Original Article

Hospital Volume, In-Hospital Mortality, and Failure to Rescue in Esophageal Surgery

An Analysis of German Hospital Discharge Data

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Summary

Background: In Germany, complex esophageal surgery is often performed in hospitals with low case numbers. For these procedures, an association exists between hospital case numbers and treatment outcomes, possibly because of differences in complication management. This aspect of the association between volume and outcome in esophageal surgery has not yet been studied in Germany.

Methods: On the basis of nationwide hospital discharge data (DRG statistics) from the years 2010 to 2015, the association between volume and outcome was analyzed in relation to in-hospital mortality, the frequency of complications, and the mortality of patients who had complications.

Results: 22 700 cases of complex esophageal surgery were identified. The probability of dying after esophageal surgery was much lower in hospitals with very high case numbers (median, 62 per year) than in those with very low case numbers (median, two per year), with an odds ratio (OR) of 0.50 (95% confidence interval, [0.42; 0.60]). At least one complication was documented for more than half of all patients; no association was found between the frequency of complications and the hospital case volume. The in-hospital mortality among patients who had complications was 12.3% [11.1; 13.7] in hospitals with very high case numbers and 20.0% [18.5; 21.6] in hospitals with very low case numbers. Of the 4032 procedures performed in 2015, 83% were for cancer of the esophagus.

Conclusion: These findings indicate that the quality of care for patients undergoing esophageal surgery in Germany could be improved if more patients were treated in hospitals with high case numbers. The observed association between case numbers and outcomes is tightly linked to failure to rescue.

Cite this as:

Nimptsch U, Haist T, Krautz C, Grützmann R, Mansky T, Lorenz D: Hospital volume, in-hospital mortality, and failure to rescue in esophageal surgery—an analysis of German hospital discharge data. *Dtsch Arztebl Int* 2018; 115: 793–800. DOI: 10.3238/arztebl.2018.0793

Operations on the esophagus are highly complex interventions that place exacting demands both on the surgeon and on the whole team involved in pre-, peri-, and postoperative care. It has long been recognized that there is a strong association between the outcome of esophageal surgery and the volume of patients treated. Meta-analyses of studies from different countries have shown that the in-hospital mortality following esophageal interventions to treat malignant neoplasia is inversely related to the number of operations carried out at the institution concerned (1–3). A recently published German study confirmed this association and showed that in this country esophageal procedures often take place in hospitals with very low case volumes (4).

The findings of international research indicate that in-hospital mortality after esophageal surgery depends on how complications are managed, i.e., on the ability of the treatment team to react swiftly and appropriately to complications (5–6). For complex operations this effect seems to account for a large part of the volume–outcome relationship (7–8). To the best of our knowledge, this issue has not yet been investigated for esophageal interventions in Germany.

This retrospective observational study of the situation regarding esophageal surgery in Germany is based on nationwide hospital discharge data and analyzes the volume–outcome relationship in respect of

TABLE 1

Characteristics of treatment cases with complex esophageal surgery in the period 2010 to 2015, by year

Variables		2010	2011	2012	2013	2014	2015
Treatment cases with complex esophageal surgery	N	3598	3656	3749	3802	3844	4032
Hospitals with at least one treatment case	N	431	413	437	439	416	406
Annual case volume per hospital	Median (IQR)	5 (1–11)	6 (2–11)	5 (1–11)	5 (2–11)	5 (2–11)	6 (2–12)
Demography							
Age 65 years or more	N (%)	1906 (53.0)	1843 (50.4)	1914 (51.1)	1928 (50.7)	1974 (51.4)	2034 (50.4)
Female	N (%)	854 (23.7)	786 (21.5)	878 (23.4)	863 (22.7)	877 (22.8)	945 (23.4)
Underlying disease							
Malignant neoplasia (MN) of esophagus	N (%)	2921 (81.2)	3008 (82.3)	3074 (82.0)	3137 (82.5)	3201 (83.3)	3366 (83.5)
MN of neighboring organs or secondary MN	N (%)	412 (11.5)	381 (10.4)	370 (9.9)	362 (9.5)	348 (9.1)	351 (8.7)
Esophageal perforation	N (%)	83 (2.3)	80 (2.2)	101 (2.7)	93 (2.4)	109 (2.8)	99 (2.5)
Benign neoplasia of upper gastrointestinal tract	N (%)	16 (0.4)	17 (0.5)	21 (0.6)	20 (0.5)	22 (0.6)	23 (0.6)
Diverticulosis, achalasia, or obstruction of esophagus	N (%)	53 (1.5)	52 (1.4)	60 (1.6)	65 (1.7)	57 (1.5)	61 (1.5)
Other	N (%)	113 (3.1)	118 (3.2)	123 (3.3)	125 (3.3)	107 (2.8)	132 (3.3)
Type of surgery							
Total esophageal resection	N (%)	1752 (48.7)	1778 (48.6)	1800 (48.0)	1927 (50.7)	2012 (52.3)	1964 (48.7)
– with abdominocervical (transmediastinal) access* ¹	n (%)	224 (12.8)	182 (10.2)	176 (9.8)	167 (8.7)	131 (6.5)	123 (6.3)
Gastrectomy with subtotal esophageal resection	N (%)	203 (5.6)	224 (6.1)	217 (5.8)	224 (5.9)	305 (7.9)	300 (7.4)
Partial esophageal resection	N (%)	1585 (44.1)	1602 (43.8)	1675 (44.7)	1599 (42.1)	1470 (38.2)	1703 (42.2)
Reconstruction of esophageal lumen (as isolated surgery)	N (%)	58 (1.6)	52 (1.4)	57 (1.5)	52 (1.4)	57 (1.5)	65 (1.6)
With splenectomy	N (%)	269 (7.5)	262 (7.2)	257 (6.9)	228 (6.0)	188 (4.9)	195 (4.8)
With cholecystectomy	N (%)	760 (21.1)	871 (23.8)	956 (25.5)	1004 (26.4)	1081 (28.1)	1211 (30.0)
With resection of other abdominal organs* ²	N (%)	453 (12.6)	448 (12.3)	448 (12.0)	423 (11.1)	384 (10.0)	419 (10.4)
Length of stay (days)	Mean	30.5	30.9	30.0	30.1	29.1	29.0
Died in hospital	N (%)	340 (9.5)	351 (9.6)	361 (9.6)	393 (10.3)	336 (8.7)	381 (9.4)
With at least one documented complication* ³	N (%)	1905 (52.9)	1991 (54.5)	2048 (54.6)	2113 (55.6)	2164 (56.3)	2221 (55.1)

IQR, Interquartile range (25th to 75th percentile); N, number; n, number (included therein); the minimum and maximum hospital case volumes cannot be stated on grounds of data protection.

*¹ Percentage refers to total esophageal resection.

*² Small intestine, large intestine, liver, or pancreas

*³ Surgical, septic, or cardiovascular complication (eTables 3 and 4)

in-hospital deaths, the incidence of complications, and the mortality among patients who develop complications (“failure to rescue”). The findings provide an empirical basis for the assessment of care and the planning of measures to improve care quality.

Methods

Data

The diagnosis-related groups (DRG) statistics microdata were accessed remotely in a controlled fashion via the Research Data Center of the German Federal Statistical Office (Destatis) (9). The DRG statistics contain the data records of all inpatient treatments billed according to the DRG system. The information available for each of these treatment cases includes age, sex, diagnoses (coded according to the International Statistical Classification of Diseases and Related Health Problems, 10th revision,

German modification, ICD-10-GM), procedures (coded according to the German Procedure Classification, OPS), length of hospital stay, and reason for discharge. The hospital where the treatment was performed can be identified by means of the anonymized institutional code number contained in every data record. Data from the period 2010 to 2015 were included.

Treatment cases

The units of analysis were treatment cases in which adult patients had undergone complex surgery on the esophagus. The treatment cases were identified by means of the OPS codes. Total and partial esophageal resections, cases of gastrectomy involving subtotal esophageal resection, and complex reconstructions of the esophageal lumen were all included. This definition corresponds to the minimum volume regulations of the

TABLE 2

Characteristics of treatment cases with complex esophageal surgery in the period 2010 to 2015, by volume quintile

Variables		Volume quintile				
		Very low	Low	Inter- mediate	High	Very high
Treatment cases with complex esophageal surgery, 2010 to 2015	N	4517	4540	4494	4402	4728
Mean annual number of hospitals	Mean	260.3	75.2	48.0	26.5	11.5
Annual case volume per hospital	Median (IQR)	2 (1–4)	10 (9–11)	15 (14–17)	26 (23–32)	62 (49–76)
Demography						
Age 65 years or more	N (%)	2568 (56.9)	2475 (54.5)	2269 (50.5)	2098 (47.7)	2189 (46.3)
Female	N (%)	1131 (25.0)	1096 (24.1)	1026 (22.8)	904 (20.5)	1046 (22.1)
Underlying disease						
Malignant neoplasia (MN) of esophagus	N (%)	3333 (73.8)	3573 (78.7)	3748 (83.4)	3853 (87.5)	4200 (88.8)
MN of neighboring organs or secondary MN	N (%)	726 (16.1)	643 (14.2)	423 (9.4)	215 (4.9)	217 (4.6)
Esophageal perforation	N (%)	153 (3.4)	86 (1.9)	111 (2.5)	96 (2.2)	119 (2.5)
Benign neoplasia of upper gastrointestinal tract	N (%)	31 (0.7)	22 (0.5)	17 (0.4)	24 (0.5)	23 (0.5)
Diverticulosis, achalasia, or obstruction of esophagus	N (%)	80 (1.8)	63 (1.4)	57 (1.3)	73 (1.7)	75 (1.6)
Other	N (%)	193 (4.3)	153 (3.4)	138 (3.1)	141 (3.2)	93 (2.0)
Type of intervention						
Total esophageal resection	N (%)	1377 (30.5)	1938 (42.7)	2171 (48.3)	2416 (54.9)	3331 (70.5)
-- with abdominocervical (transmediastinal) access ^{*1}	n (%)	179 (13.0)	244 (12.6)	210 (9.7)	177 (7.3)	193 (5.8)
Gastrectomy with subtotal esophageal resection	N (%)	439 (9.7)	384 (8.5)	259 (5.8)	178 (4.0)	213 (4.5)
Partial esophageal resection	N (%)	2646 (58.6)	2165 (47.7)	1993 (44.3)	1734 (39.4)	1096 (23.2)
Reconstruction of esophageal lumen (as isolated surgery)	N (%)	55 (1.2)	53 (1.2)	71 (1.6)	74 (1.7)	88 (1.9)
With splenectomy	N (%)	430 (9.5)	373 (8.2)	226 (5.0)	180 (4.1)	190 (4.0)
With cholecystectomy	N (%)	973 (21.5)	1043 (23.0)	1045 (23.3)	1154 (26.2)	1668 (35.3)
With resection of other abdominal organs ^{*2}	N (%)	704 (15.6)	598 (13.2)	433 (9.6)	388 (8.8)	452 (9.6)
Length of stay (days)	Mean	30.2	29.8	30.8	31.1	27.9
	Median (IQR)	22 (16–36)	22 (16–34)	22 (16–36)	22 (16–37)	20 (16–31)
Died in hospital	N (%)	553 (12.2)	453 (10.0)	449 (10.0)	384 (8.7)	323 (6.8)
With at least one documented complication ^{*3}	N (%)	2540 (56.2)	2377 (52.4)	2448 (54.5)	2533 (57.5)	2519 (53.3)

The volume quintile classifies the relative case volume of the treating hospital in the treatment year. IQR, Interquartile range (25th to 75th percentile); N, number; n, number (included therein); the minimum and maximum hospital case volumes cannot be stated on grounds of data protection.

^{*1} Percentage refers to total esophageal resection.

^{*2} Small intestine, large intestine, liver, or pancreas

^{*3} Surgical, septic, or cardiovascular complication (eTables 3 and 4)

Federal Joint Committee (G-BA)—with the exception of the codes, added in 2012, for implantation or exchange of a magnetic antireflux system. On the basis of the documented principal and secondary diagnoses, the treatment cases were divided into indication groups according to underlying disease (eTable 1).

Volume of cases at treating hospital

In order to obtain the volume of complex esophageal interventions carried out at each hospital, the treatment cases were aggregated at the level of institutional code number and year. The treatment cases

were then sorted according to the volume of their treating hospital and classified into five groups with similar numbers of cases (volume quintiles). The volume quintile categorized the relative volume of cases of the respective treating hospital in each treatment year (ranging from very low to very high). The absolute annual number of cases of the treating hospital was also regarded as a continuous variable in a separate analysis. In the course of manuscript revision, a post-hoc analysis was requested with the treatment cases divided into hospital-equivalent tertiles.

FIGURE 1

In-hospital mortality for treatment cases with complex esophageal interventions in the period 2010 to 2015, by volume quintile

The volume quintile categorizes the relative case volume of the treating hospital in the treatment year. Median volumes per year and hospital: very low 2; low 10; intermediate 15; high 26; very high 62.

* With 95% confidence interval. The variables and corresponding odds ratios considered in risk adjustment can be found in *eTable 3*.

Treatment outcome

The primary treatment outcome was risk-adjusted in-hospital mortality, and the secondary treatment outcomes were the indicators for complications and the in-hospital mortality among patients in whom such a complication was documented (“failure to rescue”) (10). The complications were categorized as surgical (e.g., endoscopic intervention as a sign of anastomotic insufficiency) (6), septic (e.g., sepsis as secondary diagnosis), and cardiovascular (e.g., acute myocardial infarction as secondary diagnosis) (*eTable 2*). Since a single treatment case could involve more than one complication, various types were summarized, in that treatment cases with at least one type of complication were counted.

Analysis

The characteristics of the treatment cases were first analyzed descriptively for each observation year, then the cumulative data were evaluated for the whole observation period.

In-hospital mortality was initially stratified according to volume quintile. We calculated not only the observed mortality but also the risk-adjusted mortality, by means of logistic regression procedures. To this end we used generalized estimation equations that took account of the distribution of patients over the hospitals. The regression models included age, sex, calendar year of treatment, and underlying disease. In addition, certain comorbidities were included that were very likely to have been present before the hospital stay (e.g., heart failure, chronic lung disease) and are possible risk factors for death in the hospital (6, 11) (*eTable 3*). For each treatment case, the expected risk of death was calculated and added up over the volume quintiles. The risk-adjusted mortality is the

ratio of observed to expected mortality multiplied by the average mortality risk in the observation period.

To define more closely the association of the case volume at the treating hospital with in-hospital mortality, we calculated risk-adjusted odds ratios (OR) for the whole observation period. The OR estimated the risk of dying in the hospital depending on the case volume at the treating institution. To this end, the case volume of the treating hospital was added to the above-mentioned regression models, on one hand as volume quintile and on the other hand as a continuous variable. Based on a method described in detail elsewhere (4, 12), we calculated a threshold value for the annual volume per hospital from which the risk of death was below the national average.

The incidence of complications and the observed in-hospital mortality of patients with complications (“failure to rescue”) were stratified by volume quintile.

The statistical significance of the results was assessed on the basis of 95% confidence intervals (CI). All calculations were made using SAS Version 9.3.

Results

Characteristics of treatment cases over time

The number of treatment cases involving a complex esophageal surgery rose from 3598 in 2010 to 4032 in 2015 (*Table 1*). The number of hospitals in which such surgeries were performed varied over time and was 406 in 2015. The median number of complex esophageal interventions per hospital and year rose from five to six during the observation period. In other words, in the year 2015 no more than six such operations took place in half of the hospitals where esophageal surgery was practiced.

FIGURE 2

Risk-adjusted odds ratio for mortality following a complex esophageal intervention, by case volume of treating hospital

*¹ The volume quintile categorizes the relative case volume of the treating hospital in the treatment year. Median volumes per year and hospital: very low 2; low 10; intermediate 15; high 26; very high 62. Area under curve (c-statistic): 0.773.

*² Actual case volume of treating hospital in treatment year. Area under curve (c-statistic): 0.774.

Malignant neoplasia constituted the most frequently coded underlying illness. In 2015 (2010), malignant neoplasia was coded in 83% (81%) of treatment cases, and in a further 9% (11%) the coded diagnosis was malignant neoplasia of a neighboring organ or secondary malignant neoplasia.

The proportion of total esophageal resections varied between 48% and 52%. Within this group, the rate of total resections with abdominocervical access decreased from 13% in 2010 to 6% in 2015.

Characteristics of treatment cases by volume quintile

After classification of the treatment cases according to the volume of cases at the treating hospital in the year concerned, each volume quintile contained more than 4400 treatment cases for analysis (Table 2). In the quintile with very low numbers of cases, 260 hospitals carried out a median of only two complex operations on the esophagus annually. In the quintile with very high numbers of cases, 12 hospitals performed a median of 62 such operations each year. The results of the post-hoc analysis according to hospital-equivalent tertiles can be found in eTable 5.

The proportion of patients aged 65 years or over was higher in hospitals with a low volume (57% in the lowest volume quintile) than in those with a high volume (46% in the highest quintile).

The rate of malignant neoplasia of the esophagus as underlying disease was lower in the lowest volume quintile than in the highest quintile (74% versus 89%), while malignant neoplasia of neighboring organs was coded more frequently (16% versus 5%).

As for the type of surgery, the proportion of operations made up by total esophageal resection was lower in the lowest volume quintile (30%) than in the highest quintile (70%), and the proportion of partial resections was higher (59% versus 23%). Gastrectomy with subtotal esophageal resection

was carried out in 10% of the patients in the bottom volume quintile and in 5% of those in the top quintile.

With regard to total esophageal resection, the proportion of surgeries with abdominocervical access was higher in hospitals with low volumes than in those with high volumes (bottom quintile 13% versus top quintile 6%).

In-hospital mortality

Figure 1 shows the observed and risk-adjusted in-hospital mortality stratified by volume quintile. The observed in-hospital mortality was 12.2% in the quintile of hospitals with very low volumes and 6.8% in the quintile with very high volumes. Risk adjustment narrowed this gap only slightly (to 11.4% versus 6.8%). Post-hoc analysis by hospital-equivalent tertile confirmed these results (eFigure).

Figure 2 shows the risk-adjusted OR. The risk of dying in hospital was around 18% lower (OR 0.82; 95% CI [0.70; 0.95]) in hospitals with low volumes than in hospitals with very low volumes. The reduction in hospitals with intermediate volumes did not attain statistical significance (OR 0.86 [0.74; 1.00]). In hospitals with high volumes the estimated reduction in mortality was 23% (OR 0.77 [0.65; 0.90]), and in those with very high volumes it was circa 50% (OR 0.50 [0.42; 0.60]).

When the annual case volume was considered as a continuous variable, each additional case per hospital and year yielded a reduction in the likelihood of dying in hospital of circa 1% (OR 0.99 [0.99; 0.99]). With 10 additional cases per hospital and year, the risk of mortality went down by about 8% (OR 0.92 [0.90; 0.94]) (Figure 2).

The threshold value from which in-hospital mortality below the national average of 9.5% in the observation period could be expected was 26 treatment cases [21; 32]. In 2015, 26 of the 406 hospitals (6%) reached this threshold (data not shown).

FIGURE 3

Incidence of complications and in-hospital mortality in patients with complications (“failure to rescue”), by volume quintile

With 95% confidence interval. The volume quintile categorizes the relative case volume of the treating hospital in the treatment year. Median volumes per year and hospital: very low 2; low 10; intermediate 15; high 26; very high 62.

* Complications included: endoscopic intervention (as sign of anastomotic insufficiency), pleural drainage/aspiration, pleural surgery, chylothorax, relaparotomy/rethoracotomy, transfusion of six or more units of blood, mediastinitis, pleural empyema, peritonitis (except with esophageal perforation), pneumonia, sepsis, acute myocardial infarction, stroke, or pulmonary embolism (see also eTables 2 and 4)

Incidence of complications, in-hospital mortality among patients with complications

Overall, more than 50% of the patients who underwent complex esophageal surgery experienced at least one complication (Figure 3). There was no trend in incidence of complications along the volume quintiles. In contrast, the in-hospital mortality among patients with one or more complications was 20% [18.5; 21.6] in hospitals with very low volumes and decreased quintile by quintile with increasing volumes. In hospitals with very high volumes, 12.3% [11.1; 13.7] of patients with complications died.

The incidence and associated mortality of the types of complications depicted in Figure 3 are listed separately in eTable 4.

In each volume quintile, at least one complication was documented in more than 90% of patients who died in hospital after a complex esophageal operation (eTable 4).

Discussion

In the year 2015 there were still more than 200 hospitals in Germany with an annual volume of six or fewer complex operations on the esophagus. In agreement with earlier investigations (13), we observed only a weak trend towards centralization over the period 2010 to 2015.

Analysis of the in-hospital mortality in relation to the treating hospital showed a clear association between case volume and outcome. The greatest reduction of mortality was seen in the highest volume quintile; in the middle quintiles, the results did not vary significantly. In the 12 hospitals with a median of 62 cases per year, which treated one fifth of all patients in the study, mortality was half that in the 260 hospitals with a median of two cases annually, which

also treated one fifth of the patients. A recently published study investigated the volume–outcome association in esophageal surgery to treat esophageal cancer (4). In contrast, our study included all types of esophageal surgery, while the risk adjustment took account of the different risks of death associated with different underlying diseases. The results of the two analyses are almost identical with regard to the association between volume and outcome. Esophageal cancer is the surgical indication for more than 80% of such operations.

Based on discharge data from all hospitals in Germany and including all indications, the study presented here estimated that the threshold above which mortality can be expected to be lower than the national average is 26 complex esophageal surgeries per year. In 2015, the most recent year analyzed, only 6% of hospitals attained this threshold. The statutory minimum volume is currently 10 cases per year, but a large proportion of hospitals do not achieve that figure (14, 15). In the Netherlands the minimum volume was raised to 20 in 2011 (16). The in-hospital mortality following complex esophageal surgery is higher in Germany than in countries such as the Netherlands, Great Britain, and Canada where these operations have been centralized (17–19).

Our analysis showed that the incidence of complications is not associated with the volume of cases. This finding has also been reported in studies from other countries (6, 7). Because the complexity of esophageal surgery means that they are associated with a host of perioperative risks, complications cannot always be avoided (20). However, the variation in survival of patients with complications shows that their management is an essential factor in explaining the volume–outcome association in complex

esophageal surgery. Comparison with the mortality in the uppermost quintile shows that around 80% of the additional deaths in the lowest quintile can be attributed to “failure to rescue.” These findings correspond with international analyses describing the “failure to rescue” effect for various complex operations (5, 7–8, 21–23).

The strength of this study lies in its use of comprehensive DRG billing data from all German hospitals. This permits depiction of the true situation with regard to complex esophageal operations and their complications, including institutions with very low case numbers. It should be pointed out, however, that the DRG data for billing purposes are documented by the individual hospitals themselves, so differences in the incidence of the characteristics analyzed may be caused by variations in coding practice. Moreover, the use of the institutional code number to distinguish the hospitals may have led to a degree of inaccuracy in determining the case volumes. Since the institutional code number does not necessarily precisely identify the location of the hospital concerned, it is possible that two or more hospitals bill under the same code number (24). This could result in overestimation of the volume of cases in some hospitals, thus introducing distortion of the differences in in-hospital mortality towards the null hypothesis. It must be remembered that no causal relationship between volume and outcome can be proved by retrospective observational studies. Although it is probable that the case volume of a hospital is correlated with specific factors that determine the treatment quality (e.g., the surgeon’s experience, the density of nursing staff, or certain structural characteristics), these details are not contained in the data we used. The patients’ social status, which may yield pointers to possible inequalities of access to care, is also not included in the data and thus could not be analyzed.

Conclusion

The findings of our study indicate that the care quality of esophageal surgery in Germany could be improved if more patients were treated in hospitals with high case volumes. The observed volume–outcome association appears to depend essentially on the management of complications. It seems plausible that greater experience of highly complex interventions may lead to timely recognition of complications by physicians, nurses, and other members of the treatment team. Furthermore, hospitals with high volumes are generally equipped and structured in a way that enables the staff to react early and appropriately to complications, however serious.

The results of this study should be used to place the care provided in German hospitals on an evidential basis. Our findings should also be made known to patients and referring physicians, who will then be able to make better-informed decisions should esophageal surgery be planned.

Conflict of interest statement

Dr. Nimptsch and Prof. Mansky work in the Department of Structural Development and Quality Management in the Health System. This department is a chair endowed by Helios Kliniken GmbH.

The remaining authors declare that no conflict of interest exists.

Manuscript submitted on 20 March 2018, revised version accepted on 9 August 2018

Translated from the original German by David Roseveare

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► Supplementary material

For eReferences please refer to:

www.aerzteblatt-international.de/ref4718

eTables, eFigure:

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Key Messages

- In 2015 half of the circa 400 hospitals in Germany where complex esophageal operations were carried out attained an annual volume of no more than six cases.
 - Analysis of in-hospital mortality in the period 2010 to 2015 showed a clear association between volume and outcome. The risk of death in hospitals with a median 62 cases per year, as estimated using the odds ratio, was half that in hospitals with a median annual volume of two cases.
 - Complications were documented in more than 50% of patients who underwent complex esophageal surgery. The complication rate was not associated with the volume of cases per hospital.
 - The mortality among patients with complications was 20% in hospitals with very low volumes and 12% in hospitals with very high volumes.
 - The management of complications seems to be an essential factor influencing the volume–outcome association in complex esophageal surgery.
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Supplementary material to:

Hospital Volume, In-Hospital Mortality, and Failure to Rescue in Esophageal Surgery

An Analysis of German Hospital Discharge Data

by Ulrike Nimptsch, Thomas Haist, Christian Krautz, Robert Grützmann, Thomas Mansky, and Dietmar Lorenz

Dtsch Arztebl Int 2018; 115: 793–800. DOI: 10.3238/arztebl.2018.0793

eTABLE 1

Definition of treatment cases and stratification variables

Variable	Inclusion	Exclusion
Treatment cases		
Adult patients with a complex operation on the esophagus	OPS 5423 5424 5425 5426 54270 54271 54380 54381 5438x*	Age under 20 years
Stratification variables		
Underlying disease		
Malignant neoplasia of esophagus	PD or SD C15 C160 D001	
Malignant neoplasia of neighboring organs or secondary malignant neoplasia	PD or SD C161–C169 C17–C26 C34 C38 C39 C761 C762 C768 C77–C79 C97 D002 D01 D02	PD or SD C15 C160 D001
Esophageal perforation	PD oder SD K223 S2783	PD or SD C15 C160 D001 C161–C169 C17–C26 C34 C38 C39 C761 C762 C768 C77–C79 C97 D002 D01 D02
Benign neoplasia of upper gastrointestinal tract	PD D130 D131 D371 D377	SD C15 C160 D001 C161–C169 C17–C26 C34 C38 C39 C761 C762 C768 C77–C79 C97 D002 D01 D02 K223 S2783
Diverticulosis, achalasia, or obstruction of esophagus	PD K225 Q3936 K220 K224 K222	SD C15 C160 D001 C161–C169 C17–C26 C34 C38 C39 C761 C762 C768 C77–C79 C97 D002 D01 D02 K223 S2783
Other		PD or SD C15 C160 D001 C161–C169 C17–C26 C34 C38 C39 C761 C762 C768 C77–C79 C97 D002 D01 D02 K223 S2783 PD D130 D131 D371 D377 K225 Q3936 K220 K224 K222
Type of surgery		
Total esophageal resection	OPS 5425 5426	
– with abdominocervical (transmediastinal) access	OPS 54250 54260	
Gastrectomy with subtotal esophageal resection	OPS 54380 54381 5438x	OPS 5425 5426
Partial esophageal resection	OPS 5423 5424	OPS 5425 5426 54380 54381 5438x
Reconstruction of esophageal lumen (as isolated surgery)	OPS 54270 54271	OPS 5425 5426 54380 54381 5438x 5423 5424
With splenectomy	OPS 5413	
With cholecystectomy	OPS 55114 55115	
With resection of other abdominal organs (small intestine, large intestine, liver, or pancreas)	OPS 5413 54540 54541 54542 54543 54544 54545 54546 5454x 5454y 5455 5502 5524 5525	

ICD-10-GM, International Statistical Classification of Diseases and Related Health Problems, 10th revision, German modification; OPS, German Procedure Classification; PD, principal diagnosis (ICD-10-GM); SD, secondary diagnosis (ICD-10-GM)

* The definition corresponds to the minimum volume regulations, with the exception of the codes, added in 2012, for implantation or exchange of a magnetic antireflux system (5–429.p and 5–429.q).

eTABLE 2

Definition of indicators for complications

Indicator	Definition
Surgical complication	
Endoscopic intervention (as sign of anastomotic insufficiency)	OPS 542941 5429d 5429j1 5429j4 5429ja 5429k1 5429n 5449d3 5449h3 5449k3
Endoscopic pleural drainage	OPS 81440 81521
Surgical intervention on the pleura (including decortication of the lung)	OPS 5344
Chylothorax	SD J940
Relaparotomy or rethoracotomy	OPS 55413 55414 55450 55451 55411
Transfusion of six or more units of erythrocytes or whole blood	OPS 88001 8800c1-cr 880070–7e
Septic complication	
Mediastinitis	SD J853 J9850
Pleural empyema	SD J86
Peritonitis*	SD K65
Pneumonia	SD A481 J100 J110 J12 J13 J14 J15 J16 J17 J18 J690 J698
Sepsis	SD A40 A41 R572 R650 R651
Cardiovascular complication	
Stroke, acute myocardial infarction or pulmonary embolism as secondary diagnosis	SD I21 I26 I60 I61 I63 I64

ICD, International Statistical Classification of Diseases and Related Health Problems, 10th revision, German modification; OPS, German Procedure Classification; SD, secondary diagnosis (ICD-10-GM)

*Not counted in treatment cases with esophageal perforation

eTABLE 3

Definition of the variables for risk adjustment and corresponding odds ratio for in-hospital mortality, 2010 to 2015*

Variable	N (%)	Definition	Risk-adjusted odds ratio (95% CI)
Treatment year		2010, 2011, 2012, 2013, 2014, 2015	1.0 [0.9; 1.0]
Five-year age group		20–24, 25–29, 30–34, ..., 70–74, 75–79, 80–84, 85–89, 90–94, 95 and over	1.2 [1.2; 1.2]
Female	5203 (22.9%)		1.1 [0.9; 1.2]
Underlying disease			
Malignant neoplasia of esophagus	18 707 (82.5%)	eTable 1	Reference
Malignant neoplasia of neighboring organs or secondary malignant neoplasia	2224 (9.8%)	eTable 1	1.3 [1.1; 1.5]
Esophageal perforation	565 (2.5%)	eTable 1	3.4 [2.7; 4.3]
Benign neoplasia of upper gastrointestinal tract, diverticulosis, achalasia, or obstruction of esophagus	348 (1.5%)	eTable 1	0.6 [0.4; 1.0]
Other	718 (3.2%)	eTable 1	2.6 [2.1; 3.3]
Comorbidity			
Cardiac arrhythmia	4378 (19.3%)	SD I442 I48 Z450 Z950	2.1 [1.9; 2.3]
Heart failure or cardiomyopathy	1948 (8.6%)	SD I50 I110 I130 I132 I420 I426 I427 I428 I429	2.0 [1.7; 2.3]
Chronic ischemic heart disease	2804 (12.4%)	SD I25	1.1 [1.0; 1.3]
Hypertensin (without renal insufficiency)	11 023 (48.6%)	SD I10 I119 I129 I139 I15	0.8 [0.7; 0.8]
Aortic or mitral valve defect	503 (2.2%)	SD I340 I342 I350 I351 I352 I050 I051 I052 I060 I061 I062 Q230 Q231 Q232 Q233	0.9 [0.7; 1.2]
Atherosclerosis of the extremity arteries	621 (2.7%)	SD I702	2.4 [1.9; 3.0]
Chronic lung disease	2 831 (12.5%)	SD J41 J42 J44 J45 J47	1.2 [1.0; 1.3]
Chronic liver disease	957 (4.2%)	SD B18 K70 K73 K74 K760 K761 K765 K766 K767 Q446 Q447	2.2 [1.8; 2.7]
Severe renal disease or chronic renal insufficiency	1968 (8.7%)	SD N03 N04 N05 N07 N08 N11 N12 N14 N15 N16 I120 I131 I132 N18 N19 Z992	1.5 [1.3; 1.7]
Diabetes mellitus	4216 (18.6%)	SD E10 E11 E12 E13 E14	1.0 [0.9; 1.1]
Obesity	1778 (7.8%)	SD E66	1.0 [0.8; 1.2]
Cachexia or malnutrition	2185 (9.6%)	SD R64 E40 E41 E42 E43 E44	0.8 [0.7; 1.0]
Coagulopathy	4449 (19.6%)	SD D66 D67 D680 D681 D682 D684 D685 D686 D888 D889 D691 D693 D694	3.1 [2.8; 3.5]

* Total of 22 681 treatment cases. Area under the curve (c-statistic): 0.768. CI, Confidence interval; ICD, International Statistical Classification of Diseases and Related Health Problems, 10th revision, German modification; N, number; SD, secondary diagnosis (ICD-10-GM)

eTABLE 4

Incidence of complications and of in-hospital mortality following complications ("failure to rescue") by volume quintile

Variables		Volume quintile									
		Very low		Low		Intermediate		High		Very high	
		N	% (95% CI)	N	% (95% CI)	N	% (95% CI)	N	% (95% CI)	N	% (95% CI)
Treatment cases with complex operation on the esophagus, 2010 to 2015	Number	4517		4540		4494		4402		4728	
Surgical complications											
Endoscopic intervention (as sign of anastomotic insufficiency)	Total number	547	12.1	535	11.8	541	12.0	444	10.1	408	8.6
	Deaths	153	28.0 [24.4; 31.9]	129	24.1 [20.7; 27.9]	127	23.5 [20.1; 27.2]	89*	20.0 [16.6; 24.0]	76*	18.6 [15.2; 22.7]
Pleural drainage/pleural aspiration	Total number	1294	28.6	1218	26.8	1272	28.3	1446	32.8	1392	29.4
	Deaths	232	17.9 [15.9; 20.1]	195	16.0 [14.1; 18.2]	208	16.4 [14.4; 18.5]	208	14.4 [12.7; 16.3]	174*	12.5 [10.9; 14.3]
Surgical intervention on pleura (incl. decortication of the lung)	Total number	154	3.4	148	3.3	145	3.2	132	3.0	186	3.9
	Deaths	39	25.5 [19.1; 32.7]	37	25.0 [18.7; 32.6]	26	17.9 [12.5; 25.0]	26	19.7 [13.8; 27.3]	27	14.5 [10.2; 20.3]
Chylothorax	Total number	39	0.9	36	0.8	54	1.2	66	1.5	41	0.9
	Deaths	6	15.4 [7.3; 29.7]	5	13.9 [6.1; 28.7]	6	11.1 [5.2; 22.2]	10	15.2 [8.4; 25.7]	5	12.2 [5.3; 25.5]
Relaparotomy or rethoracotomy	Total number	268	5.9	179	3.9	198	4.4	218	5.0	164	3.5
	Deaths	76	28.4 [23.3; 34.0]	61	34.1 [27.5; 41.3]	51	25.8 [20.2; 32.3]	63	28.9 [23.3; 35.2]	44	26.8 [20.6; 34.1]
Transfusion of six or more units of whole blood or erythrocytes	Total number	798	17.7	701	15.4	774	17.2	852	19.4	749	15.8
	Deaths	301	37.7 [34.4; 41.1]	269	38.4 [34.9; 42.0]	266	34.4 [31.1; 37.8]	279	32.7 [29.7; 36.0]	236	31.5 [28.3; 34.9]
At least one of the above-mentioned surgical complications	Total number	2042	45.2	1894	41.7	1965	43.7	2078	47.2	2018	42.7
	Deaths	431	21.1 [19.4; 22.9]	372	19.6 [17.9; 21.5]	357	18.2 [16.5; 19.9]	331*	15.9 [14.4; 17.6]	286*	14.2 [12.7; 15.8]
Septic complications											
Mediastinitis	Total number	219	4.8	157	3.5	201	4.5	214	4.9	177	3.7
	Deaths	88	40.2 [33.9; 46.8]	67	42.7 [35.2; 50.5]	81	40.3 [33.8; 47.2]	74	34.6 [28.5; 41.2]	66	37.3 [30.5; 44.6]
Pleural empyema	Total number	280	6.2	273	6.0	298	6.6	302	6.9	285	6.0
	Deaths	84	30.0 [24.9; 35.6]	82	30.0 [24.9; 35.7]	76	25.5 [20.9; 30.7]	79	26.2 [21.5; 31.4]	67	23.5 [19.0; 28.8]
Peritonitis ^{*1}	Total number	253	5.6	193	4.3	188	4.2	194	4.4	185	3.9
	Deaths	98	38.7 [32.9; 44.9]	68	35.2 [28.8; 42.2]	62	33.0 [26.7; 40.0]	70	36.1 [29.7; 43.1]	66	35.7 [29.1; 42.8]
Pneumonia	Total number	1023	22.6	1031	22.7	1052	23.4	1125	25.6	1157	24.5
	Deaths	253	24.7 [22.2; 27.5]	241	23.4 [20.9; 26.1]	235	22.3 [19.9; 25.0]	217*	19.3 [17.1; 21.7]	207*	17.9 [15.8; 20.2]
Sepsis	Total number	721	16.0	680	15.0	711	15.8	699	15.9	718	15.2

Variables		Volume quintile									
		Very low		Low		Intermediate		High		Very high	
		N	% (95% CI)	N	% (95% CI)	N	% (95% CI)	N	% (95% CI)	N	% (95% CI)
At least one of the above-mentioned septic complications	Deaths	288	39.9 [36.4; 43.6]	244	35.9 [32.4; 39.6]	260	36.6 [33.1; 40.2]	248	35.5 [32.0; 39.1]	219*	30.5 [27.2; 34.0]
	Total number	1562	34.6	1488	32.8	1534	34.1	1552	35.3	1530	32.4
	Deaths	431	27.6 [25.4; 29.9]	369	24.8 [22.7; 27.1]	365	23.8 [21.7; 26.0]	324*	20.9 [18.9; 23.0]	277*	18.1 [16.3; 20.1]
Cardiovascular complications											
Stroke, myocardial infarction or pulmonary embolism	Total number	187	4.1	181	4.0	187	4.2	201	4.6	203	4.3
	Deaths	68	36.4 [29.8; 43.5]	60	33.1 [26.7; 40.3]	61	32.6 [26.3; 39.6]	48	23.9 [18.5; 30.2]	40*	19.7 [14.8; 25.7]
Overall complications index^{*2}											
Surgical, septic, or cardiovascular complication	Total number	2540	56.2	2377	52.4	2448	54.5	2533	57.5	2519	53.3
	Deaths	509	20.0 [18.5; 21.6]	424	17.8 [16.4; 19.4]	421	17.2 [15.8; 18.7]	367*	14.5 [13.2; 15.9]	311*	12.3 [11.1; 13.7]
Overall mortality											
Total number of deaths	Number	553	12.2	453	10.0	449	10.0	384	8.7	323	6.8
	With one or more complications	509	92.0	424	93.6	421	93.8	367	95.6	311	96.3

The volume quintile categorizes the relative case volume of the treating hospital in the treatment year. Median volumes per year and hospital: very low 2; low 10; intermediate 15; high 26; very high 62.

CI, Confidence interval; N, number

* Statistically significantly lower in-hospital mortality than in volume quintile with very low volumes

*1 Not counted in treatment cases with esophageal perforation

*2 Denominator: all treatment cases in which at least one of the above-mentioned complications was documented.

Numerator: deaths among the treatment cases with at least one complication.

Since particularly those patients who die are affected by complications, the relative proportion of deaths is sometimes lower here than when considering individual types of complications.

eTABLE 5

Treatment cases with complex esophageal intervention from 2010 to 2015, by hospital-equivalent tertile (post-hoc analysis)

Variables		Hospital tertile		
		Lowest tertile	Middle tertile	Highest tertile
Treatment cases with complex esophageal intervention, 2010 to 2015	N	1 051	4 453	17 177
Mean number of hospitals with at least one treatment case per year	Mean	138.8	141.0	141.7
Annual volume per hospital	Median (IQR)	1 (1–2)	5 (3–7)	14 (11–22)

Division into hospital-equivalent tertiles resulted in an average of circa 140 hospitals per tertile.

The case numbers, at 1051 in the bottom tertile, 4453 in the middle tertile, and 17 177 in the top tertile, are very unevenly distributed.

The interquartile range (IQR; 50% of the hospitals in each case) of the annual volume is 1–2 treatment cases in the bottom tertile,

3–7 treatment cases in the middle tertile, and 11–22 treatment cases in the top tertile.

The minimum and maximum hospital case volumes cannot be stated on grounds of data protection.

Division into hospital-equivalent tertiles, demanded by the editorial office and reviewers, led to hospitals with volumes below the legal minimum, i.e., those that infringe the regulations, being divided again into two groups.

In contrast, all other hospitals with volumes of 9 to more than 70 cases per year (cf. Table 2) are contained in one group.

N, number

In-hospital mortality for treatment cases with complex esophageal interventions in the period 2010 to 2015, by hospital-equivalent tertile

Median case volume per year and hospital: bottom tertile 1; middle tertile 5; top tertile 14

* With 95% confidence interval. The variables and corresponding odds ratios considered in risk adjustment can be found in *eTable 3*. As was to be expected in light of a previous study that investigated how the outcome differed depending on adherence to the minimum volume regulations (14), also in this breakdown of the data the adjusted in-hospital mortality was significantly lower in the top tertile than in the bottom and middle tertiles. The adjusted in-hospital mortality (95% CI) in the tertiles was, respectively, 12.8% [10.9; 14.9], 10.6% [9.7; 11.6], and 9.0% (8.5; 9.5). The clear reduction in mortality in hospitals with very high case volumes that was observed in the main analysis (*Figure 1*) is concealed in this categorization.