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*Research Article*

# A Cost–Benefit Analysis of Minimally Invasive Versus Open Vein Harvesting in Cardiac Surgery Based on the German DRG System

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**Background:** A cost–benefit analysis of open vein harvesting (OVH) versus endoscopic vein harvesting (EVH) for leg wound complications in intermediate- and high-risk cardiac surgical patients was performed based on the German Diagnosis-Related Groups (G-DRG) in a retrospective cohort.
**Methods:** The highest Fowler score and EuroSCORE II were utilized as risk variables for leg wound infection. Risk adjustment (1:1) was performed to compare two groups of patients undergoing surgery with OVH or EVH techniques. Total costs, including costs of facilities, additional hospital stays, and personnel expenses based on Institute for the Hospital Remuneration System calculations, were compared with G-DRG reimbursements.
**Results:** The baseline characteristics of the two groups did not differ significantly. Thirty-four (41.8%) patients developed a wound healing disorder, 28 in the OVH group and 6 in the EVH group ($p = 0.037$). During the hospital stay, five (7.4%) patients in the OVH group had major leg wound healing disorders. Patients in the OVH group had a marginally longer hospital stay, though without statistical significance (14.3 vs. 11.7 days; $p = 0.424$). The total cost was 23,223€ for the OVH group compared with 18,627€ for the EVH group ($p < 0.001$); thus, the cost of the OVH group exceeded that of the EVH group by 4596€ based on G-DRG calculations.
**Conclusion:** EVH was associated with significant cost savings and fewer leg wound complications in intermediate- or high-risk patients. The G-DRG reimbursement system ended with the statement that case-based flat rates are not viable for hospitals treating vulnerable groups of patients.

**Keywords:** CABG; cardiac surgery; cost–benefit analysis; endoscopic vein harvesting; wound healing

## Summary

- EVH was associated with significant cost savings and fewer leg wound complications in intermediate- or high-risk patients.
- The numerous estimates based on the DRG system revealed that the real case expenses of the hospital under review are much greater than the InEK Institute's aim.
- The German-DRG reimbursement system ended with the statement that case-based flat rates are not viable for hospitals treating vulnerable groups of patients.

## 1. Introduction

For several decades, the treatment of choice for severe coronary artery disease has been conventional surgical myocardial revascularization using the left internal thoracic

artery in combination with vein grafts [1]. The open vein harvesting (OVH) technique is associated with postoperative complications as well as dehiscence, hematoma, edema, and pain in up to 44% of high-risk patients [2]. Severe surgical trauma for larger and deeper skin incisions can be avoided by endoscopic vein harvesting (EVH), as it reduces the risk of wound complications and infections and shortens hospital stays with higher patient satisfaction [3]. Bypass patency is a crucial factor for a long-term positive outcome. EVH produces a high-quality vascular conduit that maintains blood flow [4, 5].

In the study by Illig et al., the use of EVH led to cost savings totaling more than $1200 per procedure due to shorter ICU stays and significantly earlier discharges and savings of up to $2200 per procedure after accounting for the cost of readmissions to treat wound complications; the average cost per readmitted patient was $1948 (OVH) compared with $322 (EVH) [6]. A pilot study by Luckraz et al. reported a total cost savings of £42,778 per procedure for the patient undergoing EVH instead of OVH in a free health service system such as the National Health Service in the United Kingdom [7].

Nevertheless, there is no consensus regarding the cost–benefit analysis. Since German Diagnosis-Related Groups (G-DRG) financing was introduced, modern diagnostics and therapy with persistent cost under coverage have been repeatedly discussed. The care of critically ill patients entails the use of many hospital resources. Therefore, this analysis hypothesized that vascular harvesting for bypass surgery in critically ill patients would result in underrecovery of costs for the treating hospital; it has been discussed whether the procedure of vein harvesting should be optimized depending on a cost–benefit analysis.

The present study was designed to retrospectively examine procedures carried out in 2018 and to determine whether EVH is cost-effective and equally beneficial to the patient. Above all, the status quo for inpatient billing of patients was surveyed, the calculations were analyzed from an economic point of view, and the clinical benefit was assessed.

To systematically address these clinical and economic questions, a retrospective, single-center analysis was conducted, integrating patient-level medical and financial data within the framework of the G-DRG system.

## 2. Methods

*2.1. Patient Cohort.* The study is based on all patients who underwent conventional surgical myocardial revascularization in the cardiac surgery department of the University Hospital Bergmannsheil GmbH in Bochum, Germany, in 2018. The indication for surgical cardiac bypass treatment and the vascular harvesting required for this took into account the S3 guideline for cardiac surgery, the guideline of the DGTHG (German Society for Thoracic, Cardiac and Vascular Surgery) and the department's internal guidelines. For each patient, both medically relevant parameters and basic financial data were determined, and frequent diagnostic groups were subsequently combined into clusters as basic MDC-05/DRG F06A-E.

This study considered patients with an intermediate or high risk (EuroSCORE II > 4% [8]) in more detail. Using the risk model of Fowler and colleagues, postoperative wound infection was estimated in low- and high-risk patients after bypass surgery [9]. Risk factors such as age, sex, body mass index, previous surgery, comorbidities, and associated infection rates were evaluated, and two risk scores for major infections after coronary artery bypass grafting were calculated. Points were assigned and summed for each risk factor. The higher the total score, the higher the probability of developing a postoperative wound infection. The patient population of the present study was divided into two groups according to vein harvesting techniques.

The acquisition of information and the analysis of the patient database were carried out in several steps. Demographic data and diagnoses, including therapeutic measures, were first documented retrospectively. In collaboration with the financial controlling department, the data for a cost analysis were then compiled for each patient. The total costs and cost performance accounting were calculated according to a mixed procedure that adhered to principles of the calculation methodology of the Institute for the Hospital Remuneration System calculations (Institut für das Entgeltsystem im Krankenhaus [InEK]), also using the G-DRG Report Browser 2018 application.

The study was conducted with the approval of the Ethics Committee (Register No.: 19-6712-BR) of the academic research department of Ruhr University Bochum.

*2.2. Harvesting Technique.* In the minimally invasive procedure, the endoscope is inserted through a 2.5–3.0-cm incision on the inner thigh. After locating the saphenous vein, the surgeon works along the vein to expose the vein segment to be harvested, pinches off and separates side branches, preventing bleeding if necessary, and harvests the vein. Although the vein is at the level of the groin from the junction with the deep inguinal vein, an incision is no longer required in the inguinal region.

*2.3. Statistical Analysis.* Statistical analysis and data collection were performed using the statistical programs Microsoft Excel (v16.71 for Mac OS, Microsoft Corporation, Redmond, WA, USA), SPSS (v26.0.0.0 for Mac SPSS Inc., IBM, Armonk, NY, USA), and GraphPad Prism Version 8.0.0 for Mac OS (GraphPad Software released 2018, San Diego, CA, USA) after coding. *T*-tests were used for paired samples. The Kolmogorov–Smirnov test was used to examine whether the samples in each group were normally distributed. Descriptive statistical data are expressed as mean with standard deviation (SD) when continuous data were normally distributed; median and interquartile ranges (IQRs) are provided for nonnormally distributed or ordinally scaled data. Categorical variables are presented as numbers and percentages. The cost parameters were first analyzed using Kruskal–Wallis test to estimate a significant difference; if

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a significant difference was identified, a *t*-test or Mann–Whitney *U*-test was applied.

A difference was considered significant if the probability $p$ was less than 0.05 (significance level $\alpha = 5\%$). All statistical analyses were performed in duplicate. For the detection of independent risk factors, linear regression analysis ANOVA was used. Graphical representation was used to evaluate the results. Continuous variables are summarized as mean ± SD.

Based on an interim analysis of preliminary data, which were presented as a talk at the Annual Meeting of the German Society of Surgery in Leipzig, Germany [10], power analyses were performed using the G∗Power program [11]. Cohen's d was used to compare the effect across studies, even if the dependent variable was measured differently [12]. The probability of success was 76.5% in the EVH group and 47.1% in the OVH group, indicating that the likelihood of a favorable outcome increased by 29.4% in the case of vein harvesting by EVH. Accordingly, 3.4 individuals must undergo EVH for one less unfavorable outcome in the OVH group. The effect size (Cohen's d) calculated from probability (1-ß = 0.157) is 0.772, which is consistent with a strong effect that can be considered significant. Assume that a sample of 63 patients in the OVH group and 27 patients in the EVH group would be sufficient for the *t*-test to reach a significant result with a probability of 95%. Our analysis included 10% more patients in each group, resulting in 67 in the OVH group and 30 in the EVH group.

## 3. Results

*3.1. Patient Characteristics.* In 2018, a total of 456 patients with ischemic coronary artery disease underwent surgical myocardial revascularization (G-DRG/F06A-E) in cardiac surgery departments at Bergmannsheil University Hospital. OVH was used in the majority of patients (337), and the graft material was obtained endoscopically (EVH) in the rest (119). According to the study protocol, 97 patients with a mean EuroSCORE II of more than 4% were included, with 67 patients assigned to the OVH and 30 to the EVH group.

The mean age of the total population was 73.8 ± 6.1 years, and 63 (64.9%) were male. The body mass index was 25.5 ± 5.4 kg/m$^2$. Peripheral occlusive disease was previously diagnosed in 51 (52.5%) patients. The total patient collective's mean perioperative risk (EuroSCORE II) was 5.8 (SD ± 3.0). The estimated Fowler score yielded a mean of 10.8 (SD ± 5.1; median 10.1). Thus, the calculated postoperative probability of developing a postoperative wound infection in the patient collective was 4.0% (SD ± 2.72%; median 3.2%).

There were no significant differences in demographic data between the groups. The complete listing of patient demographics is provided in Table 1.

*3.2. Operative Results.* The mean duration of surgery, cardiopulmonary bypass time, and clamping time were not significantly different between the groups ($p = 0.457$, $p = 0.584$, $p = 0.186$, respectively; Table 2). The number of venous anastomoses was also not significantly different (1.5 ± 0.8 in the OVH group vs. 1.6 ± 0.7 in the EVH group; $p = 1.000$). A slight difference in intraoperative graft flow was observed between the groups: Blood flow in the EVH group (65.7 ± 54.7 mL/min) was higher than that in the OVH group (54.3 ± 26.3 mL/min), but the difference was not significant ($p = 0.168$). Pulsatility index (PI) values, which estimate the resistance in the graft, were numerically lower in the EVH group (PI 2.1 ± 1.3) than in the OVH group (PI 2.5 ± 1.59); however, significant abnormalities were not found ($p = 0.298$). The mean time needed for endoscopic vein preparation was 26.8 ± 5.2 min, with an average vein length of 53.8 ± 7.9 cm.

*3.3. Postoperative Results.* The mean length of hospital stay for all subjects was 10.7 ± 4.9 days, with no significant differences between the study groups (Table 2). Although the patients in the OVH group stayed in the hospital one day longer, this was not statistically significant ($p = 0.310$). Two patients in the OVH group and one patient in the EVH group died of multiple organ failure. Three patients in the OVH group and two patients in the EVH group required rethoracotomy for cardiac tamponade after surgery. Intensive care unit stay (72.4 ± 83.6 h OVH group vs. 68.3 ± 53.4 h EVH group) and ventilation time (23.7 ± 37.4 h OVH group vs. 14.9 ± 12.7 h EVH group) were numerically more extended in the OVH group, but this was not significant ($p = 0.806$, $p = 0.213$, respectively).

Although there was no significant difference in blood loss via the drains between the two groups, the EVH group had higher losses in absolute terms through thoracic drainage (349.8 ± 240.1 mL/d vs. 314.2 ± 348.7 mL/d, $p = 0.561$) and comparably lower blood losses via redon drainage (44.3 ± 58.6 vs. 41.7 ± 43.9 mL/d, $p = 0.829$). A mild but nonsignificant correlation is evident in the OVH group. The need for blood transfusions in absolute amounts showed a negative but nonsignificant correlation with blood loss (Table 2).

Thirty-four (35.1%) patients developed a wound healing disorder, 28 in the OVH group and 6 in the EVH group ($p = 0.037$) (Table 2). A retrospective examination of wound severity (nonirritant < reddened, hematoma, serous < bloody < purulent, necrotic, dehiscent) showed no significant differences between the groups. A deep wound healing disorder was the cause of revision in five patients in the OVH group, with an incidence of 7.4%.

There was a noticeable tendency for more serious wound findings to be present in the OVH group. After discharge, four of these abnormal wound findings in the OVH group led to outpatient readmission due to a deep wound healing disorder.

*3.4. Influence of Wound Healing Disorder on Costs.* Close examination of the study cohort revealed a mean length of hospital stay in 2018 of 11.0 days. The mean length of stay for patients with a wound healing disorder for both groups was 12.6 ± 7.3 days. Although patients in the OVH group were in the hospital 3 days longer (14.3 vs. 11.7), there was no significant difference in the length of stay ($p = 0.424$)

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Table 1: Baseline demographic characteristics and preoperative clinical variables of the study population, stratified by vein harvesting technique (EVH vs. OVH).

| Variable | Total population $n = 97$ | OVH $n = 67$ | EVH $n = 30$ | $p$ value |
|---|---|---|---|---|
| Age, y | 73.8 (±6.1) | 74.2 (±5.8) | 73.6 (±6.3) | 0.648 |
| Female sex, *n* (%) | 34 (35) | 20 (58) | 14 (47) | 0.166 |
| BMI, kg/m$^2$ | 25.5 (±5.4) | 26.5 (±6.3) | 24.5 (±4.5) | 0.120 |
| IDDM, *n* (%) | 29 (30) | 19 (28) | 10 (33) | 0.638 |
| COPD GOLD III-IV, *n* (%) | 51 (53) | 34 (50.7) | 17 (57) | 0.663 |
| NYHA Class III-IV, *n* (%) | 67 (69) | 46 (68.6) | 21 (70) | 0.895 |
| CCS III-IV, *n* (%) | 61 (62.9) | 39 (58.2) | 22 (73.3) | 0.179 |
| Ejection fraction < 20%, *n* (%) | 29 (29.9) | 20 (29.8) | 9 (30.0) | 0.988 |
| Extracardiac arteriopathy, *n* (%) | 51 (52.5) | 36 (53.7) | 15 (50.0) | 0.827 |
| Dyslipidemia, *n* (%) | 40 (41.2) | 28 (41.8) | 12 (40) | 0.869 |
| Arterial hypertension, *n* (%) | 69 (71.1) | 46 (68.7) | 23 (76.7) | 0.452 |
| GFR, mL/min/1.73 m$^{2*}$ | 85.3 (±21.5) | 85.8 (±20.3) | 84.7 (±22.7) | 0.813 |
| Fowler score, % | 10.8 (±5.1) | 10.3 (±5.3) | 11.3 (±4.9) | 0.382 |
| EuroSCORE II, % | 5.8 (±3.0) | 5.9 (±2.8) | 5.6 (±3.1) | 0.638 |

*Note:* Values are mean ± SD or *n* (%).

Abbreviations: BMI = body mass index, CCS = Canadian Cardiovascular Society, COPD = chronic obstructive pulmonary disease, EVH = endoscopic vein harvesting, GFR = glomerular filtration rate, IDDM = insulin-dependent diabetes mellitus, NYHA = New York Heart Association, OVH = open vein harvesting.

*Cockcroft–Gault equation [13].

(Figure 1). Thus, the majority of patients without a wound healing disorder leave the hospital within approximately 11 days. The costs for the patient length of stay were estimated according to the G-DRG system, resulting in a mean DRG revenue of €14,639 for patients without a wound healing disorder. For patients with a wound healing disorder, the estimated cost of the OVH group was €4376 higher than that of the EVH group ($p < 0.001$) (Figure 2(a)).

The mean total cost of the EVH group without a wound healing disorder calculated according to the InEK Institute also differed from that of the OVH group, particularly due to the direct costs incurred for the endoscopy set. However, the savings improved significantly in favor of the EVH group in patients with a wound healing disorder, with a difference in the total cost between the two groups of €10,989 (Figure 2(b)).

## 4. Discussion

*4.1. Medical Aspects.* This comparative study retrospectively considered inpatient data from 01/01/2018 to 12/31/2018 at a single institution. The medical data were compared, and a cost–benefit analysis was performed on two vein harvesting techniques in a G-DRG setting. It was necessary to analyze and calculate the costs of the cases using the conventional vein harvesting technique separately from the new, minimally invasive approach since the two groups cannot be compared one to one and different aspects must be considered in a cost and benefit analysis.

Beyond clinical outcomes, procedural efficiency and perioperative timing are also critical parameters influencing both resource utilization and surgical decision-making.

*4.2. Temporal Aspects.* The clinical superiority of EVH over OVH is well established. As with OVH, a learning curve is required to master the EVH technique until it can be performed safely and quickly; however, this curve is steep for most surgeons, so a high-quality standard with short preparation times can be achieved after only a few cases under the supervision of an experienced EVH operator. The present analysis showed a mean preparation time of 26.8 ± 5.2 min for a mean vein length of 53.8 ± 7.9 cm in the EVH group. The duration of vein harvesting is highly dependent on the experience of the person harvesting the vein. According to the meta-analysis by Marker et al. [14], the actual procedure duration is comparable for the two techniques. However, the duration of wound closure with EVH is significantly shorter due to the shorter length of the wound to be closed and the lower number of wounds, although the duration of vein preparation is comparable in both groups [15].

*4.3. Quality of the Vein Material.* Intraoperative measurements for endoscopically harvested vein material show numerically higher flow velocities and less resistance than the respective values for conventionally harvested vein material, although the differences were not significant. According to Markar et al. [14], the results on the bypass quality of the venous material by EVH and OVH are heterogeneous. However, EVH provides a saphenous conduit of high quality, with recent studies reporting no increase in graft failure or adverse cardiac events compared to open harvesting techniques [2].

Recent high-quality evidence has substantiated the long-term safety and clinical equivalence of EVH compared to OVH. In particular, the multicenter randomized REGROUP trial demonstrated no significant difference in major adverse cardiovascular events over a median follow-up of 2.8 years [2]. Complementary findings from a meta-analysis by Li et al. further corroborate the absence of long-term differences in survival and cardiovascular outcomes, suggesting that earlier concerns regarding inferior graft patency with EVH have been largely alleviated through advances in

Table 2: Intraoperative parameters and immediate periprocedural outcomes comparing endoscopic (EVH) and open (OVH) vein harvesting techniques.

| Variable | OVH $n = 67$ | EVH $n = 30$ | $p$ value |
|---|---|---|---|
| Intraoperative data | | | |
| Duration of surgery, min | 215.3 (±96.2) | 201.2 (±56.3) | 0.457 |
| Cardiopulmonary bypass time, min | 101.2 (±67.3) | 92.8 (±74.5) | 0.584 |
| Clamp time, min | 44.1 (±28.2) | 35.9 (±27.7) | 0.186 |
| Number of anastomoses | 173 | 77 | |
| Vein graft | 102 (58.9) | 48 (62.3) | 0.678 |
| Vein grafts per patient | 1.5 (0.8) | 1.6 (0.7) | 1.000 |
| Vein graft transit-time flowmetry | | | |
| Mean graft flow volume, mL/min | 54.3 (±26.3) | 65.7 (±54.7) | 0.168 |
| Pulsatility index* | 2.5 (±1.9) | 2.1 (±1.3) | 0.298 |
| Arterial graft transit-time flowmetry | | | |
| Mean graft flow volume, mL/min | 43.5 (±42.9) | 45.8 (±44.2) | 0.810 |
| Pulsatility index* | 2.8 (±1.3) | 3.1 (±1.8) | 0.356 |
| Periprocedural outcomes | | | |
| Hospital mortality, $n$ (%) | 2 | 1 | 1.000 |
| Hospital stay, d | 11.3 (±5.9) | 10.6 (±3.8) | 0.700 |
| Intensive care stay, h | 72.4 (±83.6) | 68.3 (±53.4) | 0.806 |
| Ventilation time, h | 23.7 (±37.4) | 14.9 (±12.7) | 0.213 |
| Rethoracotomy | 3 | 2 | 0.643 |
| Blood loss volume, mL/d | | | |
| Thoracic drainage (TD) | 349.8 (±240.1) | 314.2 (±348.7) | 0.561 |
| Redon drainage (RD) | 44.3 (±58.6) | 41.7 (±43.9) | 0.829 |
| Number of drains | | | |
| Thoracic | 157 | 75 | 0.816 |
| Redon | 91 | 41 | 0.817 |
| Blood and coagulation product transfusions | | | |
| Red blood cells, units | 3.8 (±4.9) | 2.8 (2.1) | 0.286 |
| Platelets, units | 0.7 (±1.9) | 0.5 (0.8) | 0.581 |
| Fibrinogen, g | 2.8 (±3.3) | 1.5 (±2.2) | 0.053 |
| Prothrombin complex concentrate, IE | 1154.9 (±2361.8) | 541.4 (±698.3) | 0.167 |
| Postoperative leg wound complications (intrahospital) | | | |
| Wound healing disorder, $n$ (%) | 28 (41.8) | 6 (20) | 0.037 |
| Superficial** | 23 | 6 | |
| Major deep | 5 | 0 | |
| Wound secretion, $n$ (%) | 25 (37.3) | 4 (13.3) | 0.017 |
| Bloody | 6 | 1 | |
| Serous | 19 | 4 | |
| Skin dehiscence, $n$ (%) | 11 (16.4) | 3 (10) | 0.406 |
| Hematoma, $n$ (%) | 12 (17.9) | 3 (10) | 0.319 |
| Conservative antibiotic therapy, $n$ (%) | 17 (25.3) | 4 (13.3) | 0.183 |
| Surgical therapy, $n$ (%) | 5 (7.4) | 0 (0) | 0.124 |
| Extension of hospital stay (days) | 1.8 | 0.2 | 0.002 |
| Ambulatory readmissions, $n$ | 4 | 0 | 0.152 |

*Note:* Values are mean ± SD or $n$ (%).

Abbreviations: EVH = endoscopic vein harvesting, OVH = open vein harvesting, RD = redon drainage, TD = thoracic drainage.

*(Max flow volume – min flow volume)/mean graft flow.

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surgical technique and increased operator experience [1]. Collectively, these data support EVH as a clinically safe and durable alternative to OVH in contemporary practice.

*4.4. Wound Healing.* Thirty-four patients (35.1%) developed a wound healing disorder during the analysis. There was a noticeable trend toward more severe wounds in the OVH group, whereas the EVH group demonstrated a significant reduction in postoperative wound healing complications. Here, postoperative wound infections, wound healing disorders with protracted wound secretion and dehiscence of the wound edges, postoperative hematoma formation, and postoperative pain symptoms were considered. During the analysis period, 28 patients in the OVH group and six in the EVH group developed a wound healing disorder with a significant difference ($p = 0.037$).

The OVH technique is associated with postoperative leg wound complications—including wound dehiscence, hematoma, edema, and pain—in a considerable proportion of high-risk patients, with reported rates reaching up to 44% [2].

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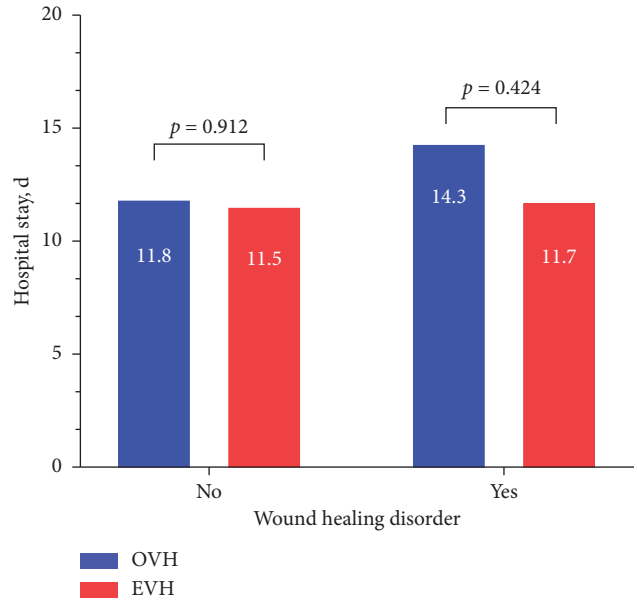



Figure 1: The mean length of hospital stay with and without wound healing disorder in the OVH and EVH groups.

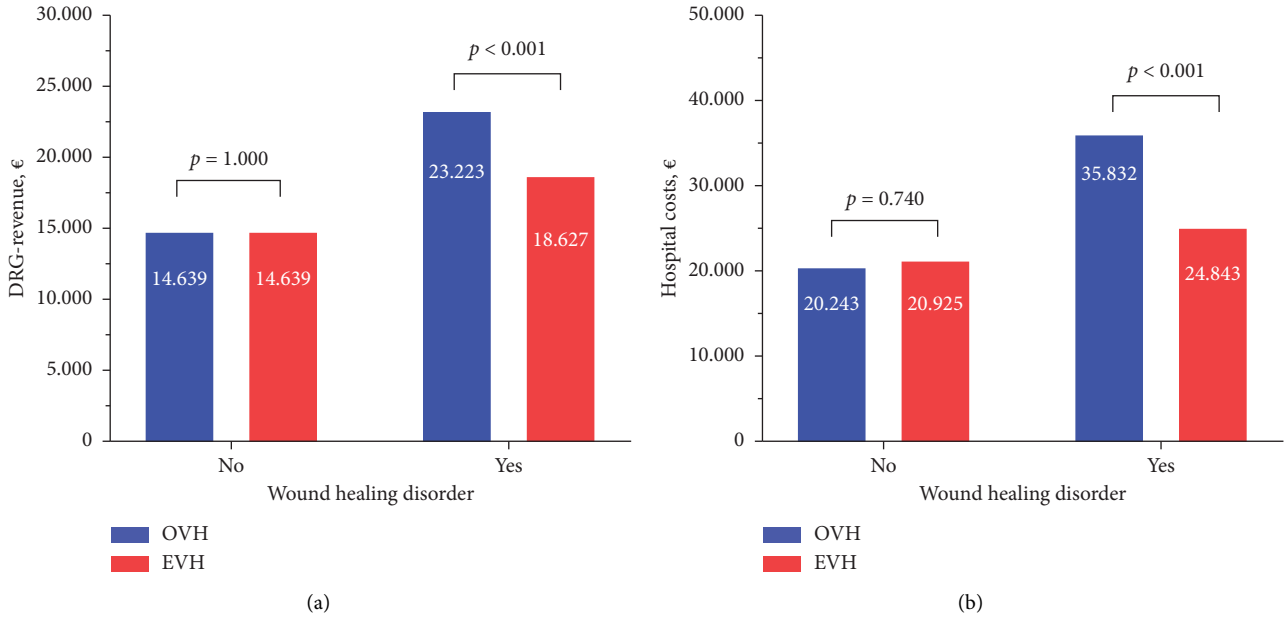



Figure 2: (a) Mean DRG revenue without wound healing disorder (left) and with wound healing disorder (right) of the OVH and EVH groups. (b) The mean total costs without wound healing disorder (left) and with wound healing disorder (right) of the OVH and EVH groups (hospital costs determined according to the InEK calculation).

The incidence of major or deep wound infection in our observation was seen in 5.2% (5 of 97 patients) of intermediate- and high-risk patients. This rate exceeds the calculated postoperative probability of developing a wound infection, which was estimated at 4.0% for this patient cohort according to Fowler criteria. Furthermore, Fowler et al. examined 331,429 patients in an all-comers sample from the STS National Cardiac Database to determine risk variables for severe infection [9]. A simplified risk assessment method with 12 criteria successfully predicted the probability of major wound infection (33% saphenous harvest sites with an infection probability of 3.5% overall). A recent multicenter study ($n = 2174$) similarly found a 3.0% incidence of harvest site infection and identified obesity and blood transfusion as significant risk factors; notably, EVH was utilized less frequently in patients who developed infections [2]. Patients with a severe infection had a considerably greater mortality rate compared with patients without an infection (17.3% vs. 3.0%) [9].

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*4.5. Aspects of the Cost Analysis.* The trend in cost incurrence was likely related to the much less invasive procedure and the associated lower rate of wound healing disruption for the EVH method, resulting in lower consumption of pharmaceuticals, less laboratory requirements, lower overhead, and lower need for surgical and ICU staffing. The cost of the EVH set was accounted for as a direct procedural expense within the remaining medical budget, resulting in a measurable cost increase in the EVH group; however, this was offset by reduced postoperative treatment costs. Institutional heterogeneity in equipment procurement practices and resource allocation may affect the broader applicability of these findings. Furthermore, given that cost structures differ across institutions and healthcare systems, the reported economic balance must be interpreted as context-specific. Accordingly, future multicenter investigations or scenario-based sensitivity analyses are recommended to assess the robustness and generalizability of the economic outcomes.

In the study by Illig et al., EVH yielded direct cost savings of over $1200 per case due to shorter ICU stays and earlier discharges, rising to approximately $2200 in savings after accounting for readmissions; the average readmission cost was $1948 (OVH) versus $322 (EVH) [6].

Retrospectively, there was a significant discrepancy between the revenues and the opposing costs on the balance sheet. After adjusting the prime rates for the length of stay according to the DRG system, the mean DRG revenue was €14,639 for patients without wound healing disorders in both treatment groups, whereas it was €4596 higher in the OVH group in patients with wound healing issues. From the analysis of total in-clinic costs, there was a significant difference in the total sum of the expenses between the EVH and OVH groups. Thus, the various calculations based on the DRG system revealed that the actual case costs of the hospital under investigation are significantly higher than the target of the InEK Institute.

However, the implementation of reimbursement reforms for high-risk surgical populations remains impeded by regulatory inertia, divergent stakeholder priorities—particularly between payers and providers—and the methodological challenges involved in establishing dynamic, risk-adjusted DRG classifications. These systemic barriers within DRG-based hospital financing systems have been extensively described in the literature [16], and while the present findings suggest marked under-reimbursement in high-risk patients undergoing OVH, translating such evidence into actionable payment reforms would necessitate national-level consensus and robust validation through multicenter data.

In the context studied, there should be defined per-case flat rates for high-cost case groups, similar to the DRG system for inpatients, which would make it possible to cover outpatient care costs. However, this would not cover all costs: As soon as the patient enters the hospital for the second time, costs rise without generating additional revenue unless the initial treatment already exceeds the revenue-generating quarterly flat rate, which is to be assumed in the majority of cases.

Moreover, when university hospitals experience strong growth in services, there is a more pronounced increase in costs than in revenue, thus an increasing widening of the cost gap. This work underlines the necessity of counter-financing: A possible solution would be not only an improvement of the F06(A-E) within the DRG system but also a surcharge on individual remunerations (DRG increase) or a separate additional financing pillar in the sense of a system surcharge for maximum care centers.

## 5. Conclusions

EVH was associated with significant cost savings and fewer leg wound complications in patients with intermediate or high risk. The G-DRG reimbursement system ended with the statement that case-based flat rates are not viable for hospitals treating vulnerable groups of patients.

In addition to the need to maintain the quality of the removed transplant as good as possible in the technical implementation, establishing the procedure in the clinical routine was, without a doubt, the biggest challenge. The long-term quality of the vein material when used as a bypass graft cannot be answered ad hoc; however, it is of central interest to physicians and patients.

In its current form, the German healthcare system operates in a comprehensive and complex manner. It is difficult to capture and analyze a single patient population from an economic point of view. It is also questionable whether the homogeneous cost grouping in the DRG system will cover the costs of care for each patient in the future. G-DRG F06A-E for critically ill patients is significantly underestimated in its revenue measurement, and the effective prime rate must be corrected upward.

*5.1. Study Limitations.* The study is a retrospective, single-center analysis. The relatively small sample size, consisting of 97 cases, constrained the statistical power. A prospective inclusion of additional cases could enhance the study's power, potentially leading to more robust and generalizable conclusions.

## Nomenclature

| | |
|---|---|
| BMI | Body mass index |
| CABG | Coronary artery bypass grafting |
| CCS | Canadian Cardiovascular Society |
| COPD | Chronic obstructive pulmonary disease |
| DGTHG | Deutsche Gesellschaft für Thorax-, Herz- und Gefäßchirurgie |
| DRG | Diagnosis-related groups |
| EVH | Endoscopic vein harvesting |
| F06A–E | DRG code cluster for cardiac surgery interventions |
| G-DRG | German Diagnosis-Related Groups |
| GFR | Glomerular filtration rate |
| ICU | Intensive care unit |
| IDDM | Insulin-dependent diabetes mellitus |
| IQR | Interquartile range |

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| | |
|---|---|
| InEK | Institut für das Entgeltsystem im Krankenhaus |
| MDC-05 | Major Diagnostic Category 05 (circulatory system disorders) |
| NYHA | New York Heart Association |
| OVH | Open vein harvesting |
| PI | Pulsatility index |
| RD | Redon drainage |
| SD | Standard deviation |
| STS | Society of Thoracic Surgeons |
| TD | Thoracic drainage |
| TTFM | Transit-time flow measurement |

## Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

## Disclosure

The preliminary data of the study were presented as a talk at the Annual Meeting of the German Society of Surgery in Leipzig, Germany, on April 25, 2024.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Author Contributions

Zulfugar T. Taghiyev: conceptualization, data collection and curation, investigation, methodology, supervision, validation, visualization, formal analysis, and writing–original draft.

Justus T. Strauch: administration, supervision, conceptualization, data curation, data validation, and review and editing.

Yeong-Hoon Choi: administration, supervision, conceptualization, data curation, data validation, and writing–review and editing.

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