

## Lower hospital volume is associated with higher mortality after oesophageal, gastric, pancreatic and rectal cancer resection

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### Summary

**BACKGROUND:** In various countries, the association of lower hospital volume and higher mortality after oesophageal, gastric, pancreatic and rectal cancer resection has been clearly demonstrated. However, scientific evidence regarding the volume-outcomes relationship for high-risk visceral surgical procedures in Switzerland is lacking. The *a priori* hypothesis of this retrospective population-based cohort study analysis was that low-volume hospitals in Switzerland have a higher rate of postoperative mortality after oesophageal, gastric, pancreatic and rectal cancer resection.

**METHODS:** Patients undergoing elective resection of oesophageal, gastric, pancreatic and rectal cancer between 1999 and 2012 were identified in the inpatient database of the Swiss Federal Statistical Office. Nonparametric correlation analyses were used to assess time trends. Mortality was assessed in univariable and risk-adjusted conditional logistic regression analyses with stratification for year of surgery.

**RESULTS:** A total of 1487 oesophageal, 4404 gastric, 2668 pancreatic and 9743 rectal cancer patients were identified. For all cancer entities, significant treatment centralisation was observed over the time period (all  $p < 0.001$ ). The rate of mortality was inversely related to the annual number of patients treated at a certain hospital. The decrease of postoperative mortality from low-volume to high-volume hospitals was 6.3% to 3.3% for oesophageal cancer ( $p = 0.019$ ), 4.9% to 3.3% for gastric cancer ( $p = 0.023$ ), 5.4% to 2.0% for pancreatic cancer ( $p = 0.037$ ), and 2.4% to 1.6% for rectal cancer ( $p = 0.008$ ). These results were confirmed in risk-adjusted analyses with a decreased odds of post-operative death by 49% for oesophageal (odds ratio [OR] 0.51, 95% confidence interval [CI] 0.22–1.18;  $p = 0.085$ ), 32% for gastric (OR 0.68, 95% CI 0.48–0.98;  $p = 0.032$ ), 68% for pancreatic (OR 0.32, 95% CI 0.11–0.89;  $p = 0.011$ ) and 29% for rectal cancer (OR 0.71, 95% CI 0.52–0.98;  $p = 0.033$ ).

**CONCLUSION:** This population-based analysis – the first of its kind in the literature – demonstrates a higher post-operative mortality in low-volume hospitals for patients undergoing oesophageal, gastric, pancreatic and rectal cancer resection in Switzerland. Hence, such operations should preferably be performed in high-volume hospitals.

**Key words:** hospital volume, mortality, oesophageal cancer, gastric cancer, rectal cancer, pancreatic cancer

### Background

For most early stage solid tumours, modern cancer management consists of complete resection of the primary tumour combined with other local and systemic therapies. Surgical skills, experienced clinical judgment, accurate staging and multidisciplinary treatments are key components of high-quality oncological care [1, 2]. Advances in the understanding of cancer biology, pathology, interventional radiology, radiation oncology and systemic therapy, combined with the rapid progress of sophisticated imaging techniques and molecular analyses have dramatically increased the level of knowledge required to deliver high-quality oncological care. Hence, an optimal management of oncological patients is best met in multidisciplinary teams existing at high-volume hospitals [1, 3]. The impact of hospital volume on short- and long-term outcomes in cancer patients has been extensively studied. Indeed, many investigations over the past decade provided compelling evidence that patient outcomes, including post-operative morbidity and mortality, are improved – especially for complex surgical procedures – if performed within high-volume hospitals and by high-volume surgeons [4–15]. It is intuitive that improvements in outcomes result from the enhanced performance gained through increased practice and experience – “practice makes perfect”! This volume-outcomes relationship exists on different levels. At the individual level, a surgeon is able to reduce operative time and blood loss as well as intra- and postoperative complications through increasing expertise in the field [16–20]. At the structural level, a high-volume hospi-

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tal is able to implement evidence-based guidelines and provide excellence through multidisciplinary team work [2, 21–23].

The volume-outcomes relationship for high-risk gastrointestinal cancer surgery has been demonstrated in various studies in several countries [10, 11, 20, 24, 25]. However, to the best of our knowledge, there are no data in Switzerland concerning the type of institutions where patients undergo high-risk cancer surgery and if, as shown in other countries, a relationship exists between low hospital volume and worse patient outcomes. It is of utmost importance to understand where high-risk cancer surgery procedures in Switzerland are performed and whether a volume-outcomes relationship does exist. Such knowledge represents a key prerequisite of quality of care improvement in Switzerland.

Therefore, the primary objective of this study was to assess whether high-risk surgical procedures for oesophageal, gastric, pancreatic and rectal cancer types are centralised in Switzerland and whether low-volume hospitals have higher rates of postoperative mortality.

## Methods

### Cohort definition

Since 1998 the Federal Statistical Office (FSO) has prospectively collected information on all hospitalisations in Switzerland. This database includes detailed information on up to 99 diagnoses and procedures for each individual patient, intensive care unit stay, type of admission and discharge, as well as an identification number and type of the hospital where a specific procedure takes place. The identification number enables calculation of the hospital caseload, such as the number of a specific surgical procedure that has been performed per year at a certain hospital. Based on a federal law, all in-patients with a hospital stay exceeding 24 hours must be recorded. No data are

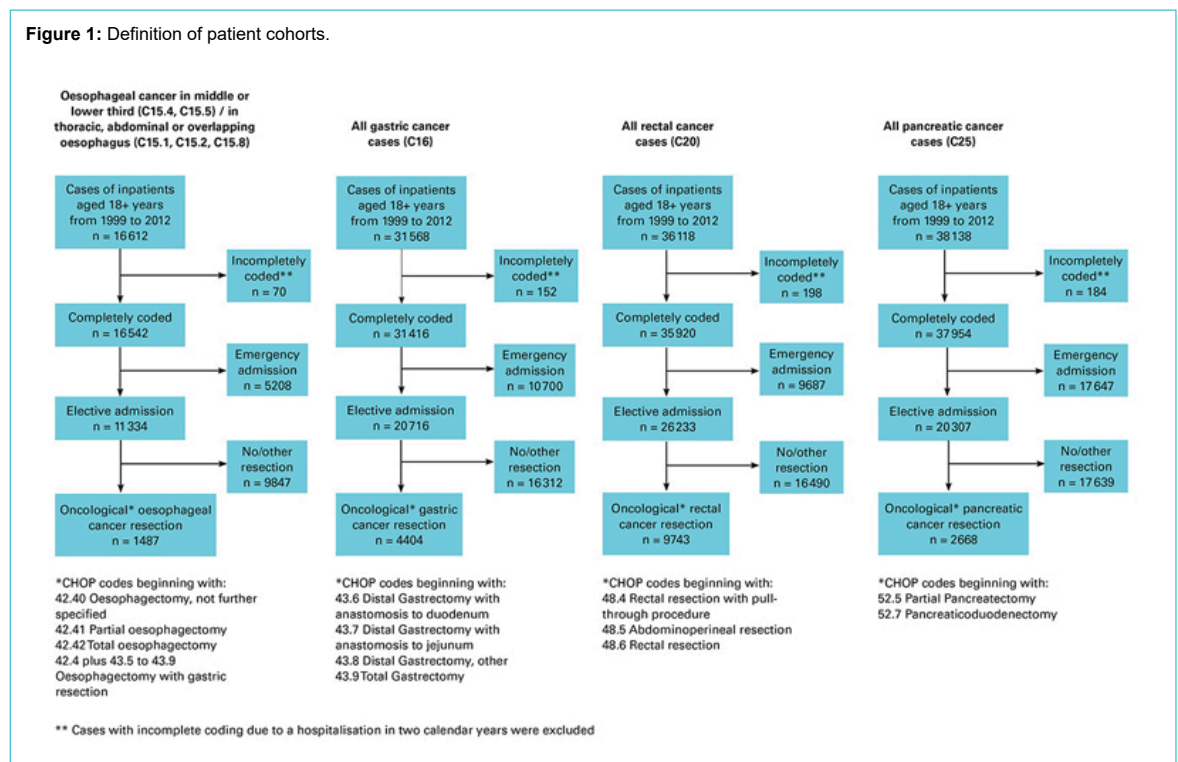
recorded after patient discharge. Hence, this database represents an invaluable, nationwide complete data source to gain insight regarding important aspects of patterns of care in Swiss cancer patients.

The inpatient database from 1999–2012 of the Swiss Federal Statistical Office served as the data source of the present investigation. In this database inpatient treatments in Switzerland are covered with annual reporting from each Swiss hospital. Patients with oesophageal cancer were identified by one of the International Classification of Diseases tenth edition (ICD-10) codes C15.1, C15.2, C15.4, C15.5, or C15.8 in either the primary diagnosis field or in one of 49 secondary diagnosis fields. For patients with gastric, rectal, and pancreatic cancer, the ICD-10 codes C16, C20, and C25 were used. The Swiss Federal Statistical Office data are strictly based on full calendar years from 1 January to 31 December. Data from patients with a hospital stay over 31 December are therefore incomplete. Patients with incomplete coding due to a hospitalisation in two calendar years, patients with emergency admission and patients not undergoing primary cancer resection were excluded (fig. 1).

### Statistical analyses

The 2014 data were imported into a PostgreSQL database and thereafter the above-described selection procedures were performed. Two authors (U. G. and R. W.) checked the various analytical steps to create the final data set. The R statistical software ([www.r-project.org](http://www.r-project.org)) was used for statistical analyses. A two-sided p-value <0.05 was considered statistically significant. Chi-square statistics were used to analyse proportions. The primary endpoint of this study was postoperative mortality, defined as in-hospital death after the surgical procedures chosen for the study. As a secondary endpoint, treatment centralisation was assessed. Trends between year and treatment centralisation, as well as hospital volume and mortality were assessed

Figure 1: Definition of patient cohorts.



with Spearman's rank correlation coefficient  $\rho$ , serving as a nonparametric measure of statistical dependence. Additionally, linear regression analyses were performed to visualise these trends. To further assess the relationship between hospital volume and mortality, univariable and multivariable conditional logistic regression analyses were performed. This was done with stratification for year of diagnosis and dichotomised annual numbers of patients per hospital (low- vs high-volume hospitals), according to the predefined following cut-off values: for oesophageal and gastric cancer, high-volume hospitals were defined by a minimum of more than 10 patients per year; for rectal and pancreatic cancer high-volume hospitals were defined by more than 20 patients per year. These cut-offs were based on the discussions of the Swiss Scientific HSM (highly specialised medicine) board on defining the minimal thresholds for a given hospital to perform a certain high-risk surgical procedure. These analyses were stratified by year to optimally adjust for differences in the coding quality and completeness. We refrained from data-driven "best" cut-off definition, as this approach is methodologically questionable from a statistical point of view and prone to bias.

In addition to univariable and multivariable analyses, propensity score adjusted analyses were performed, with use of the "MatchIt" and the "optmatch" R packages to optimally adjust for potential baseline confounding [26–28]. The distance measure was estimated with a logistic link function of the main effects and interaction to minimise bias. Patients from high-volume hospitals not having a counterpart regarding the distance measure among the patients from low-volume hospitals and vice versa were excluded. Finally, a logistic regression conditional on the subsets obtained by the propensity score matching ("paired analysis") was performed.

The *a priori* hypothesis of the analysis was that low-volume hospitals in Switzerland have a higher rate of postoperative mortality after oesophageal, gastric, pancreatic and rectal cancer resection. Based on these *a priori* stated hypotheses with one primary predictor (hospital volume) and one primary endpoint (in-hospital mortality) per tumour entity no adjustments were made for multiple testing.

## Results

### Patient characteristics

Overall, 1487 patients with oesophageal cancer, 4404 patients with gastric cancer, 2668 patients with pancreatic cancer and 9743 patients with rectal cancer underwent cancer resection between 1999 and 2012 (fig. 1). Tables 1, 2, 3 and 4 depict the patient characteristics for the four different cancer entities.

### Treatment centralisation

To assess the treatment centralisation, the mean annual number of patients per hospital undergoing resection of a certain cancer was correlated with the year of diagnosis. For all cancer entities, a relevant treatment centralisation was observed, with a significantly increasing mean annual numbers of patients per hospital (fig. 2a, b, c and d). For pancreatic cancer, the mean number of patients per hospital and annum increased from 1999 to 2012 from 3 to 7 pa-

tients ( $p < 0.001$ ), for rectal cancer from 6 to 12 patients ( $p < 0.001$ ), for gastric cancer from 3 to 5 patients ( $p < 0.001$ ) and for oesophageal cancer from 3 to 4 patients ( $p < 0.001$ ).

### Hospital volume and mortality

To assess the impact of hospital volume on postoperative mortality, the association between the annual numbers of patients per hospital undergoing resection for a certain cancer were correlated with the rate of mortality (fig. 3). For all four cancer entities, a significant inverse association was observed, with higher mortality rates for hospitals with lower volumes and vice versa. The decrease of postoperative mortality from low-volume to high-volume hospitals was from 6.3 to 3.3% for oesophageal cancer ( $p = 0.019$ ), 4.9 to 3.3% for gastric cancer ( $p = 0.023$ ), 5.4 to 2.0% for pancreatic cancer ( $p = 0.037$ ) and 2.4 to 1.6% for rectal cancer ( $p = 0.008$ ).

These results were confirmed in risk-adjusted analyses with a decreased odds of postoperative death by of 49% for oesophageal (odds ratio [OR] 0.51, 95% confidence interval [CI] 0.22–1.18;  $p = 0.085$ ), 32% for gastric (OR 0.68, 95% CI 0.48–0.98;  $p = 0.032$ ), 68% for pancreatic (OR 0.32, 95% CI 0.11–0.89;  $p = 0.011$ ) and 29% for rectal cancer (OR 0.71, 95% CI 0.52–0.98;  $p = 0.033$ ). These findings were further supported by a significantly reduced odds for mortality in propensity score matched analyses for all entities (tables 1, 2, 3, 4).

## Discussion

Our population-based analyses provide evidence that patients undergoing oesophageal, gastric, pancreatic and rectal cancer resection in low-volume hospitals in Switzerland have remarkably higher postoperative mortality rates compared with those in high-volume hospitals. Indeed, for all cancer entities there was a relative decrease of postoperative mortality of between 29 and 68% in high-volume hospitals. These clinically relevant results demonstrate that high-risk surgical procedures such as oesophageal, gastric, pancreatic and rectal cancer resection must be performed in high-volume hospitals in Switzerland.

The awareness of the hospital volume-outcomes relationship for high-risk surgical procedures started with the landmark publication by Birkmeyer and colleagues in the *New England Journal of Medicine* in 2002 [11]. In this key study, the investigators convincingly showed that lower hospital volume is associated with significantly increased mortality for different cancer surgeries. Indeed, the postoperative mortality for pancreatic cancer resections decreased from 16.3% in low-volume hospitals to 3.8% in high-volume centres. Similarly, the postoperative mortality for oesophageal cancer resection decreased from 20.3% in low-volume hospitals to only 8.4% in high-volume centres [11]. A year later, the same group of investigators reported on surgeon experience and postoperative mortality after various cancer operations in the US [10]. They concluded that patients have the lowest risk of dying of a cancer surgery if operated in a high-volume hospital by a surgeon who performs the specific cancer operation frequently.

The observed relationship between hospital volume and patient outcomes may be explained by several factors. A mortality decrease was shown to be associated with repeti-

tion of a specific operational procedure [29]. It is intuitive that a well-trained and experienced surgeon is able to reduce operative time, blood loss, and intra- and postoperative complications through increasing expertise in the field [2, 16, 20, 30]. Furthermore, at the structural level, high-volume hospitals are able to provide excellence through multidisciplinary teamwork [4, 17, 21]. For the treatment of oesophageal, gastric, pancreatic and rectal cancer, the collaboration between medical oncologists, radiation oncologists, gastroenterologists, radiologists, interventional radiologists and pathologists are of key importance [2, 30] and have become increasingly relevant over recent years. Moreover, there also needs to be an experienced hospital team, including nurses, physical therapists and technical staff, to look after these patients. This multidisciplinary care is not a given at smaller hospitals and exists usually only in larger health care centres. Nonetheless, although this study demonstrates a clear relationship between lower hospital volume and higher mortality, there are small-volume

hospitals with low mortality as well as high-volume hospitals with a high rate of post-operative deaths (fig. 3). There is no doubt that many patient lives could be saved if all surgeons in Switzerland performing complex cancer resections were operating above a certain minimum number of patients per year to improve and maintain their surgical skills. Although we did see some centralisation of high-risk cancer surgery in Switzerland over time, our study demonstrates that there are still many low-volume hospitals and low-volume surgeons. Most importantly, even in later time periods, the vast majority of high-risk cancer surgery in Switzerland is still being performed in low-volume hospitals. In the present investigation in Swiss patients, cut-off values of more than 10 patients per year were chosen for oesophageal and gastric cancer and above 20 patients per year for rectal and pancreatic cancer. There was a longstanding debate within the highly specialised Medicine Scientific Board in Switzerland (HSM) about defining cut-offs of operations/year, below which a hos-

**Table 1:** Patient characteristics and logistic regression for mortality in oesophageal cancer.

		Patient characteristics				Conditional logistic regression for mortality					
		Total	Low volume (1–10 per year)	High volume (11+ per year)		Unadjusted analyses		Multivariable analyses		Propensity score-adjusted analyses	
		n = 1487	n = 1305	n = 182	p-value*	OR (95% CI)	p-value†	OR (95% CI)	p-value†	OR (95% CI)	p-value†
Hospital volume	1–10 per year	1305 (87.8%)	1305 (100%)	–	–	Reference	0.087	Reference	0.085	Reference	0.034
	11+ per year	182 (12.2%)	–	182 (100%)		0.52 (0.22–1.19)		0.5 (0.22–1.18)		0.40 (0.16–0.99)	
Age	<50 years	120 (8.1%)	109 (8.4%)	11 (6.0%)	0.738	Reference	<0.001	Reference	<0.001	–	–
	50–64 years	660 (44.4%)	578 (44.3%)	82 (45.1%)		1.23 (0.43–3.52)		1.26 (0.44–3.62)		–	
	65–79 years	642 (43.2%)	562 (43.1%)	80 (44.0%)		2.20 (0.79–6.10)		2.25 (0.80–6.31)		–	
	80+ years	65 (4.4%)	56 (4.3%)	9 (4.9%)		5.44 (1.73–17.08)		5.51 (1.74–17.50)		–	
Gender	Male	1193 (80.2%)	1048 (80.3%)	145 (79.7%)	0.840	Reference	0.665	Reference	0.896	–	–
	Female	294 (19.8%)	257 (19.7%)	37 (20.3%)		1.12 (0.67–1.86)		1.03 (0.62–1.73)		–	
Swiss nationality	No	182 (12.2%)	153 (11.7%)	29 (15.9%)	0.105	Reference	0.545	Reference	0.778	–	–
	Yes	1305 (87.8%)	1152 (88.3%)	153 (84.1%)		1.23 (0.62–2.45)		1.10 (0.55–2.21)		–	
Oesophagectomy	Partial	722 (48.6%)	621 (47.6%)	101 (55.5%)	0.038	Reference	0.532	Reference	0.657	–	–
	Total	380 (25.6%)	347 (26.6%)	33 (18.1%)		1.09 (0.64–1.85)		1.08 (0.64–1.84)		–	
	With gastrectomy	385 (25.9%)	337 (25.8%)	48 (26.4%)		1.34 (0.80–2.25)		1.27 (0.76–2.14)		–	
Insurance	General	974 (65.5%)	867 (66.4%)	107 (58.8%)	0.042	Reference	0.759	Reference	0.639	–	–
	Private	513 (34.5%)	438 (33.6%)	75 (41.2%)		0.93 (0.60–1.46)		0.90 (0.57–1.41)		–	
Year	1999–2003	430 (28.9%)	369 (28.3%)	61 (33.5%)	<0.001	–		–		–	
	2004–2008	546 (36.7%)	503 (38.5%)	43 (23.6%)		–		–		–	
	2009–2012	511 (34.4%)	433 (33.2%)	78 (42.9%)		–		–		–	
Mortality	No	1399 (94.1%)	1223 (93.7%)	176 (96.7%)	0.110	–		–		–	
	Yes	88 (5.9%)	82 (6.3%)	6 (3.3%)		–		–		–	

\* Chi-square test; † likelihood ratio test n (%) for patient characteristics and odds ratio (OR) with 95% confidence interval (95% CI)

pital is not allowed to perform a specific cancer surgery. The debated cut-offs fluctuated between 10 and 20 operations per annum, which is the reason for choosing such predefined limits for the present investigation. However, there is compelling evidence that these cut-offs are too low. Henneman and colleagues convincingly demonstrated, on the basis of over 10 000 patients from the Netherlands Cancer Registry, that for oesophageal cancer resections at least 40 to 60 operations per annum are necessary for each centre [31]. In this Dutch cohort, a patient undergoing an oesophageal cancer resection at a hospital with a volume above 60 operations/year had a 33% mortality reduction compared with a patient operated in a hospital with less than 20 per year. Similarly, cut-offs higher than 10 to 20/annum for pancreatic and gastric cancer surgeries were shown to be associated with lower postoperative mortality rates [20, 32].

In an investigation by Mariette and colleagues presented at the annual conference of the ESMO 2016, the authors convincingly showed a clear relationship between low-volume

hospitals and higher mortality in oesophageal and gastric cancer patients [32]. It is noteworthy that the cut-off value for low-volume was set at 20 specific cancer operations per year, not – as in the present investigation – at 10 per year. In the highest volume category, defined as having a case load of 60 oesophageal or gastric cancer resections or higher, the 30-day postoperative mortality reduction was from 5.7% in low-volume hospitals to 1.7% in high-volume hospitals, the 90-day mortality rate from 10.2% in low-volume to 3.6% in high-volume hospitals.

The limitations of the present investigation arise from information, which cannot be ascertained from the database of the Federal Statistical Office such as pathological stages, grading, chemotherapeutic treatments, comorbidities and performance status. Hence, it cannot be determined to what extent these factors might have influenced our analysis. However, the population-based nature of the database, with a large number of patients, is associated with a high degree of generalisability and mirrors the real-world situation in Switzerland. Furthermore, the results of

**Table 2:** Patient characteristics and logistic regression for mortality in gastric cancer.

		Patient characteristics				p-value*	Conditional logistic regression for mortality		Multivariable analyses		Propensity score-adjusted analyses	
		Total	Low volume (1–10 per year)	High volume (11+ per year)			Unadjusted analyses		OR (95% CI)	p-value†	OR (95% CI)	p-value†
		n = 4404	n = 3245	n = 1159		OR (95% CI)	p-value†	OR (95% CI)	p-value†	OR (95% CI)	p-value†	
Hospital volume	1–10 per year	3245 (73.7%)	3245 (100%)		–	Reference	0.013	Reference	0.032	Reference	0.048	
	11+ per year	1159 (26.3%)		1159 (100%)		0.65 (0.45–0.93)		0.68 (0.48–0.98)		0.67 (0.45–1.00)		
Age	<50 years	564 (12.8%)	366 (11.3%)	198 (17.1%)	<0.001	Reference	<0.001	Reference	<0.001	–	–	
	50–64 years	1175 (26.7%)	859 (26.5%)	316 (27.3%)		2.74 (1.15–6.54)		2.64 (1.10–6.31)		–		
	65–79 years	1968 (44.7%)	1471 (45.3%)	497 (42.9%)		4.99 (2.19–11.38)		5.09 (2.21–11.71)		–		
	80+ years	697 (15.8%)	549 (16.9%)	148 (12.8%)		8.21 (3.54–19.04)		9.48 (4.02–22.38)		–		
Gender	Male	2675 (60.7%)	1968 (60.6%)	707 (61.0%)	0.832	Reference	0.002	Reference	0.001	–	–	
	Female	1729 (39.3%)	1277 (39.4%)	452 (39.0%)		0.62 (0.45–0.84)		0.61 (0.45–0.84)		–		
Swiss nationality	No	1042 (23.7%)	700 (21.6%)	342 (29.5%)	<0.001	Reference	0.023	Reference	0.717	–	–	
	Yes	3362 (76.3%)	2545 (78.4%)	817 (70.5%)		1.51 (1.04–2.18)		1.07 (0.73–1.58)		–		
Gastrectomy	Distal	2095 (47.6%)	1597 (49.2%)	498 (43.0%)	<0.001	Reference	0.005	Reference	<0.001	–	–	
	Total	2309 (52.4%)	1648 (50.8%)	661 (57.0%)		1.50 (1.13–2.01)		1.85 (1.38–2.48)		–		
Insurance	General	3245 (73.7%)	2371 (73.1%)	874 (75.4%)	0.120	Reference	0.310	Reference	0.223	–	–	
	Private	1159 (26.3%)	874 (26.9%)	285 (24.6%)		0.85 (0.61–1.18)		0.82 (0.58–1.14)		–	–	
Year	1999–2003	1500 (34.1%)	1212 (37.3%)	288 (24.8%)	<0.001	–		–		–		
	2004–2008	1590 (36.1%)	1181 (36.4%)	409 (35.3%)		–		–		–		
	2009–2012	1314 (29.8%)	852 (26.3%)	462 (39.9%)		–		–		–		
Mortality	No	4206 (95.5%)	3085 (95.1%)	1121 (96.7%)	0.020	–		–		–		
	Yes	198 (4.5%)	160 (4.9%)	38 (3.3%)		–		–		–		

\* Chi-square test; † likelihood ratio test n (%) for patient characteristics and odds ratio (OR) with 95% confidence interval (95% CI)

unadjusted analysis were confirmed by multivariable and propensity score adjusted analyses.

## Conclusion

The present population-based analysis – the first of its kind in the literature - demonstrates that post-operative mortality rates after oesophageal, gastric, pancreatic and rectal cancer resection are increased in low-volume hospitals in Switzerland. Therefore, high-risk operations should preferably be performed in high-volume hospitals to ensure optimal patient outcomes in Switzerland.

## Disclosure statement

This study was supported through a grant of the Swiss Cancer Foundation. The grant was used to compensate the data manager and statistician (RW) of the present study. The authors have no conflict of interest.

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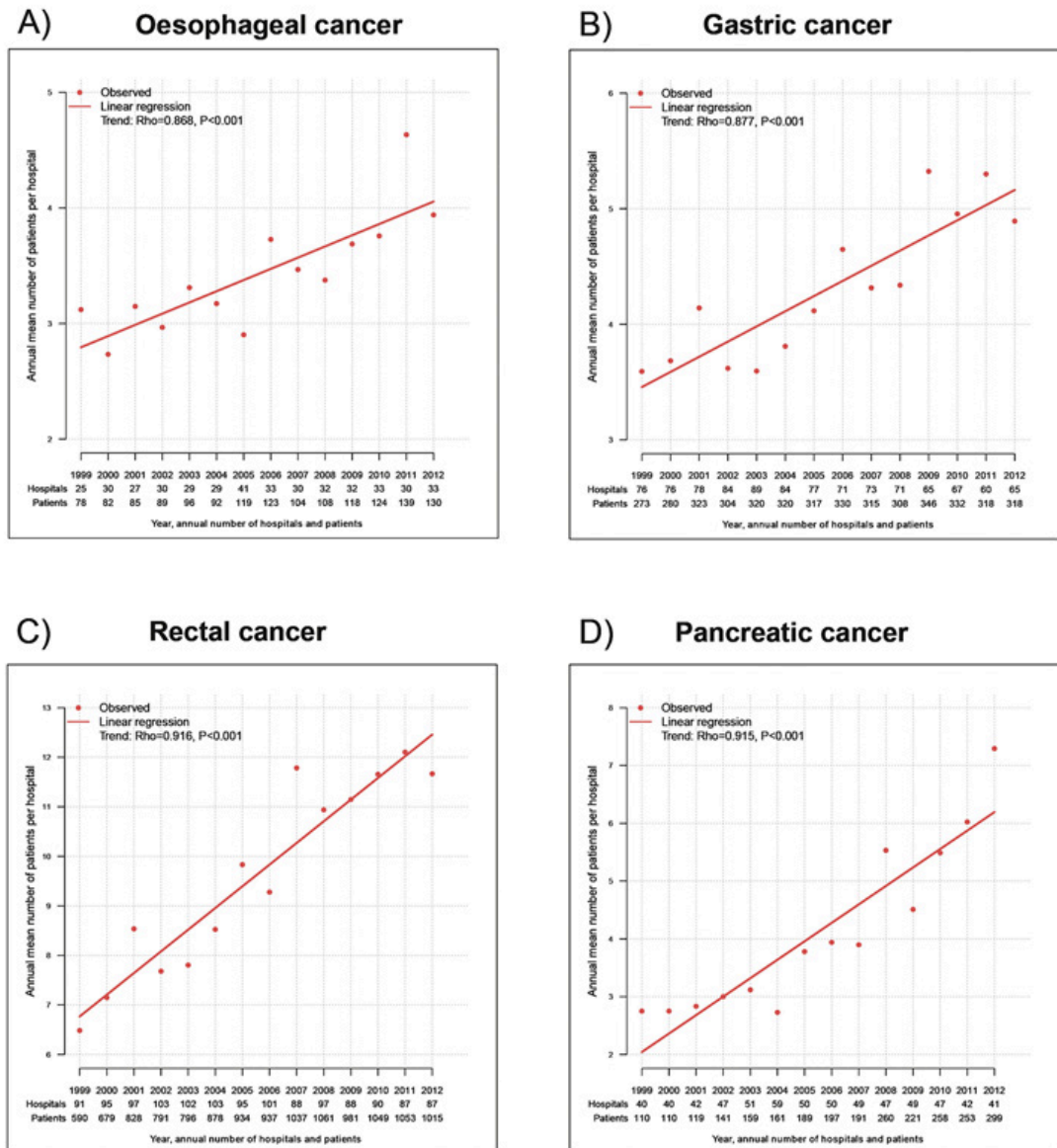
**Table 3:** Patient characteristics and logistic regression for mortality in pancreatic cancer.

		Patient characteristics				Conditional logistic regression for mortality						
		Total	Low volume (1–20 per year)	High volume (21+ per year)			Unadjusted analyses		Multivariable analyses		Propensity score-adjusted analyses	
		n = 2668	n = 2467	n = 201	p-value*		OR (95% CI)	p-value†	OR (95% CI)	p-value†	OR (95% CI)	p-value†
Hospital volume	1–20 per year	2467 (92.5%)	2467 (100%)		–	Reference	0.005	Reference	0.011	Reference	0.027	
	21+ per year	201 (7.5%)		201 (100%)		0.29 (0.10–0.81)		0.32 (0.11–0.89)		0.32 (0.10–1.00)		
Age	<50 years	261 (9.8%)	234 (9.5%)	27 (13.4%)	0.099	Reference	<0.001	Reference	<0.001	–	–	
	50–64 years	898 (33.7%)	831 (33.7%)	67 (33.3%)		4.41 (1.05–18.46)		4.49 (1.07–18.87)		–	–	
	65–79 years	1298 (48.7%)	1212 (49.1%)	86 (42.8%)		8.92 (2.19–36.22)		9.24 (2.26–37.75)		–	–	
	80+ years	211 (7.9%)	190 (7.7%)	21 (10.4%)		11.60 (2.69–50.03)		12.96 (2.98–56.28)		–	–	
Gender	Male	1368 (51.3%)	1265 (51.3%)	103 (51.2%)	0.993	Reference	0.189	Reference	0.164	–	–	
	Female	1300 (48.7%)	1202 (48.7%)	98 (48.8%)		0.80 (0.57–1.12)		0.79 (0.56–1.10)		–	–	
Swiss nationality	No	356 (13.3%)	333 (13.5%)	23 (11.4%)	0.410	Reference	0.871	Reference	0.433	–	–	
	Yes	2312 (86.7%)	2134 (86.5%)	178 (88.6%)		0.96 (0.59–1.56)		0.82 (0.50–1.34)		–	–	
OP	Pancreatico-duodenectomy	1334 (50.0%)	1263 (51.2%)	71 (35.3%)	<0.001	Reference	0.006	Reference	0.023	–	–	
	Partial pancreatectomy	1334 (50.0%)	1204 (48.8%)	130 (64.7%)		0.62 (0.44–0.88)		0.67 (0.48–0.95)		–	–	
Insurance	General	1572 (58.9%)	1432 (58.0%)	140 (69.7%)	0.001	Reference	0.123	Reference	0.030	–	–	
	Private	1096 (41.1%)	1035 (42.0%)	61 (30.3%)		0.76 (0.54–1.08)		0.68 (0.48–0.97)		–	–	
Year	1999–2003	639 (24.0%)	639 (25.9%)	0 (0.0%)	<0.001	–	–	–	–	–	–	
	2004–2008	998 (37.4%)	950 (38.5%)	48 (23.9%)		–	–	–	–	–	–	
	2009–2012	1031 (38.6%)	878 (35.6%)	153 (76.1%)		–	–	–	–	–	–	
Mortality	No	2530 (94.8%)	2333 (94.6%)	197 (98.0%)	0.034	–	–	–	–	–	–	
	Yes	138 (5.2%)	134 (5.4%)	4 (2.0%)		–	–	–	–	–	–	

OP = operation \* Chi-square test; † likelihood ratio test n (%) for patient characteristics and odds ratio (OR) with 95% confidence interval (95% CI)

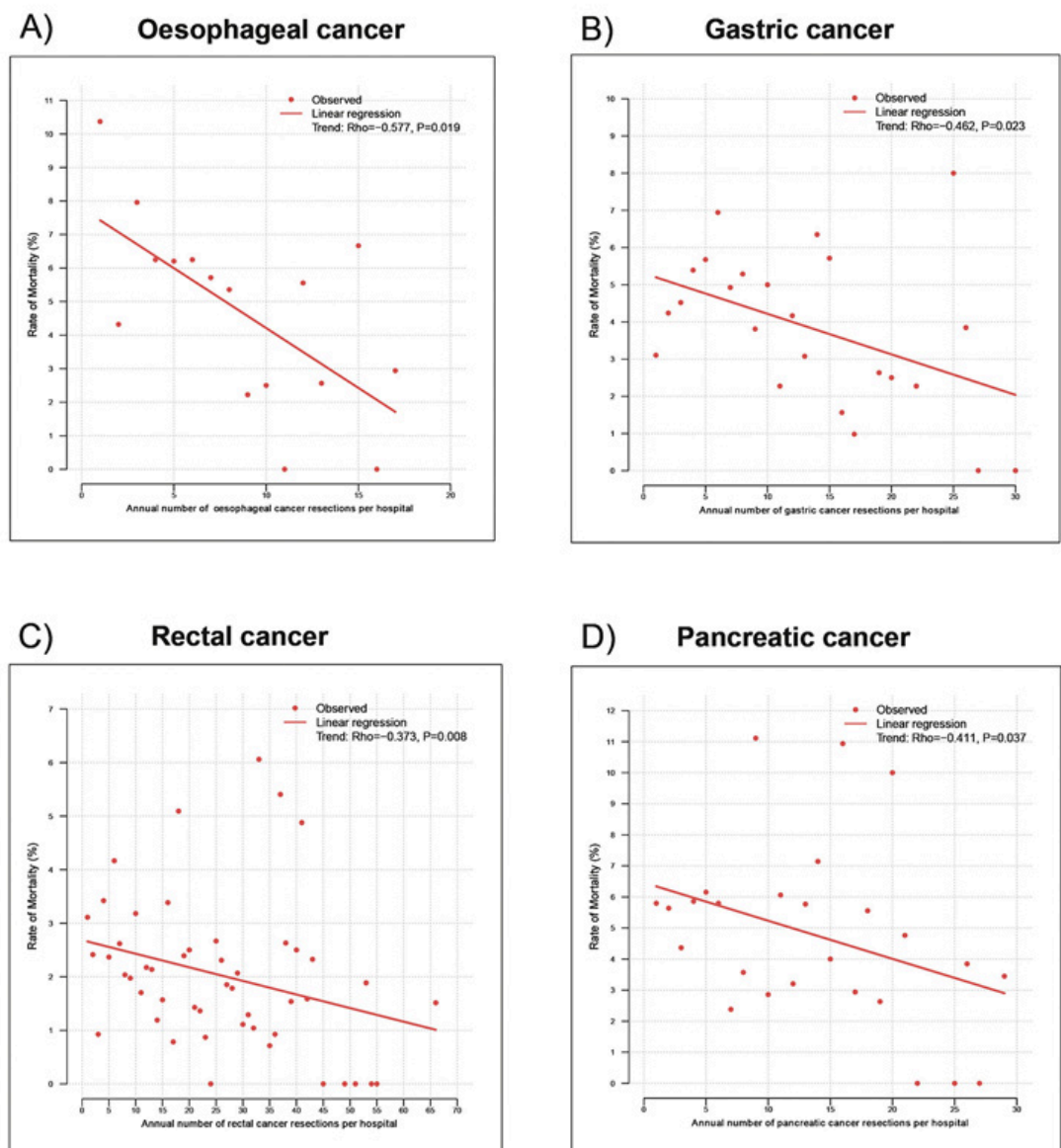
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**Figure 2:** Treatment centralisation. The annual number of hospitals/patients is displayed on the x-axes, the annual mean number of patients per hospital shown on the y-axes. The time trend analyses were performed using Spearman’s rank correlation.



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**Figure 3:** Hospital volume and mortality. Panels A, B, C and D demonstrate a significant correlation between hospital volume and mortality after resection of oesophageal, gastric, pancreatic and rectal cancer. For each tumour entity the annual number of patients per hospital is plotted against the mortality rate. A trend analysis was performed with Spearman's rank correlation.





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**Table 4:** Patient characteristics and logistic regression for mortality in rectal cancer.

		Patient characteristics				Conditional logistic regression for mortality					
		Total	Low volume (1–20 per year)	High volume (21+ per year)		Unadjusted analyses		Multivariable analyses		Propensity score-adjusted analyses	
		n = 9743	n = 6552	n = 3191	p-value*	OR (95% CI)	p-value†	OR (95% CI)	p-value†	OR (95% CI)	p-value†
Hospital volume	1–20 per year	6552 (67.2%)	6552 (100%)		–	Reference	0.008	Reference	0.033	Reference	0.014
	21+ per year	3191 (32.8%)		3191 (100%)		0.66 (0.48–0.90)		0.71 (0.52–0.98)		0.65 (0.45–0.92)	
Age	<50 years	751 (7.7%)	474 (7.2%)	277 (8.7%)	0.001	Reference	<0.001	Reference	<0.001	–	–
	50–64 years	3072 (31.5%)	2014 (30.7%)	1058 (33.2%)		1.17 (0.45–3.07)		1.11 (0.42–2.92)		–	–
	65–79 years	4497 (46.2%)	3065 (46.8%)	1432 (44.9%)		2.95 (1.20–7.26)		2.73 (1.11–6.76)		–	–
	80+ years	1423 (14.6%)	999 (15.2%)	424 (13.3%)		10.15 (4.13–24.96)		9.95 (4.02–24.59)		–	–
Gender	Male	6101 (62.6%)	4069 (62.1%)	2032 (63.7%)	0.131	Reference	<0.001	Reference	<0.001	–	–
	Female	3642 (37.4%)	2483 (37.9%)	1159 (36.3%)		0.59 (0.43–0.80)		0.50 (0.37–0.69)		–	–
Swiss nationality	No	1398 (14.3%)	905 (13.8%)	493 (15.4%)	0.031	Reference	0.037	Reference	0.453	–	–
	Yes	8345 (85.7%)	5647 (86.2%)	2698 (84.6%)		1.58 (1.00–2.51)		1.19 (0.75–1.90)		–	–
Rectal resection	Rectal resection	7230 (74.2%)	4821 (73.6%)	2409 (75.5%)	0.049	Reference	0.616	Reference	0.772	–	–
	Pull-through	495 (5.1%)	354 (5.4%)	141 (4.4%)		1.19 (0.66–2.14)		1.25 (0.69–2.26)		–	–
	Abdomino-perineal	2018 (20.7%)	1377 (21.0%)	641 (20.1%)		1.16 (0.84–1.60)		1.02 (0.73–1.41)		–	–
Insurance	General	6459 (66.3%)	4459 (68.1%)	2000 (62.7%)	<0.001	Reference	0.098	Reference	0.281	–	–
	Private	3284 (33.7%)	2093 (31.9%)	1191 (37.3%)		0.78 (0.58–1.05)		0.85 (0.63–1.15)		–	–
Year	1999–2003	2895 (29.7%)	2023 (30.9%)	872 (27.3%)	<0.001	–	–	–	–	–	–
	2004–2008	3718 (38.2%)	2572 (39.3%)	1146 (35.9%)		–	–	–	–	–	–
	2009–2012	3130 (32.1%)	1957 (29.9%)	1173 (36.8%)		–	–	–	–	–	–
Mortality	No	9532 (97.8%)	6393 (97.6%)	3139 (98.4%)	0.011	–	–	–	–	–	–
	Yes	211 (2.2%)	159 (2.4%)	52 (1.6%)		–	–	–	–	–	–

\* Chi-square test; † likelihood ratio test n (%) for patient characteristics and odds ratio (OR) with 95% confidence interval (95% CI)