Costs of excessive postoperative hemorrhage in cardiac surgery

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Background: Excessive postoperative hemorrhage in cardiac surgery is a serious clinical complication placing substantial demands on hospital resources. This study quantifies the exact impact of postoperative hemorrhage on hospital costs in Germany.

Methods: We retrospectively analyzed data collected prospectively in the Quality Assurance Database at the Heart Center of the Klinikum Augsburg, Germany. All relevant perioperative data for resources consumption were analyzed and compared in patients with and without excessive postoperative hemorrhage in cardiac surgery. Multivariate regression analysis identified the incremental costs of postoperative hemorrhage while adjusting for potential confounding.

Results: A total of 1118 patients had cardiac surgery between January and December 2006. Six percent were identified with excessive postoperative hemorrhage. The risk of experiencing a postoperative complication (including death) ($P < .0001$), returning to operating room for reexploration ($P < .0001$), staying in intensive care unit for longer than 72 hours ($P < .0001$), receiving ventilation for longer than 24 hours ($P < .0001$), and receiving any kind of postoperative blood transfusion ($P < .0001$) was significantly higher in patients with excessive postoperative hemorrhage. Twenty-two percent of patients with excessive postoperative hemorrhage died compared with 6% of the patients without excessive postoperative hemorrhage ($P < .0001$). When adjusting for potential confounding factors, the incremental costs of excessive postoperative hemorrhage was €6251 (95% confidence interval, 4594–7909).

Conclusions: The average hospital costs related to excessive postoperative hemorrhage in cardiac surgery in Germany are substantial and associated with a significant risk of postoperative complications and death. Clinical interventions that can effectively prevent or address excessive postoperative hemorrhage in cardiac surgery are likely to have substantial cost-effectiveness potential.

Excessive postoperative hemorrhage in cardiac surgery is a serious complication that is independently associated with serious postoperative adverse events, including sepsis, acute respiratory distress syndrome, renal failure, and death.^{1–5} Excessive postoperative hemorrhage and its associated risk of reexploration also place a high demand on hospital resources in terms of transfusion needs, ventilatory support requirements, intensive care support, and manpower requirements.^{5–9} No standard definition of excessive postoperative hemorrhage exists,¹⁰ and there is a lack of solid incidence data as a result, yet reports in the literature indicate that 3% to 5% of patients undergoing cardiac surgery require a second operation to control postoperative hemorrhage.^{3,4,9,11}

Despite the substantial toll on hospital resources, little is in fact known about the exact economic impact of this complication. To our knowledge, only one group of researchers has examined the cost of postoperative hemorrhage in cardiac surgery.^{7,8} In these small case-control US studies, patients with postoperative hemorrhage required significantly more blood transfusion and longer intensive care unit (ICU) and hospital stay. The mean incremental costs of excessive postoperative hemorrhage, defined as postoperative chest tube drainage greater than 800 mL during a 4-hour period, was \$11,266.⁸

Knowledge of the economic consequences of excessive postoperative hemorrhage is a highly essential step in the efforts to identify potentially cost-effective clinical interventions in cardiac surgery. Avoidance of postoperative hemorrhage may reduce morbidity and mortality and reduce the requirements for hospital resources.^{12,13} Depending on their costs, new clinical interventions can either be cost-saving (if hospital costs savings are greater than the cost of the intervention), cost-effective (if the incremental costs of using the clinical intervention is reasonable in regards to the clinical benefits obtained), or cost-enhancing (if the clinical intervention induces higher hospital costs without any clinical benefit). By quantifying the economic consequences of excessive postoperative hemorrhage, it is possible to evaluate the cost-effectiveness of clinical interventions to avoid excessive hemorrhage and hopefully optimize the clinical pathway and outcome.

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Abbreviations and Acronyms

AMI	= acute myocardial infarction
CPB	= cardiopulmonary bypass
ICU	= intensive care unit
TISS-28	= Therapeutic Intervention Scoring System

The objective of this study is to quantify the incremental average hospital costs of excessive postoperative hemorrhage in cardiac surgery in Germany.

METHODS**Definition of Excessive Postoperative Hemorrhage**

We defined excessive postoperative hemorrhage as postoperative bleeding into drains placed in the cardiothoracic cavity after admission to the ICU. Drainage loss was assessed on an hourly basis after completion of a 30-minute stabilization period. Drainage loss was defined by at least 1 of the following criteria: (1) ≥ 200 mL/h in any 1 hour or part thereof, or (2) ≥ 2 mL/kg/h for 2 consecutive hours in the first 6 hours after surgery. Blood loss during the stabilization period was not included in the definition of the volume criteria as such loss may be due to postural changes when transferring the patient from the operating room table to the bed or due to fluid in the pleural or mediastinal cavity, which may have arisen from the rinsing with water as an attempt to achieve surgical hemostasis. Information on hourly bleeding was manually extracted from patient records.

Study Population

The Quality Assurance Database in Germany was established in 2001 to enhance the quality of all surgical interventions performed in the country. All cardiac surgery units submit annually a standard set of perioperative data related to all cardiac surgeries performed. In this study, we obtained data for all patients aged 18+ having cardiac surgery at the Heart Center of the Klinikum Augsburg between January 1, 2006 and December 31, 2006. A total of 1233 patients had cardiac surgery with cardiopulmonary bypass (CPB) at this hospital that year, and after adjusting for inconsistent data, 1188 patients were eligible to be included in the study. The Institutional Review Board at Klinikum Augsburg approved the study (IRB No. 45033).

Data Collection and Cost Assessment

All relevant data on patient characteristics, surgical care, postoperative care, and clinical outcomes were collected. All postoperative complications identified were defined according to the National Bundesgeschäftsstelle Qualitätssicherung gGmbH definitions¹⁴ as the Quality Assurance database at Klinikum Augsburg follows the exact same data structure as the national Bundesgeschäftsstelle Qualitätssicherung gGmbH database. We calculated treatment costs for each patient according to resources consumed during surgery, resources consumed in ICU, and resources consumed in general ward before hospital discharge. Specifically, we investigated costs by type of surgery, surgery time, need and time for hemofiltration, intra-aortic balloon pump, and extracorporeal membrane oxygenation, incidence of re-exploration for bleeding and other causes, blood transfusion (all types of products), admission and length of stay in ICU, ventilatory support requirements, manpower requirements in ICU as measured by the Therapeutic Intervention Scoring System (TISS-28) score, and length of stay in hospital after discharge from ICU. Data on unit costs were obtained for all relevant resource use (Appendix 1). Treatment costs were determined on a patient-level basis by multiplying the individual resource use with the relevant unit costs. Overhead costs were not specifically accounted for in this anal-

ysis, yet they were captured in the cost for ICU and general ward stay (cost per day).

Statistical Analysis

First, we examined the demographic and clinical characteristics (pre- and postoperative) of the study population and the acute treatment provided in the total cohort and separately in patients with and without postoperative hemorrhage. Noncontinuous variables were compared using the chi-square test or Fisher exact test, as appropriate. Continuous variables were described by the mean $\pm$ standard deviation. The Mann-Whitney rank-sum test was used to compare medians where a normality test failed. Second, we computed treatment costs for every patient and calculated average treatment costs for the total study population. The average costs of treatment was analyzed according to the main components of care and the unadjusted differences in costs between patients with and without excessive postoperative hemorrhage were analyzed. Third, to identify the incremental costs of excessive postoperative hemorrhage while adjusting for potential confounding factors, we undertook a multivariate regression analysis using ordinary least squares. We adjusted for all pre- and intraoperative characteristics that potentially could explain differences in treatment costs between patients with and without excessive postoperative hemorrhage. All statistical analyses were performed using LimDep Software, Version 3.0.5, 2003.

RESULTS

Of the 1188 patients with complete data, 57.2% had primary coronary artery bypass grafting surgery; 18.3%, single valve surgery (repair or replacement); 22%, both types of surgeries; and 2.5%, other types of major cardiac surgery, including aortic root replacement. A total of 76 patients (6.4%) were identified with excessive postoperative hemorrhage after applying the criteria for hemorrhage in the ICU. The preoperative characteristics of patients are shown in Table 1. Seventy-two percent ($n = 865$) of the patients were men, and the mean age was 67 years (± 11). Forty-nine percent were admitted with a primary diagnosis of acute myocardial infarction (AMI), and 24% were admitted with valve disorder. Patient with excessive postoperative hemorrhage were significantly more likely to have preoperative renal dysfunction ($P = .0229$), liver disease ($P = .0458$), preoperative coagulopathy ($P = .0207$), and emergency surgery ($P = .0416$). Duration of surgery ($P = .0012$) and time on CPB ($P = .0015$) were also significantly longer in patients with excessive postoperative hemorrhage (Table 2), and they were significantly more likely to require hemofiltration ($P = .001$) and intra-aortic balloon pump support ($P = .0488$) and to experience intraoperative complications ($P = .0024$).

Differences in postoperative characteristics between patients with and without excessive postoperative hemorrhage are shown in Table 3. Excessive postoperative hemorrhage was significantly associated with postoperative complications, including stroke ($P = .0002$), low cardiac output ($P = .0240$), pleural effusion ($P < .0001$), postoperative pericardial tamponade ($P = .0013$), and coagulopathy ($P < .0001$). Patients with excessive postoperative hemorrhage were also significantly more likely to require prolonged ventilation after surgery ($P < .0001$), re-exploration for bleeding ($P < .0001$) and other causes ($P = .0075$),

TABLE 1. Preoperative characteristics of the patient cohort

Variable	Total cohort (n = 1188)	No bleeding (n = 1112)	Bleeding (n = 76)	P value, bleeding vs no bleeding
All patients (n, %)	1,188	1,112	76 (6.4%)	—
Mean age, y (mean ± SD)	67.2 (±10.8)	67.2 (±10.8)	66.9 (±12.1)	.4950
Male sex (n, %)	865 (72.8%)	803 (72.2%)	62 (81.6%)	.0710
Mean BMI (mean ± SD)	27.6 (±4.9)	27.6 (±4.9)	27.1 (±4.9)	.347
Admitting diagnosis (n, %)				
Unstable angina	79 (6.6%)	75 (6.7%)	4 (5.3%)	.6576
Acute myocardial infarction	583 (49.1%)	551 (49.6%)	32 (42.1%)	.2119
Valve disorder	290 (24.4%)	270 (36.8%)	20 (26.3%)	.6800
Other underlying disorder	236 (19.9%)	216 (19.7%)	20 (26.3%)	.1560
Preoperative antithrombotics (aspirin and clopidogrel)	663 (55.8%)	623 (56.0%)	40 (52.6%)	.5656
Preoperative anticoagulants (n, %)	263 (22.1%)	246 (22.1%)	17 (22.4%)	.9426
IV nitrate (n, %)	55 (4.6%)	52 (4.7%)	3 (3.9%)	.8232
IV inotrope (n, %)	22 (1.9%)	19 (1.7%)	3 (3.9%)	.2087
Preoperative HCT (mean ± SD)	40.0 (±5.14)	40.1 (±5.12)	39.1 (±5.2)	.1083
Preoperative renal dysfunction (n, %)	302 (25.4%)	274 (24.6%)	28 (36.8%)	.0229
Preoperative creatinine (mg/dL)	1.15 (±0.6)	1.13 (±0.6)	1.3 (±0.6)	.013
Comorbidities (n, %)				
Liver disease	61 (5.1%)	53 (4.8%)	8 (10.5%)	.0485
GI disease	68 (5.7%)	65 (5.8%)	3 (3.9%)	.5269
Endocrine disease	85 (7.2%)	76 (6.8%)	9 (11.8%)	.1243
Malignancy	35 (2.9%)	33 (3.0%)	2 (2.6%)	.9406
Other	334 (28.1%)	317 (28.5%)	17 (22.4%)	.2510
Acute infections	83 (7%)	78 (7.0%)	5 (6.6%)	.9316
Preoperative coagulopathy	17 (1.4%)	13 (1.2%)	4 (5.3%)	.0207
Previous OR (n, %)	87 (7.3%)	77 (6.9%)	10 (13.2%)	.0631
Urgency (n, %)				
Elective	450 (37.9%)	431 (38.8%)	19 (25.0%)	.0152
Urgent	485 (40.8%)	452 (40.6%)	33 (43.4%)	.6333
Emergent	241 (20.3%)	220 (19.8%)	21 (27.6%)	.1107
Emergency/resuscitation	12 (1.0%)	9 (0.8%)	3 (3.9%)	.0416

BMI, Body mass index; CABG, coronary artery bypass graft; HCT, hematocrit; IV, intravenous; GI, gastrointestinal; OR, operations; SD, standard deviation.

transfusion of all blood products ($P < .0001$), stay in the ICU for more than 72 hours ($P < .0001$), and more manpower while in the ICU as measured by the TISS-28 score ($P < .0001$). In total, 22.4% of the patients with excessive postoperative hemorrhage were dead at 30 days after cardiac surgery, which was significantly higher than the 5.5% mortality rate observed in patients without excessive hemorrhage ($P < .0001$).

Univariate analysis of the key cost drivers in cardiac surgery revealed significantly higher costs in patients with excessive postoperative hemorrhage (Table 4). The cost of

ICU stay dominated overall costs (51%), followed by the cost of manpower requirements (TISS-28 score) (28%), surgery (27%), and length of stay in general ward (10%). The cost of reexploration (3%) and blood transfusion (4%) contributed little to the overall hospital costs. Without adjustment for potential confounding factors, the average hospital costs of patients with and without excessive postoperative hemorrhage were €15,404 (±8986) and €8027 (±7557), respectively. Adjustment for relevant confounders in multivariate analysis indicated a significant incremental cost of excessive postoperative hemorrhage of €6251

TABLE 2. Intraoperative characteristics of patient cohort

Surgery-related covariates	Total cohort (n = 1188)	No bleeding (n = 1112)	Bleeding (n = 76)	P value, bleeding vs no bleeding
Surgery time (min)	172.8 (±50.2)	170.6 (±46.2)	205.2 (±84.7)	.0012
CPB duration (min)	78.3 (±33.3)	77.1 (±31.5)	96.3 (±50.8)	.0015
Body temperature	34.8 (±2.9)	34.9 (±2.8)	33.8 (±3.5)	.0009
Use of IABP	40 (3.4%)	34 (3.1%)	6 (7.9%)	.0488
Any intraoperative complications*	38 (3.2%)	30 (2.7%)	8 (10.5%)	.0024
Other intraoperative complications	20 (1.7%)	16 (1.4%)	4 (5.3%)	.0410

CPB, Cardiopulmonary bypass; IABP, intra-aortic balloon pump; ECMO, extracorporeal membrane oxygenation. *Intraoperative complications included low cardiac output, hypoxemia, and other intraoperative complications.

TABLE 3. Postoperative characteristics of patient cohort

Variable	Total cohort (n = 1188)	No bleeding (n = 1112)	Bleeding (n = 76)	P value, bleeding vs no bleeding
Postoperative complications	75 (6.3%)	60 (5.4%)	15 (19.7%)	<.0001
Stroke	58 (4.9%)	46 (4.1%)	12 (15.8%)	.0002
Low cardiac output	65 (5.5%)	54 (4.9%)	11 (14.5%)	.0240
Pleural effusion	106 (8.9%)	93 (8.4%)	26 (34.2%)	<.0001
Tamponade	43 (3.6%)	34 (3.1%)	9 (11.8%)	.0013
Coagulopathy	16 (1.3%)	7 (0.6%)	9 (11.8%)	<.0001
Postoperative ventilation				
>24 h	147 (12.4%)	120 (10.8%)	27 (35.5%)	<.0001
Hemofiltration	188 (15.8%)	165 (14.8%)	23 (30.3%)	.001
Reexploration	84 (7.1%)	38 (3.4%)	45 (59.2%)	
For bleeding	47 (4.0%)	9 (0.8%)	38 (50%)	<.0001
For other causes	37 (3.0%)	29 (2.6%)	7 (9.2%)	.0075
Postoperative blood transfusions	463 (39.0%)	388 (34.9%)	64 (84.2%)	<.0001
RBC	452 (38.0%)	388 (34.9%)	64 (84.2%)	<.0001
FFP	95 (8.0%)	56 (5.0%)	39 (51.3%)	<.0001
Platelets	39 (3.3%)	19 (1.7%)	19 (25.0%)	<.0001
Units of RBC transfused	1.1 ($\pm$ 2.3)	0.9 ($\pm$ 1.9)	4.5 ($\pm$ 3.8)	<.0001
Units FFP transfused	0.5 ($\pm$ 2.2)	0.3 ($\pm$ 1.6)	4.1 ($\pm$ 5.2)	<.0001
Mean postoperative blood loss	549 ($\pm$ 941)	472 ($\pm$ 873)	1,669 ($\pm$ 1170)	<.0001
LOS ICU				
>72 h (n, %)	290 (24.4%)	251 (22.6%)	39 (51.3%)	<.0001
Total	4.1 ($\pm$ 4.7)	3.1 ($\pm$ 5.0)	5.7 ($\pm$ 5.3)	<.0001
TISS-28	66.9 ($\pm$ 69.5)	44.7 ($\pm$ 52.8)	85.9 ($\pm$ 76.5)	<.0001
Mortality	72 (6.1%)	56 (5.0%)	16 (21.1%)	<.0001
30-day mortality	78 (6.6%)	61 (5.5%)	17 (22.4%)	<.0001

RBC, Red blood cell; FFP, fresh frozen plasma; ICU, intensive care unit; LOS, length of stay; TISS-28, Therapeutic Intervention Scoring System.

(95% confidence interval, 4594–7909; Table 5). Using this adjusted estimate, the average hospital cost of patients with excessive postoperative hemorrhage was €14,279, all else equal. In addition to postoperative hemorrhage, the multivariate analysis also indicated that preoperative inotrope use ($P = .000$), preoperative renal dysfunction ($P = .000$), any infection ($P = .000$), previous operation ($P = .0269$), elective ($P = .0052$) and urgent procedures ($P = .000$) were significant independent determinants of hospital costs.

DISCUSSION

The objective of this study was to quantify the incremental costs of excessive postoperative hemorrhage in cardiac

surgery. We found that patients with excessive postoperative hemorrhage are significantly more likely to require prolonged ventilation after surgery, reexploration for bleeding and other causes, transfusion of all blood products, stay in the ICU for more than 72 hours, and more manpower while in the ICU as measured by the TISS-28 score. Adjusted for potential confounders, the higher resource requirements of patients with excessive postoperative hemorrhage resulted in significantly higher average hospital costs compared with patients without postoperative hemorrhage.

Our results compare well with those published by Herwaldt and colleagues^{7,8} despite differences in the definition of excessive postoperative hemorrhage. In their case-control

TABLE 4. Univariate analysis of hospital cost (€) for cardiac surgery: effect of postoperative hemorrhage

Cost components	All patients (n = 1188)	No bleeding (n = 1112)	Bleeding (n = 76)	P value
Surgery-related* (mean $\pm$ SD)	2304 ($\pm$ 669)	2274 ($\pm$ 615)	4018 ($\pm$ 1753)	<.0001
Postoperative complications† (mean $\pm$ SD)	208 ($\pm$ 848)	178 ($\pm$ 785)	652 ($\pm$ 1429)	<.0001
Reexploration for bleeding (mean $\pm$ SD)	230 ($\pm$ 842)	112 ($\pm$ 600)	1956 ($\pm$ 1635)	<.0001
Cost of blood products (mean $\pm$ SD)	134 ($\pm$ 346)	93 ($\pm$ 257)	732 ($\pm$ 730)	<.0001
Cost of total ICU stay (mean $\pm$ SD)	4370 ($\pm$ 6779)	4150 ($\pm$ 6699)	7582 ($\pm$ 7172)	<.0001
Cost by TISS-28 score	2407 ($\pm$ 2502)	1609 ($\pm$ 1902)	3095 ($\pm$ 2754)	<.0001
Cost of ward stay	876 ($\pm$ 661)	877 ($\pm$ 640)	859 ($\pm$ 928)	.0461
Total cost (mean $\pm$ SD)‡	8499 ($\pm$ 7862)	8027 ($\pm$ 7557)	15,404 ($\pm$ 8986)	<.0001

*Based on surgery time and CPB time, postoperative complications include cost for myocardial infarction and stroke. †Intraoperative complications included low cardiac output, hypoxemia, and other intraoperative complications. ‡Total cost should not be summed, represents mean total cost of cost components only.

TABLE 5. Multivariate analysis of hospital costs (€) for cardiac surgery

	Incremental cost	Standard error	t value	P value	95% confidence interval
Constant*	8027.51	1.8696606	4293.565	.000	8023.84–8031.17
Age	11.33	20.415367	0.555	.579	–28.69–51.34
Male	995.74	478.70688	2.08	.0375	57.48–1934.01
BMI	69.73	41.987478	1.661	.0968	–12.57–152.03
Admitting diagnosis					
MI	–348.99	849.89334	–0.411	.6813	–2014.78–1316.80
Valve disorder	57.72	906.06157	0.064	.9492	–1718.16–1833.60
Other	202.35	934.87075	0.216	.8286	–1630.00–2034.70
Antithrombotics use	9.60	8.3284475	1.153	.2491	–6.72–25.92
Preoperative anticoagulants	–6.62	4.1160559	–1.607	.108	–14.68–1.45
IV nitrate	–201.64	1003.816	–0.201	.8408	–2169.12–1765.84
IV inotrope	11,737.56	1630.3749	7.199	.000	8542.02–14,933.09
HCT	–0.45	1.577093	–0.284	.7765	–3.54–2.64
Renal dysfunction	3078.31	508.93187	6.049	.000	2080.81–4075.82
Creatinine	3.42	7.2556871	0.471	.6376	–10.80–17.64
Comorbidities					
Liver disease	0.98	3.5436956	0.275	.783	–5.97–7.92
GI disease	8.43	8.2886632	1.017	.3092	–7.82–24.67
Endocrine disease	–1.30	5.0370064	–0.258	.7964	–11.17–8.57
Malignancy	–54.66	1245.7818	–0.044	.965	–2496.40–2387.07
Other comorbidity	–0.21	4.0891052	–0.05	.96	–8.22–7.81
Any infection	3492.79	831.63853	4.2	.000	1862.78–5122.80
Coagulopathy	–2.25	2.367213	–0.951	.3417	–6.89–2.39
Previous operation	1781.62	804.87552	2.214	.0269	204.06–3359.17
Elective	–1317.33	471.63121	–2.793	.0052	–2241.73–392.93
Urgent	2376.88	577.36643	4.117	.000	1245.24–3508.52
Emergent	–2047.63	2196.2459	–0.932	.3512	–6352.27–2257.01
Bleeding†	6251.38	845.60114	7.393	.000	4594.00–7908.76

BMI, Body mass index; MI, myocardial infarction; IV, intravenous; HCT, hematocrit; GI, gastrointestinal. *Average cost for patients without postoperative hemorrhage, all else equal. †Incremental cost for patients with postoperative hemorrhage.

studies, excessive postoperative hemorrhage was defined by either a surrogate for bleeding (reoperation for bleeding regardless of the amount of blood lost in chest tubes) or by postoperative chest tube drainage greater than 800 mL during a 4-hour period. In the first study,⁷ the authors found patients with postoperative chest tube drainage greater than 800 mL to have significantly more blood transfusions and longer hospital stays than controls. The unadjusted mean difference in hospital costs was \$11,266 (or €7702 when using current exchange rate), which is very close to the unadjusted cost difference of €7377 observed in our study. In the second study, using a mixture of patients identified with postoperative hemorrhage due to the surgery or volume criteria, the mean difference in hospital costs was substantially smaller (\$2945), yet this is likely explained by the difference in eligibility criteria.

In our study, we found the average incremental (extra) cost of excessive postoperative hemorrhage to be €6251 per patient. Although this amount may not seem excessive on a larger scale of health care spending, it is important to note that this cost estimate only relates to the resources required during the initial hospitalization. The cost of follow-up care (inpatient and outpatient) may be significant,

in particular in regards to postoperative complications such as AMI and stroke.^{15–17} Indeed, the long-term health care costs associated with AMI and stroke may represent the majority of the life-costs in AMI and stroke survivors. In addition, there are the indirect costs of excessive postoperative hemorrhage in terms of foregone productivity attributable to premature mortality and morbidity. In gauging the potential of new clinical interventions to address the cost of excessive postoperative hemorrhage, the perspective of the assessor is clearly paramount (eg, hospital, insurance company, or government). However, when the cost of excessive postoperative hemorrhage is considered from a national long-term perspective, both the direct and indirect costs of the complication should clearly be evaluated.

The etiology of excessive postoperative hemorrhage in cardiac surgery is multifactorial and may be related to medications, history of preexisting coagulopathy, surgical procedure, and other unrecognized factors.¹⁰ An important aspect of addressing excessive hemorrhage relates to preoperatively identifying patients at risk during or after surgery. In our study, we found patients with excessive postoperative hemorrhage to be more likely to have preoperative renal dysfunction, liver disease, and coagulopathy; to need

emergency/resuscitation surgery; and to require longer surgery time, including time spent on the CPB. In other studies, increased age, nonelective surgery, low body surface area, prolonged CPB time (>150 minutes), combined intracardiac and coronary bypass graft surgery, number of bypass grafts (≥ 5), reoperative surgery, and preoperative antiplatelet agents have been consistently identified as risk factors for postoperative hemorrhage.^{4,18,19} Though more research on the risk factors for excessive postoperative hemorrhage is needed,⁸ it is clear that, from a cost-effectiveness perspective, clinical interventions that can either prevent or effectively address postoperative hemorrhage are likely to be cost-effective. In our study, we observed a mortality rate of 22.4% in patients with excessive postoperative hemorrhage compared with 5.5% in patients without this complication. At an average incremental cost of €6251, the difference in survival implies an average €36,771 per life lost as a result of this complication. In other words, patients with excessive postoperative hemorrhage are more expensive and more likely to die than those without excessive postoperative hemorrhage. Even without taking the long-term costs (direct or indirect) of excessive postoperative hemorrhage into account, there seems ample economic potential for addressing this critical clinical complication.

Our study has a number of limitations. First, our estimate of the incremental costs of excessive postoperative hemorrhage depends in part on the unit cost associated with the extra resources required to treat this complication. Unit costs are inherently idiosyncratic for the health care system in which they are retrieved, and hence it is questionable to what extent our estimation can be generalized to other health care systems outside of Germany. Second, we did not include the long-term costs (direct or indirect) associated with excessive postoperative hemorrhage. In patients with thromboembolic complications such as AMI and stroke, these costs are likely to be substantial. Additionally, the high mortality rate associated with excessive postoperative hemorrhage indicates that there are substantial societal losses associated with this complication relating to lost productivity. Future research should aim to quantify the long-term economic implications of excessive postoperative hemorrhage and its associated clinical outcomes. Third, our assessment did not take into account the impact of excessive postoperative hemorrhage on quality of life. For the patients left with significant functional disabilities due to stroke, the nonmonetary cost to survivors and their family can be substantial.

CONCLUSIONS

We find the average hospital costs of excessive postoperative hemorrhage in cardiac surgery to be substantial and associated with a significant risk of postoperative complications and death. Clinical interventions that can effectively prevent or address excessive postoperative hemorrhage in

cardiac surgery are likely to have substantial cost-effectiveness potential.

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APPENDIX 1. Unit cost by hospital resource

Cost component	Cost (€)	Source/reference
Surgery		
Surgery time (per minute)	13.33	OP Management, 2007 (€800 per hour)
Hemofiltration (run time per day)	943.00	Herzchirurgie, Bad Krozingen, 2007 ²⁰
ECMO	5736.00	Herzchirurgie, Bad Krozingen, 2007 ²⁰
IABP	1283.00	Herzchirurgie, Bad Krozingen, 2007 ²⁰
Recovery		
Cost for reexploration	3305.00	Herzchirurgie, Bad Krozingen, 2007 ²⁰
Transfusion of RBC (cost per unit)	75.00	Harig et al., 2007 ²¹
Transfusion of FFP (cost per unit)	67.00	Harig et al., 2007 ²¹
Transfusion of platelets (cost per unit)	467.00	Harig et al., 2007 ²¹
ICU cost per day (24 h)	1334.00	Graf et al., 2002 ²²
Cost per ward day	62.00	Herzchirurgie, Bad Krozingen, 2007 ²⁰
TISS-28 (cost per point/score)	36.00	Graf et al., 2002 ²²

ECMO, Extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; RBC, red blood cells; FFP, fresh frozen platelets; ICU, intensive care unit; TISS-28, Therapeutic Intervention Scoring System; AMI, acute myocardial infarction.