing not included in analyses based on relatively small group.

^b History of liver disease containing liver cirrhosis, esophageal variceal disease, hepatorenal syndrome, liver failure, alcoholic liver disease, toxic liver disease (mild), (chronic) hepatitis or liver fibrosis.

^c Type of hospital: tertiary referral centre are defined as hospitals with highest expertise on oncological surgery.

ablation, type of hospital where treatment took place which was either a tertiary referral centre (i.e. academic centre or comprehensive cancer centre) or regional hospital and annual oncological network volume. Major liver resection was defined as resection of three or more adjacent Couinaud segments [16].

2.4. Statistical analysis

Mean percentage and upper and lower limits of separate factors in all oncological networks was calculated to assess variation between oncological networks. The significance of these differences in factors between oncological networks was assessed using univariable logistic regression models. Differences between oncological networks were assessed also grouped by oncological network size as differences might be attributable to the size of oncological networks. Oncological networks were categorized in low procedural volume (<500 resections), middle procedural volume (500–1000 resections) and high procedural volume (>1000 resections).

Association of case-mix factors with outcomes was assessed using multivariable logistic regression. Case-mix factors were included in multivariable analysis based on the p-value observed in univariable logistic regression (p < 0.10). Restriction of the multivariable logistic regression model was needed due to the number of degrees of freedom in the model for mortality due to low number of events.

To visualize differences in 30-day major morbidity and 30-day mortality, uncorrected funnel plots were created. These funnel plots show the number of patients treated in an oncological network compared to the mean number of events in the same oncological network. This is plotted and compared to the mean number of events of all included patients. If an oncological network is above the mean outcome of all included patients, the oncological

network performs worse compared to other oncological networks. If an oncological network is under the mean outcome, it performs better than average. Also, 95% confidence intervals are created on the basis of the mean outcomes and total included patients indicating statistical significance of outliers.

In case-mix corrected funnel plots, the observed/expected ratio (O/E ratio) was used to assess differences between oncological networks. Using multivariable logistic regression, expected 30-day morbidity and 30-day mortality was calculated per patient. All patients in an oncological network together compose the expected morbidity and mortality per oncological network. By dividing the observed morbidity of every oncological network by the expected morbidity of that oncological network, the O/E ratio was calculated. An O/E ratio above 1 indicated that an oncological network performed worse than expected, an O/E ratio below 1 indicated that an oncological network performed better than expected. The 95% confidence intervals (CI) were calculated to indicate whether the O/E ratio of an oncological network was statistically different compared to the average O/E ratio of all oncological networks together. All plots were compared between on a hospital level and an oncological network level.

Multicollinearity in multivariable models was tested using the Variance Inflation Factor (VIF). A VIF of 3 was the cut-off value indicating multicollinearity and if so, one variable was excluded of the analysis. Patients with missing values were analysed as a separate group in multivariable logistic regression if these exceeded 5% of the total included number of patients. If the missing values in a variable was below 5%, the missing patients were excluded from the analysis.

All analyses were performed in R version 3.2.2® (R Core Team (2018): A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria).

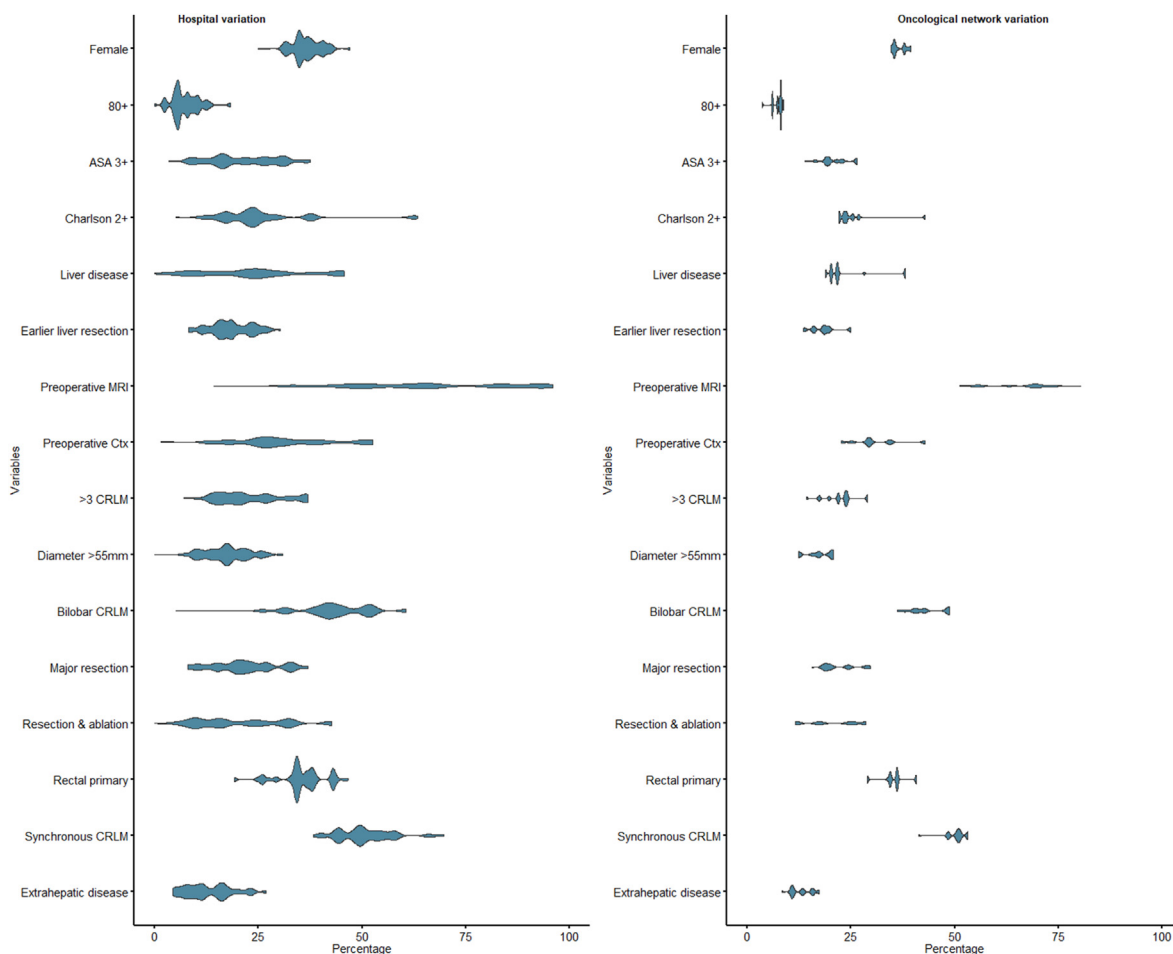


Fig. 2. a&b. Violin graph showing the distribution of mean percentages (range) of case-mix variables per hospital and per oncological network in the Netherlands in patients who underwent liver resection for colorectal liver metastases between 2014 and 2019.

3. Results

In total 5383 patients who underwent liver resection for CRLM in the Netherlands were included from 28 hospitals together assembling 7 oncological networks. Oncological networks were different in size with the largest oncological network treating 1189 patients and the smallest treating 226 patients during the study period (Table 1). Overall 30-day major morbidity was 5.7% and 30-day mortality was 1.5%. Different collaboration agreements regarding preoperative workup and treatment of CRLM were observed between oncological networks (Supplementary Table 1).

3.1. Between-hospital and oncological network variation

Differences in patient characteristics between hospitals were observed for age (80 years or older, 0.0%–18.2%, $p < 0.001$), CCI (2 or higher, 5.0%–63.3%, $p < 0.001$), ASA classification (3 or higher, 3.3%–37.4%, $p < 0.001$), history of liver resection (8.1%–30.3%, $p < 0.001$), liver disease (0.0%–45.6%, $p < 0.001$), use of preoperative MRI (14.3%–96.0%, $p < 0.001$) and use of preoperative chemotherapy (1.5%–52.6%, $p < 0.001$). Variation in tumour characteristics between hospitals included: number of metastases (3 or more CRLM, 7.0–37.0, $p < 0.001$), maximum diameter of largest CRLM prior to treatment of 55 mm (0.0–30.8, $p < 0.001$), use of combined resection and ablation (0.0%–42.7%, $p < 0.001$), major liver resection performed (7.0%–37.0%, $p < 0.001$), rectal primary

tumour (19.1%–46.6%, $p < 0.001$), bilobar disease (5.0%–60.6%, $p < 0.001$), and extrahepatic disease (4.4%–26.9%, $p < 0.001$) (Fig. 2a & Supplementary Table 2a).

Differences in patient and tumour characteristics between oncological networks were smaller as compared to hospital variation in case-mix factors. Differences regarding patient characteristics were observed with regard to CCI (2 or higher, 22.1%–42.3%, $p < 0.001$), ASA classification (3 or higher, 13.9%–26.4%, $p < 0.001$), history of liver resection (13.5%–24.9%, $p < 0.001$), liver disease (18.8%–38.0%, $p < 0.001$), use of preoperative MRI (51.2%–80.4%, $p < 0.001$) and use of preoperative chemotherapy (22.7%–42.8%, $p < 0.001$). Variation in tumour characteristics observed between oncological networks included: number of metastases (3 or more CRLM, 14.3%–28.9%, $p < 0.001$), maximum diameter of largest CRLM prior to treatment of 55 mm (12.4%–20.6%, $p < 0.001$), use of combined resection and ablation (11.8%–28.5%, $p < 0.001$), major liver resection performed (15.5%–29.7%, $p < 0.001$), rectal primary tumour (28.9%–40.7%, $p = 0.002$), bilobar disease (36.2%–48.7%, $p < 0.001$), and extrahepatic disease (8.4%–17.3%, $p < 0.001$) (Fig. 2b, Supplementary Table 2b). Other case-mix factors were not different between oncological networks.

3.2. Factors associated with 30-day major morbidity and 30-day mortality

Factors associated with 30-day major morbidity included sex

Table 2a

Univariable and multivariable logistic regression model to assess the association of patient and tumour characteristics with 30-day major morbidity in patients with colorectal liver metastasis (CRLM) in the Netherlands between 2014 and 2019.

Factor	N	Univariable analysis			Multivariable analysis		
		OR	CI (95%)	P-value	aOR	CI (95%)	P-value
Sex							
Male	3405	1			1		
Female	1963	0.64	0.49–0.82		0.64	0.48–0.86	
Missing*	15						
				<0.001			0.003
Age in years							
<50	386	1			1		
50–64	1871	1.88	1.05–3.76	0.050	1.60	0.88–3.22	0.154
65–79	2722	2.26	1.27–4.45	0.010	1.79	0.99–3.59	0.072
≥80	395	2.70	1.37–5.72	0.006	2.31	1.12–5.07	0.028
Missing*	9						
				0.079			0.519
Charlson Comorbidity Index (CCI)							
0/1	4016	1			1		
≥2	1367	1.25	0.97–1.61		1.09	0.82–1.45	
				0.715	1.01	0.98–1.01	0.623
Body Mass Index American Society of Anesthesiology (ASA) classification				<0.001			0.015
I/II	4152	1			1		
III +	1107	1.57	1.20–2.03		1.44	1.07–1.91	
Missing*	124						
				0.116			0.368
Histopathology liver parenchyma§							
Normal liver	3467	1			1		
Steatosis	856	1.36	1.01–1.82	0.042	1.33	0.96–1.91	0.081
Steato-hepatitis	86	1.55	0.64–3.17	0.278	1.70	0.70–3.56	0.196
Cirrhosis	41	1.38	0.33–3.85	0.597	0.50	0.03–2.39	0.499
Sinusoidal dilatation	57	2.05	0.78–4.48	0.101	1.49	0.50–3.60	0.416
Missing	876	0.86	0.60–1.20	0.380	0.98	0.65–3.56	0.924
				0.469			0.422
History of liver resection							
No	4299	1			1		
Yes	975	1.11	0.83–1.48		1.36	0.63–2.78	
Missing*	109						
				0.855			0.763
History of preoperative chemotherapy							
No	3480	1			1		
Yes	1563	1.04	0.80–1.34	0.756	1.01	0.82–1.41	0.652
Missing	340	1.11	0.68–1.72	0.663	1.03	0.71–1.74	0.813
				0.697			0.368
Number of lesions							
1	2302	1			1		
2	1113	0.89	0.64–1.21	0.458	1.09	0.78–1.53	0.625
3	580	1.17	0.80–1.69	0.406	1.16	0.78–1.71	0.456
4	372	0.85	0.50–1.37	0.527	1.35	0.87–2.06	0.172
≥5	798	1.05	0.73–1.46	0.799	1.31	0.82–2.03	0.243
Missing*	218						
				0.007			0.638
Maximum diameter largest CRLM (mm)*							
<20	1445	1			1		
20–34	1727	1.12	0.81–1.56	0.491	0.77	0.54–1.11	0.166
35–54	899	1.41	0.98–2.04	0.062	1.12	0.70–1.51	0.713
≥55	549	2.00	1.36–2.94	<0.001	1.54	0.84–1.97	0.099
Missing	763	1.40	0.95–2.05	0.083	0.75	0.48–1.15	0.190
				<0.001			<0.001
Major liver resection							
No	4204	1			1		
Yes	1179	2.06	1.61–2.62		1.98	1.49–2.62	
				0.982			0.802
Bilobar disease							
No	2963	1			1		
Yes	2259	1.00	0.79–1.26		1.04	0.77–1.41	
Missing*	161						
				0.005			0.024
Location primary tumour							
Colon	3470	1			1		
Rectal	1898	0.70	0.54–0.90		0.73	0.55–0.96	
Missing*	15						
				0.010			
Type of metastasis							
Metachronous	2145	1					
Synchronous	2182	1.48	1.15–1.93	0.003			
Missing	1056	1.15	0.82–1.61	0.398			
				0.122			0.267
Extrahepatic disease							
No	4423	1			1		
Yes	658	1.22	0.87–1.68	0.235	1.34	0.93–1.88	0.102
Missing	302	0.63	0.32–1.11	0.139	0.91	0.34–2.00	0.836
				0.145			0.263
Type of hospital¹							
Regional	2952	1			1		
Tertiary referral centres	2431	1.19	0.94–1.49		1.15	0.90–1.50	

Bold font represents significant p-value.

Mm = millimeter.

§ Unclear why percentage missing is so high.

(female, aOR 0.64, CI 0.48–0.86, $p = 0.003$), age (80 or higher aOR 2.31, CI 1.12–5.07, $p = 0.028$), ASA classification (3 or higher aOR 1.44, CI 1.07–1.91, $p = 0.015$), major liver resection (aOR 1.98, CI 1.49–2.62, $p < 0.001$), rectal primary tumour (aOR 0.73, CI 0.55–0.96, $p = 0.024$), and synchronous metastases (aOR 1.84, CI 1.38–2.47, $p < 0.001$) (Table 2a).

Factors associated with 30-day mortality included age of 80 or higher (aOR 9.32, CI 1.66–1.75, $p = 0.037$), ASA classification of 3 or higher (aOR 3.61, CI 2.27–5.75, $p > 0.001$), histological steatohepatitis (aOR 4.66, CI 1.32–12.7, $p = 0.006$), histological sinusoidal dilatation (aOR 4.08, CI 1.08–12.1, $p = 0.020$), history of liver resection (aOR 2.00, CI 1.19–3.26, $p = 0.007$), and major liver resection (aOR 5.80, CI 3.58–9.52, $p < 0.001$) (Table 2b).

Multicollinearity was assessed in all models and synchronous metastases was excluded from the statistical model for 30-day major morbidity due to multicollinearity with previous liver surgery.

3.3. Comparison of 30-day major morbidity and 30-day mortality on hospital and oncological network level

Uncorrected 30-day major morbidity ranged between 3.3% and 13.1% for hospitals (Fig. 3a). Uncorrected 30-day mortality ranged between 0.0% and 4.5% for hospitals (Fig. 4a). Expected 30-day morbidity between hospitals ranged between 4.8% and 6.9%. Expected 30-day mortality between hospitals ranged between 0.9% and 3.1%. After case-mix correction, variation between hospitals in both outcomes was observed with a few positive outliers (Fig. 5a & Fig. 6a).

Uncorrected 30-day major morbidity ranged between 4.4% and 6.0% for oncological networks (Fig. 3b). Uncorrected 30-day mortality ranged between 0.0% and 2.5% (Fig. 4b). Expected 30-day major morbidity ranged between 5.5% and 6.0% between oncological networks and expected 30-day mortality ranged between 1.0% and 2.2%. After case-mix correction, variation between oncological networks in both outcomes was observed but this variation was smaller as compared to comparison on a hospital level (Figs. 5b and 6b).

3.4. Variation case-mix and outcomes in high procedural oncological networks

In the three largest oncological networks differences in case-mix variables observed included ASA classification (3 or higher 19.0%–26.4%, $p < 0.001$), use of preoperative MRI (55.6%–70.1%, $p < 0.001$), use of preoperative chemotherapy (29.2%–34.4%, $p = 0.014$), size of largest CRLM (maximum diameter prior to treatment of 55 mm 12.4%–20.3%, $p < 0.001$), bilobar disease (40.7%–48.9%, $p < 0.001$), extrahepatic disease (10.7%–15.7%, $p < 0.001$), combined resection and ablation (17.2%–28.5%, $p < 0.001$) and major liver resection performed (18.4%–24.3%, $p = 0.002$).

Uncorrected 30-day morbidity ranged between 7.0% and 9.2% between these large oncological networks and uncorrected 30-day mortality ranged between 1.2% and 1.8%. Expected 30-day morbidity ranged between 5.5% and 5.8% between these large oncological networks and expected 30-day mortality ranged between 1.4% and 1.7%.

4. Discussion

This study is the first to describe nationwide oncological network formation, and to assess differences in patient demographics, disease burden and postoperative outcomes between oncological networks for CRLM surgery. Collaboration of hospitals within oncological networks has been initiated in the Netherlands to decrease variation in clinical practice and to improve outcomes. Differences in patient demographics, disease burden and treatment characteristics were observed between oncological networks and reflects current variation in workup and treatment between Dutch oncological networks. However, variability between oncological networks regarding case-mix and outcomes was considerably smaller as compared to between-hospital variation. This results from procedural volumes of oncological networks, topographical orientation of oncological networks and inclusion of at least one tertiary referral centre and several regional hospitals in every oncological network. Therefore, comparing outcomes and auditing on an oncological network level should be pursued instead of on a hospital level as a result of differences in type of care delivered in the hospitals performing liver surgery.

Oncological networks were formed during centralization of surgery in the Netherlands to create referral patterns within oncological networks resulting in decreased variation in preoperative assessment, operative treatment and outcomes [12,17,18]. Due to centralization of liver surgery, differences between hospitals have increased as more complex cases are referred to tertiary centres while regional hospitals perform less complex resections as has been shown previously [19,20]. For this reason, it is harder to compare quality of care on a hospital level as variation in treatment plans is present between hepatobiliary specialists and probability of resection depends on outcomes of MDT meetings [9,21–29]. In this study, variation in case-mix and outcomes existed on an oncological network level but was much smaller as compared to on a hospital level. This might be a result of inconsistencies that exist between oncological networks regarding criteria of resectability and differences in therapeutic strategies regarding CRLM [21,23]. However, formation of oncological networks has improved collaboration of hospitals in oncological networks and decreases variability in case-mix and outcomes between oncological networks. This is a result of specific tertiary care which is delivered in high specialty centres. For this reason, comparing quality of care should be pursued on an oncological network level as differences between oncological networks are smaller due to inclusion of at least one tertiary referral centre and several regional hospitals.

Although differences in case-mix exist between oncological networks, influence of several case-mix factors on 30-day major morbidity and 30-day mortality were comparable to an earlier study regarding use of case-mix correction to compare hospital performances using data from the DHBA [12]. However, differences in case-mix factors and expected outcomes between oncological networks as observed in the current study are smaller compared to differences between hospitals [12]. Differences in uncorrected and expected outcomes are the main reason for case-mix correction as the difference between observed and expected outcomes is a result of factors that cannot be influenced by the surgical team [12,17,18]. The authors hypothesize that due to the procedural volume in oncological networks as well as inclusion of both tertiary referral centres and regional hospitals from a specific topographical region differences in case-mix play a minor role in comparing outcomes

* Missing not included in analyses based on relatively small group.

§ History of liver disease containing liver cirrhosis, esophageal variceal disease, hepatorenal syndrome, liver failure, alcoholic liver disease, toxic liver disease (mild), (chronic) hepatitis or liver fibrosis.

¹ Type of hospital: tertiary referral centre are defined as hospitals with highest expertise on oncologic surgery.

Table 2b

Univariable and multivariable logistic regression model to assess the association of patient and tumour characteristics with 30-day mortality in patients with colorectal liver metastasis (CRLM) in the Netherlands between 2014 and 2019.

Factor	N	Univariable analysis			Multivariable analysis		
		OR	CI (95%)	P-value	aOR	CI (95%)	P-value
Sex							
Male	3405	1			1		0.120
Female	1963	0.60	0.36–0.98		0.66	0.39–1.10	
Missing*	15						
Age in years							0.014
<50	386	1			1		
50–64	1871	4.16	0.86–74.8	0.165	4.14	0.84–74.8	0.169
65–79	2722	7.35	1.61–130	0.049	6.97	1.48–125	0.057
≥80	395	8.98	1.68–165	0.038	9.32	1.66–175	0.037
Missing*	9						
Charlson Comorbidity Index (CCI)							0.713
0/1	4016	1					
≥2	1367	1.10	0.66–1.77				
Body Mass Index							1.03
American Society of Anesthesiology (ASA) classification							0.99–1.08
I/II	4152	1		0.144	1		<0.001
III +	1107	4.16	2.67–6.48	<0.001	3.61	2.27–5.75	
Missing*	1234						
Histopathology liver parenchyma§							0.013
Normal liver	3467	1			1		0.043
Steatosis	856	1.52	0.83–2.65	0.158	1.41	0.75–2.52	0.259
Steato-hepatitis	86	3.88	1.15–9.88	0.011	4.66	1.32–12.7	0.006
Cirrhosis	41	4.08	0.65–13.9	0.058	3.79	0.55–15.1	0.099
Sinusoidal dilatation	57	6.01	1.76–15.5	<0.001	4.08	1.08–12.1	0.020
Missing	876	1.11	0.56–2.04	0.759	1.16	0.56–2.21	0.676
History of liver resection							0.007
No	4299	1			1		
Yes	975	2.11	1.30–3.35		2.00	1.19–3.26	
Missing*	109						
History of preoperative chemotherapy							0.024
No	3480	1			1		0.292
Yes	1563	1.42	0.89–2.22	0.132	1.10	0.67–1.80	0.697
Missing	340	0.21	0.01–0.95	0.049	0.30	0.02–1.40	0.235
Number of CRLM							0.107
1	2302	1					
2	1113	1.20	0.62–2.24	0.584			
3	580	2.01	1.00–3.85	0.042			
4	372	0.71	0.17–2.03	0.579			
≥5	798	2.02	1.08–3.68	0.023			
Missing*	218						
Maximum diameter largest CRLM (mm)*							0.009
<20	1445	1			1		0.222
20–34	1727	2.02	0.99–4.44	0.062	1.76	0.85–3.93	0.145
35–54	899	2.93	1.37–6.63	0.007	2.05	0.93–4.75	0.078
≥55	549	3.48	1.52–8.20	0.003	1.69	0.70–4.19	0.243
Missing	763	3.07	1.41–7.05	0.006	2.56	1.12–6.06	0.027
Major liver resection							<0.001
No	4204	1			1		
Yes	1179	5.96	3.81–9.47		5.80	3.58–9.52	
Bilobar disease							0.184
No	2963	1					
Yes	2259	1.35	0.87–2.11				
Missing*	161						
Location primary tumour							0.395
Colon	3470	1					
Rectal	1898	0.81	0.50–1.30				
Missing*	15						
Type of metastasis							0.379
Metachronous	2145	1					
Synchronous	2182	0.98	0.59–1.64	0.947			
Missing	1056	1.43	0.80–2.50	0.212			
Extrahepatic disease							0.752
No	4423	1					
Yes	658	1.27	0.65–2.27	0.459			
Missing	302	1.15	0.40–2.60	0.770			
Type of hospital¹							0.321
Regional	2952	1					
Tertiary referral centres	2431	1.25	0.80–1.94				

Bold font represents significant p-value.

Mm = millimeter.

§ Unclear why percentage missing is so high.

* Missing not included in analyses based on relatively small group.

§ History of liver disease containing liver cirrhosis, esophageal variceal disease, hepatorenal syndrome, liver failure, alcoholic liver disease, toxic liver disease (mild), (chronic) hepatitis or liver fibrosis.

¹ Type of hospital: tertiary referral centre are defined as hospitals with highest expertise on oncologic surgery.

between oncological networks. Centralization and formation of oncological networks has decreased variation in practice and outcomes on an oncological network level compared to on a hospital level. However, variation is still present. Therefore, collaboration of hospitals within oncological networks and between oncological networks should be intensified to further equalize quality of care between oncological networks.

The authors' perspective for the future of these oncological networks includes a more intensive collaboration of hospitals within oncological networks using best practice guidelines for preoperative screening and interventions to optimize modifiable risk factors. Current variation regarding collaboration agreements within Dutch oncological networks is present and has been described by differences in case-mix and treatment strategies in the Dutch oncological networks. Intensifying collaboration of hospitals within oncological networks based on strict best practice nationwide guidelines will address and decrease practice variation in treatment strategies between oncological networks. As a result, all oncological networks will provide care for CRLM patients according nationwide guidelines on preoperative workup and treatment thus providing equal quality of care in every oncological network independent of the oncological network where treatment takes place. Important reasons to decrease the observed practice variation are the associated better outcomes for patients and lower costs [4,30,31]. From an auditing perspective, comparing outcomes between oncological networks instead of between hospitals can be

more valuable as the influence of confounding factors is smaller as compared to comparing quality of care on a hospital level. This is particularly true for high procedural oncological networks. In the authors opinion, striving for comparable oncological networks regarding procedural volume will make comparison of outcomes more valid as influence of case-mix is decreasing as procedural volume increase. As a result, patients will receive comparable quality of care and possibilities regarding outcomes will be equal and will not depend on the oncological network where the patient is treated. This study can be used for formation and comparison of oncological networks in several oncological surgical fields as this is the first to referral patterns of specialized oncological care on a nationwide basis.

Limitations of this study include lacking of 90-day postoperative outcomes which have shown to be a better estimate of post-operative outcomes compared to 30-day postoperative outcomes [32]. Technical complexity of the procedure and several other factors that might be thought of as case-mix factors were not retrievable as this study was performed from an auditing database. Type of hospital was included in the case-mix model as this reflects complexity of procedures of which data was not available in the DHBA [12]. Future studies on oncological networks should also include variation in oncological outcomes of CRLM patients to assess which case-mix factors influence disease-free survival, overall survival and compare oncological networks on these outcomes. To date, no long-term oncological outcomes are available in

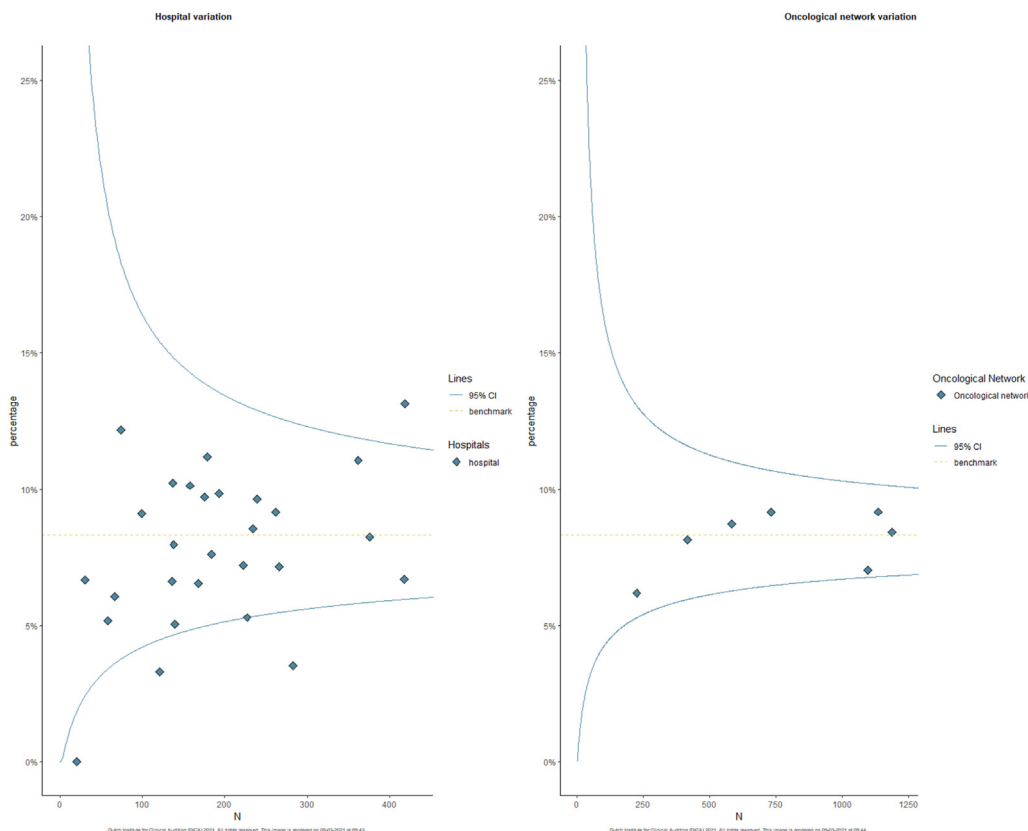


Fig. 3. a&b. Uncorrected funnel plot of between-hospital and between oncological-network variation in 30-day major morbidity in patients with colorectal liver metastases in the Netherlands between 2014 and 2019.

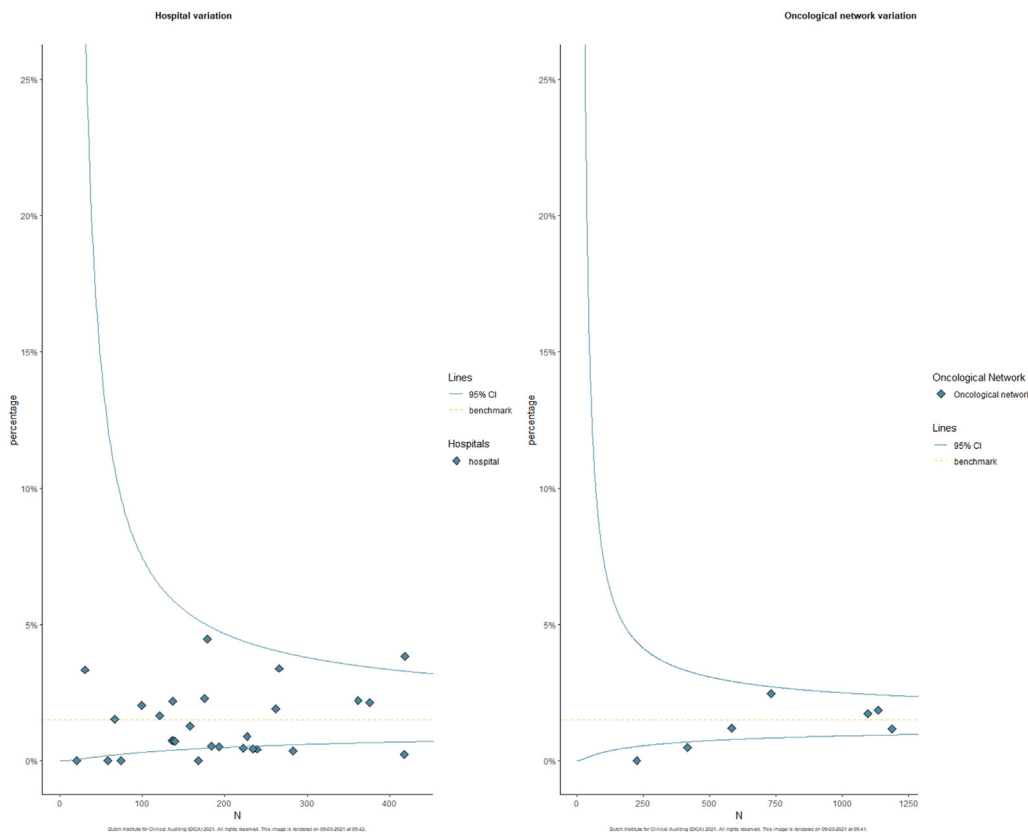


Fig. 4. a&b. Uncorrected funnel plot of between-hospital and between oncological-network variation in 30-day mortality in patients with colorectal liver metastases in the Netherlands between 2014 and 2019.

the DHBA.

In conclusion, this study shows that patient demographics, disease burden, therapeutic strategies and surgical outcomes are different between oncological networks consisting of tertiary care centres and regional hospitals from a topographical region in the Netherlands. This reflects that differences in workup and treatment of CRLM is still present between oncological networks the Netherlands. However, the observed variation is much smaller as compared to between-hospital variation. This underlines that auditing and measuring quality of care should be pursued on an oncological network level rather than on a hospital level. To further decrease variation between oncological network, nationwide agreements regarding preoperative and operative treatment of CRLM should be focused on as well as intensifying collaboration of hospitals within oncological networks. Ultimately, the objective is that treatment of patients will be independent of the oncological network where they receive treatment.

Author contribution

AE: Conceptualization, Funding acquisition, Formal analysis, Writing – original draft, Writing – review & editing, Study concepts, Study design, Data acquisition, Quality control of data and algorithms, Data analysis and interpretation, Statistical analysis, Manuscript preparation, Manuscript editing, Manuscript review. NK: Conceptualization, Funding acquisition, Formal analysis, Writing – original draft, Writing – review & editing, Study concepts, Study design, Data acquisition, Quality control of data and algorithms, Data analysis and interpretation, Statistical analysis, Manuscript preparation, Manuscript editing, Manuscript review. MW: Conceptualization, Formal analysis, Study concepts, Study

design, Quality control of data and algorithms, Data analysis and interpretation, Statistical analysis. DG: Conceptualization, Formal analysis, Study concepts, Study design, Quality control of data and algorithms, Data analysis and interpretation, Statistical analysis. JK: Conceptualization, Formal analysis, Study concepts, Study design, Quality control of data and algorithms, Data analysis and interpretation, Statistical analysis. RS: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. MD: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. PB: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. HH: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. WR: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. GP: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. WL: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. DL: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. NA: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. CV: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. KK: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. CB: Funding acquisition,

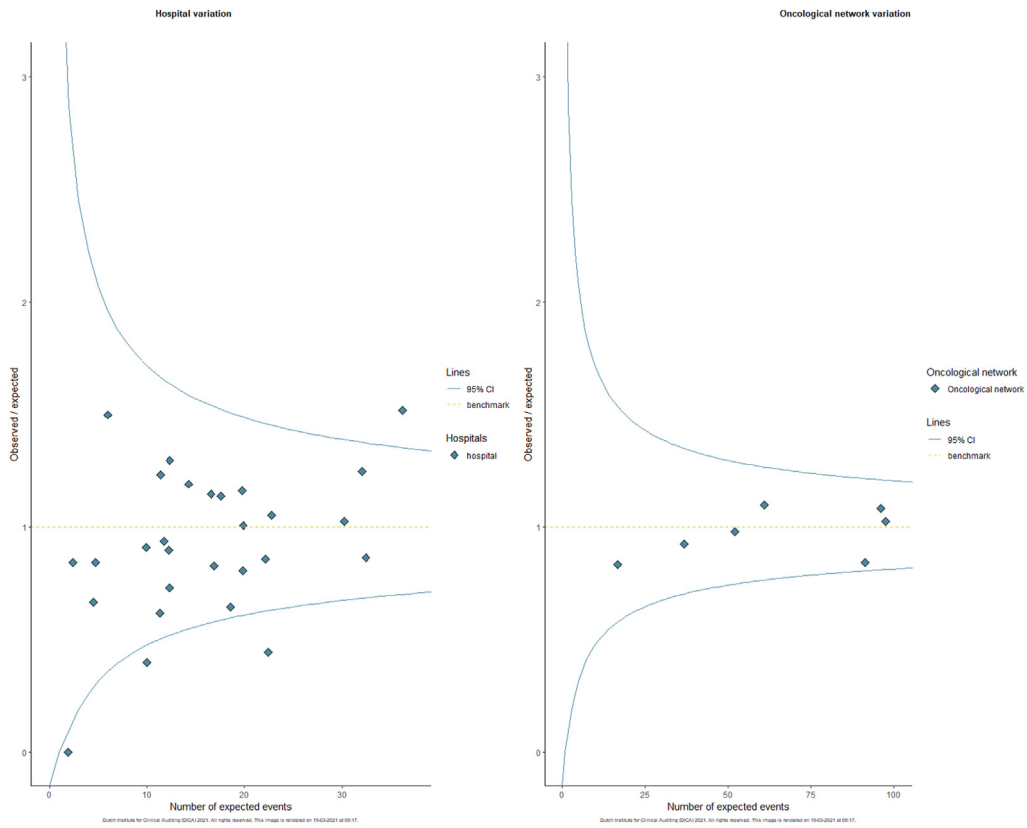


Fig. 5. a&b. Case-mix corrected funnel plot of between-hospital and between oncological-network variation in 30-day major morbidity in patients with colorectal liver metastases in the Netherlands between 2014 and 2019.

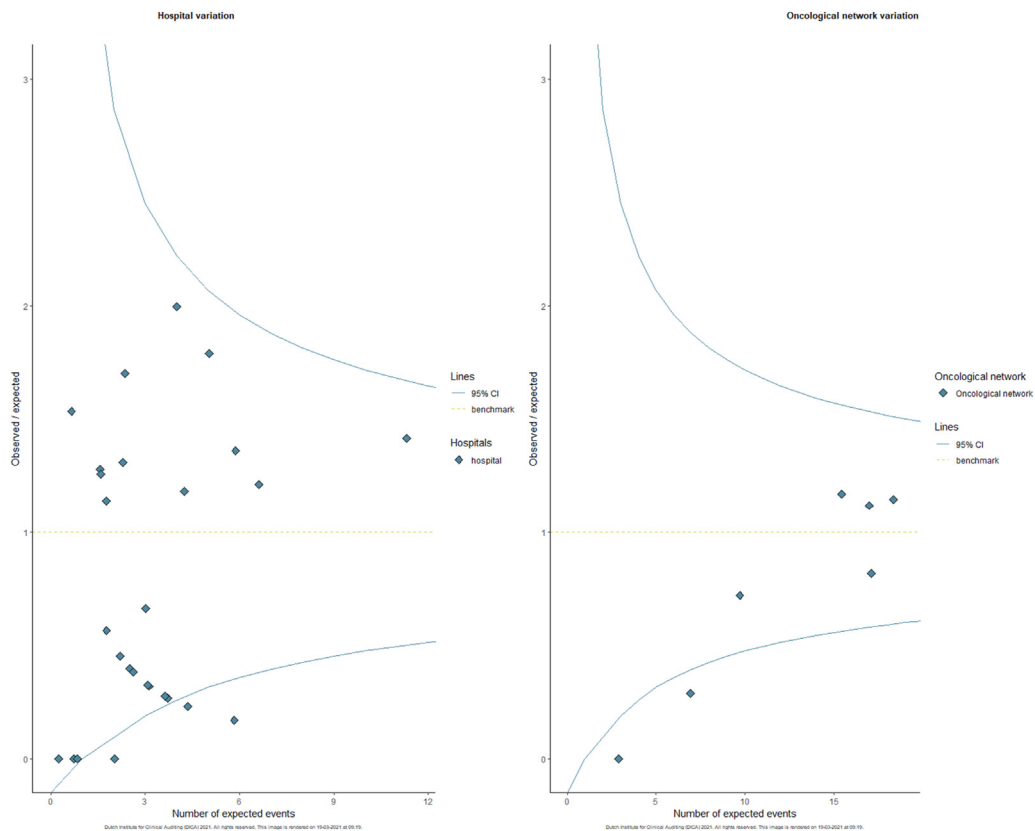


Fig. 6. a&b. Case-mix corrected funnel plot of between-hospital and between oncological-network variation in 30-day mortality in patients with colorectal liver metastases in the Netherlands between 2014 and 2019.

Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. KB: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. EB: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. MV: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. NH: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. SO: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. HT: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. HE: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. EC: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. HM: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. GK: Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. MW: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. DG: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review. JK: Funding acquisition, Writing – original draft, Writing – review & editing, Data acquisition, Manuscript preparation, Manuscript editing, Manuscript review

Funding

None.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank all surgeons, interventional radiologists and administrative nurses for data registration in the DHBA database, as well as the Dutch Hepato Biliary Audit Group for scientific input.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ejso.2021.09.004>.

References

- [1] Manfredi S, Lepage C, Hatem C, Coatmeur O, Faivre J, Bouvier AM. Epidemiology and management of liver metastases from colorectal cancer. *Ann Surg* 2006;244(2):254–9.
- [2] Hackl C, Neumann P, Gerken M, Loss M, Klinkhammer-Schalke M, Schlitt HJ. Treatment of colorectal liver metastases in Germany: a ten-year population-based analysis of 5772 cases of primary colorectal adenocarcinoma. *BMC Canc* 2014;14:810.
- [3] Olthof PB, Elfrink AKE, Marra E, Belt EJT, van den Boezem PB, Bosscha K, et al. Volume-outcome relationship of liver surgery: a nationwide analysis. *Br J Surg* 2020;107(7):917–26.
- [4] Birkmeyer JD, Reames BN, McCulloch P, Carr AJ, Campbell WB, Wennberg JE. Understanding of regional variation in the use of surgery. *Lancet* 2013;382(9898):1121–9.
- [5] SONCOS. Preserving quality of care in The Netherlands. 2017.

- [6] Lam-Boer J t, van der Stok EP, Huiskens J, Verhoeven RH, Punt CJ, Elfrink MA, et al. Regional and inter-hospital differences in the utilisation of liver surgery for patients with synchronous colorectal liver metastases in The Netherlands. *Eur J Canc* 2017;71:109–16.
- [7] Elfrink AKE, Kok NFM, van der Werf LR, Krul MF, Marra E, Wouters M, et al. Population-based study on practice variation regarding preoperative systemic chemotherapy in patients with colorectal liver metastases and impact on short-term outcomes. *Eur J Surg Oncol* 2020;46(9):1742–55.
- [8] database O-DG. Dutch guideline - colorectal carcinoma. 2014. <https://www.oncolinenl/colorectaalcarcinoom>.
- [9] Lam-Boer J t, Al Ali C, Verhoeven RH, Roumen RM, Lemmens VE, Rijken AM, et al. Large variation in the utilization of liver resections in stage IV colorectal cancer patients with metastases confined to the liver. *Eur J Surg Oncol* 2015;41(9):1217–25.
- [10] Elfrink AKE, Pool M, van der Werf LR, Marra E, Burgmans MC, Meijerink MR, et al. Preoperative imaging for colorectal liver metastases: a nationwide population-based study. *BJS Open* 2020.
- [11] Elfrink Ake SN, van den Tol MP, Kok NFM, Grunhagen DJ, Klaase JM, et al. Hospital variation in combined liver resection and thermal ablation for colorectal liver metastases and impact on short-term postoperative outcomes: a nationwide population-based study. *HPB (Oxford)* 2021 Jun;23(6):827–39. <https://doi.org/10.1016/j.hpb.2020.10.003>. Epub 2020 Nov 18. in press.
- [12] Elfrink AKE, Kok NFM, Grunhagen DJ, Klaase JM, Group DHBA. Case-mix adjustment to compare hospital performances after resection of colorectal liver metastases. *Eur J Surg Oncol* 2021 Mar;47(3 Pt B):649–59. <https://doi.org/10.1016/j.ejso.2020.10.016>. Epub 2020 Oct 16.
- [13] Beck N, van Bommel AC, Eddes EH, van Leersum NJ, Tollenaar RA, Wouters MW, et al. The Dutch institute for clinical auditing: achieving codman's dream on a nationwide basis. *Ann Surg* 2020;271(4):627–31.
- [14] van der Werf LR, Kok NFM, Buis CI, Grunhagen DJ, Hoogwater FJH, Swijnenburg RJ, et al. Implementation and first results of a mandatory, nationwide audit on liver surgery. *HPB* 2019;21(10):1400–10.
- [15] Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, et al. The Clavien-Dindo classification of surgical complications: five-year experience. *Ann Surg* 2009;250(2):187–96.
- [16] Pang YY. The Brisbane 2000 terminology of liver anatomy and resections. *HPB* 2000;2:333–9. *HPB (Oxford)*. 2002;4(2):99; author reply 99–100.
- [17] Beck N, Hoeijmakers F, van der Willik EM, Heineman DJ, Braun J, Tollenaar R, et al. National comparison of hospital performances in lung cancer surgery: the role of case mix adjustment. *Ann Thorac Surg* 2018;106(2):412–20.
- [18] Kolschoten NE, Marang van de Mheen PJ, Gooiker GA, Eddes EH, Kievit J, Tollenaar RA, et al. Variation in case-mix between hospitals treating colorectal cancer patients in The Netherlands. *Eur J Surg Oncol* 2011;37(11):956–63.
- [19] Torzilli G, Viganò L, Giuliani F, Pinna AD. Liver surgery in Italy. Criteria to identify the hospital units and the tertiary referral centers entitled to perform it. *Updates Surg* 2016;68(2):135–42.
- [20] Ravaioli M, Pinna AD, Francioni G, Montorsi M, Veneroni L, Grazi GL, et al. A partnership model between high- and low-volume hospitals to improve results in hepatobiliary pancreatic surgery. *Ann Surg* 2014;260(5):871–5. ; discussion 875–877.
- [21] Ignatavicius P, Oberkofler CE, Chapman WC, DeMatteo RP, Clary BM, D'Angelica MI, et al. Choices of therapeutic strategies for colorectal liver metastases among expert liver surgeons: a throw of the dice? *Ann Surg* 2020;272(5):715–22.
- [22] Krell RW, Reames BN, Hendren S, Frankel TL, Pawlik TM, Chung M, et al. Surgical referral for colorectal liver metastases: a population-based survey. *Ann Surg Oncol* 2015;22(7):2179–94.
- [23] Huiskens J, Bolhuis K, Engelbrecht MR, De Jong KP, Duzemier G, Liem MS, et al. Outcomes of resectability assessment of the Dutch colorectal cancer group liver metastases expert panel. *J Am Coll Surg* 2019;229(6):523–532 e522.
- [24] Fenton HM, Taylor JC, Lodge JPA, Toogood GJ, Finan PJ, Young AL, et al. Variation in the use of resection for colorectal cancer liver metastases. *Ann Surg* 2019;270(5):892–8.
- [25] Hellingman T, de Swart ME, Joosten JJA, Meijerink MR, de Vries JJJ, de Waard JWD, et al. The value of a dedicated multidisciplinary expert panel to assess treatment strategy in patients suffering from colorectal cancer liver metastases. *Surg Oncol* 2020;35:412–7.
- [26] Engstrand J, Kartalis N, Stromberg C, Broberg M, Stillstrom A, Lekberg T, et al. The impact of a hepatobiliary multidisciplinary team Assessment in patients with colorectal cancer liver metastases: a population-based study. *Oncol* 2017;22(9):1067–74.
- [27] Lordan JT, Karanjia ND, Quiney N, Fawcett WJ, Worthington TR. A 10-year study of outcome following hepatic resection for colorectal liver metastases - the effect of evaluation in a multidisciplinary team setting. *Eur J Surg Oncol* 2009;35(3):302–6.
- [28] Vallance AE, vanderMeulen J, Kuryba A, Botterill ID, Hill J, Jayne DG, et al. Impact of hepatobiliary service centralization on treatment and outcomes in patients with colorectal cancer and liver metastases. *Br J Surg* 2017;104(7):918–25.
- [29] Basso M, Corallo S, Calegari MA, Zurlo IV, Ardito F, Vellone M, et al. The impact of multidisciplinary team management on outcome of hepatic resection in liver-limited colorectal metastases. *Sci Rep* 2020;10(1):10871.
- [30] Nelson-Williams H, Gani F, Kilic A, Spolverato G, Kim Y, Wagner D, et al. Factors associated with interhospital variability in inpatient costs of liver and

- pancreatic resections. *JAMA Surg* 2016;151(2):155–63.
- [31] Idrees JJ, Johnston FM, Canner JK, Dillhoff M, Schmidt C, Haut ER, et al. Cost of major complications after liver resection in the United States: are high-volume centers cost-effective? *Ann Surg* 2019;269(3):503–10.
- [32] Schiergens TS, Dorsch M, Mittermeier L, Brand K, Kuchenhoff H, Lee SM, et al. Thirty-day mortality leads to underestimation of postoperative death after liver resection: a novel method to define the acute postoperative period. *Surgery* 2015;158(6):1530–7.