Early unplanned readmission of neurosurgical patients after treatment of intracranial lesions: a comparison between surgical and non-surgical intervention group

Caroline Sander¹ · Henry Oppermann¹ · Ulf Nestler¹ · Katharina Sander² · Nikolaus von Dercks³ · Jürgen Meixensberger¹

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Abstract

Background Recent health care policy making has highlighted the necessity for understanding factors that influence readmission. To elucidate the rate, reason, and predictors of readmissions in neurosurgical patients, we analyzed unscheduled readmissions to our neurosurgical department after treatment for cranial or cerebral lesions.

Methods From 2015 to 2017, all adult patients who had been discharged from our Department of Neurosurgery and were readmitted within 30 days were included into the study cohort. The patients were divided into a surgical and a non-surgical group. The main outcome measure was unplanned inpatient admission within 30 days of discharge.

Results During the observation period, 183 (7.4%) of 2486 patients had to be readmitted unexpectedly within 30 days after discharge. The main readmission causes were surgical site infection (34.4%) and seizure (16.4%) in the surgical group, compared to natural progression of the original diagnosis (38.2%) in the non-surgical group. Most important predictors for an unplanned readmission were younger age, presence of malignoma (OR: 2.44), and presence of cardiovascular side diagnoses in the surgical group. In the non-surgical group, predictors were length of stay (OR: 1.07) and the need for intensive care (OR: 5.79).

Conclusions We demonstrated that reasons for readmission vary between operated and non-operated patients and are preventable in large numbers. In addition, we identified treatment-related partly modifiable factors as predictors of unplanned readmission in the non-surgical group, while unmodifiable patient-related factors predominated in the surgical group. Further patient-related risk adjustment models are needed to establish an individualized preventive strategy in order to reduce unplanned readmissions.

Keywords Neurosurgery · Surgical treatment · Conservative treatment · Intervention · 30-day readmission · Unplanned readmission · Adverse events

Introduction

Early readmission has emerged as a surrogate marker for assessing the quality of hospitals. Since financial hospital reimbursement policies are becoming more important, identifying risk factors for unplanned readmissions is of crucial interest [2, 24].

Mastering of reasons and predictive factors for unplanned readmission is useful for saving costs and optimizing resources. In addition to, and from a medical point of view far more important than economic reasons, the focus lies on defining patient groups at risk, to help in the development of preventive strategies and to increase patient safety and satisfaction [1, 6, 12]. Thirty-day hospital readmission is a marker associated to short-term complications and is often employed by health care politicians for outcome measurements [3].
In the literature, early re-hospitalization within 30 days after a neurosurgical procedure prognosticates an adverse outcome in patients with glioblastoma [5].

However, for neurosurgical procedures, there is a certain lack of readmission data. Especially readmission rates, predictive factors for readmission and outcome measurements after cranial neurosurgical treatment are missing. Due to the complex spectrum of neurosurgical diagnoses and the large scope in techniques and decision making, the already established predictive factors from other surgical or medical disciplines cannot be implemented unequivocally.

Patients with neurosurgical diseases suffer from a particular potential for rapid deterioration. Specific strategies and definition of risk factors to prevent unplanned readmission for this patient cohort are needed [22]. The incomparability of the different health systems worldwide is additionally complicating this procedure in neurosurgical conditions [8, 20]. Several datasets of neurosurgical patients from the USA are available [5, 13, 14, 22], but there is only few information about readmission analysis in European and especially the German health care system [19, 20, 23]. In addition, with the growing availability of interventional treatment and the aging population, the amount of patients without surgical treatment, meaningful conservative or interventional neurosurgical therapy, is increasing. This patient group has been neglected in other readmission analyses and risk assessments.

The primary goal of this study was to identify predictive factors for unplanned early readmission in surgical and non-surgical groups in order to define patients with high risk. Additionally, we aimed to detect the causes of preventable readmissions as an approach to reduce readmission rates and to enable prevention strategies.

**Methods**

The internal review board of the Medical Faculty of the University of Leipzig had agreed to the retrospective data analysis (167/18-ek). According to the approval of the ethics committee, the patient’s written consent is not required.

Assessing administrative data from January, 1st, 2015 to December, 31st, 2017, adult patients (> 18 years) who had undergone neurosurgical treatment for cranial or cerebral disease at the neurosurgical department were included in the monocentric, retrospective study. Index diagnoses were categorized according to the Classification of Diseases and Related Health Problems (10th Revision, German Modification; see Table S1 in supporting information).

From this group, patients were identified who were readmitted to any department or service at the University Hospital Leipzig within 30 days. We did not track readmissions to other hospitals. We excluded patients who came back for scheduled interventions. The first “index admission” diagnoses contain all cranial or cerebral neurosurgical disorders, irrespective of the following surgical or nonsurgical/interventional treatment. For the observation period, we reviewed the hospital charts of each readmitted patient and obtained demographic information.

Patient clinical complexity level (PCCL) is defined via the effective assessment ratio of the German DRG (diagnose related group) coding level and integrates also clinical course, technical procedures, and the patient’s secondary diagnoses. The PCCL represents a standardized measure of case severity; higher values indicate a higher case severity.

Causes for readmission were categorized into (1) surgical complications (e.g., surgical site infections (SSI), cerebrospinal fluid (CSF) leak, hemorrhage), (2) medical complications (e.g., electrolyte disorder, nosocomial infections, medication adverse effects), (3) diagnosis-related complications (e.g., tumor progression, hydrocephalus), (4) neurological decompensation (e.g., stroke, seizure, progressive neurologic symptoms), (5) pain management, and (6) miscellaneous (e.g., psychiatric admissions, “social” admissions due to lacking home care).

For addressing the wide variability and the complexity of neurosurgical disorders, we subcategorized the patients into groups with surgical and non-surgical/interventional treatment and compared the outcome separately. Four categories of readmission were defined: (1) preventable reasons (e.g., SSI, CSF leak, postoperative hemorrhage, nosocomial infection, postoperative pain, falls), (2) reasons related to the natural progression of the disease (e.g., hydrocephalus, new onset of seizures due to recurrent tumor growth), (3) reasons despite best practice (e.g., stroke, new neurological symptoms), and (4) unrelated reasons according to the study by Shah et al. [22]

**Statistical methods**

Statistical analysis was performed with IBM SPSS Statistics 25.0 software (IBM, Armonk, New York, USA). The associations between continuous variables were examined using the *t* test, categorical variables employing the Fisher exact test. Continuous variables were described using mean values, while categorical variables were described with counts and frequencies. Binary multivariate logistic regression was used to assess significant predictive factors. Factors associated with an unplanned readmission at the univariate level with a *p* value of 0.20 or lower were integrated into the model. The threshold of continuous variables was estimated using the area under the curve. A two-tailed *p* value < 0.05 was considered to be statistically significant.
Results

Study population

The demographic and descriptive parameters are shown in Table 1. Overall, 2486 patients had been treated in the department of neurosurgery between 2015 and 2017. Most common index diagnoses for hospital admission were intracranial neoplasm (903 cases, 36.3%), followed by vascular diseases (834 cases, 33.6%) and traumatic injuries (408 cases, 16.4%). Altogether, 1412 patients (56.8%) received a neurosurgical operation, whereas 1074 cases (43.2%) were treated non-surgically/interventionally. A total of 212 cases (15%) underwent more than one operation at index admission.

The surgical study group showed a significantly higher case severity measured by PCCL, longer length of stay (LOS), and increased number of second diagnoses in comparison to the non-surgical/interventional group. In addition, patients after surgery were significantly more often discharged directly to rehabilitation, whereas patients in the non-surgical cohort were significantly more often discharged home or according to their discretion. Results are illustrated in Table 2.

Readmission cohort

Among the 2486 neurosurgical patients of the study population, 183 (7.4%) patients were readmitted for unplanned reasons (Tables 3 and 4). In readmitted patients, the most common diagnosis at index admission had been intracranial neoplasm (83 patients, 45.4%), among them most often glioblastoma (33 cases, 18% of readmitted cases). The second most common readmission diagnosis was vascular disease with 48 cases (26.2%).

The majority of patients was readmitted to our neurosurgical department (80.3%), followed by readmission to the operative intensive care unit (9.3%) and the department of internal medicine (6% with 2.2% readmission to the internal intensive care unit).

The most frequent causes of readmission were surgery-related adverse events, followed by neurological deterioration and by difficulties in pain management. Of the 76 patients (41.5%) readmitted for surgical complications, 64.5% were readmitted for SSI, 22.7% for recurrent hemorrhage, and 6.7% for shunt dysfunction. Of the 34 patients admitted due to neurological deterioration, 76.5% had a seizure and 5.9% developed hydrocephalus. Besides infections (33.3%) and seizures (14.2%), unspecific reasons (19.1%) were among the most frequent causes for unplanned readmission. They mostly consisted in deterioration of the patient’s general condition. Unplanned operations were needed in 78 cases, the major reasons were SSI (30 cases; 38.5%), recurrent bleeding (17 cases; 21.8%), and shunt dysfunction (4 cases; 5.1%).

Preventable readmission

The reasons for readmission were carefully analyzed based on the previously described criteria to determine whether a readmission might have been prevented [22]. Among the 183 unplanned readmissions, 79 cases (43.2%) were classified as preventable (Table 4). The majority of preventable readmissions were caused by SSI, postoperative complications, or postoperative pain.

Procedure-related readmission

The assessment of the 183 readmitted patients stratified to the treatment modality at first index admission included 55 patients with non-surgical treatment and 128 patients with surgery (Table 5). Comparison confirmed significant differences in most examined aspects, especially the PCCL and LOS. Readmission cause was significantly more often a surgical problem, and category set as “preventable” in the operated patients, but significantly less due to the “original diagnosis” and “other” reasons. “Other” readmission reasons in the non-surgical group were unspecific deterioration such as vertigo, nausea, or vomiting (8 cases).

In the non-surgical group, “preventable” readmissions consisted of SSI, triggered by previous surgeries dating back more than 30 days before the index admission (five cases), insufficient pain therapy (seven cases), or repeated falls (three cases). The majority of unplanned readmissions were categorized as “natural progression”, including seizures (5 cases) and non-specific complaints such as progressive neurological deficits or nausea (11 cases).

In the group of operated patients (Table 6), surgical patients with unplanned readmission were significantly younger (< 65 years), suffered more often from comorbidities, and stayed longer at index admission than patients without the need for readmission. The frequencies of concurrent malignancies and pulmonic heart disease were significantly higher in readmitted surgical patients.

With regard to the non-surgical group (Table 7), readmitted patients had a significantly longer LOS at index admission and a higher frequency of ICU treatment. The unplanned readmitted cases in the non-surgical group significantly more often were diagnosed with pre-existing cardiac diseases or malignancies.

Predictors for unplanned readmission

We identified patient-dependent predictors for unplanned readmission in the study groups (Table 8). The side diagnosis “malignoma” was significantly more frequent in readmitted patients of both groups. While in the surgical group, the presence of secondary diseases was predictors of unplanned readmission, we identified the treatment-dependent factors LOS and the need for intensive care as predictors in the non-
### Table 1: Patient demographics and hospital characteristics of the study population

| Whole group $n = 2486$ | Average/No. (%) |
|------------------------|----------------|
| **Index admission diagnosis** |                       |
| Hydrocephalus           | 242 (9.74) |
| Functional disorders    | 87 (3.50)  |
| Neoplasm                | 903 (36.32) |
| Other                   | 12 (0.48)  |
| Traumatic head injury   | 408 (16.41) |
| Vascular disease        | 834 (33.55) |
| **PCCL**                | 2.87         |
| **Age in years**        | 60.19        |
| > 65                    | 1072 (43.12) |
| **Discharge**           |               |
| Home                   | 2166 (87.13) |
| Rehabilitation          | 164 (6.60)  |
| External hospital       | 102 (4.10)  |
| Patients discretion     | 15 (0.60)   |
| Death                   | 38 (1.53)   |
| **Gender**              |               |
| Female                 | 1211 (48.71) |
| **LOS in days**         | 9.60         |
| 1–8                    | 1468 (56.77) |
| 9–16                   | 646 (24.98)  |
| 17–24                  | 240 (9.28)   |
| ≥ 25                   | 132 (5.31)   |
| **Treatment at ICU unit at index admission** | 503 (20.23) |
| 1                      | 450 (17.40)  |
| 2                      | 44 (1.70)    |
| ≥ 3                    | 9 (0.36)     |
| **LOS ICU at index admission in days** | 2.67 |
| Surgical treatment      | 1412 (56.80) |
| **Number surgeries per case** | 0.69 |
| 1                      | 1200 (46.40) |
| 2                      | 150 (5.80)   |
| 3                      | 45 (1.74)    |
| ≥ 4                    | 17 (0.68)    |
| **Surgery time in minutes** | 146 |
| **Time point surgery** | Day shift 1224 (49.24) |
| **Number second diagnoses per case** | 6.36 |
| Comorbidity**           | 1317 (52.98) |
| Hypertension            | 1305 (52.49) |
| Cerebrovascular disease | 695 (27.96) |
| Malignoma               | 426 (17.14) |
| Diabetes mellitus       | 359 (14.44) |
| Cardiovascular disease  | 423 (17.02) |
| Other**                 | 182 (7.32)  |
| Chronic kidney disease  | 149 (5.99)  |
| Chronic obstructive pulmonary disease | 123 (4.95) |

*HIV* human immunodeficiency virus, *ICU* intensive care unit, *LOS* length of stay, *No.* number, *PCCL* patient clinical complexity level  

* Surgery time: day time: 7 a.m. until before 7 p.m.; night shift: 7 p.m. until before 7 a.m.  

* Comorbidity: yes in the case of three or more side diagnoses  

* Other side diagnosis: infection with HIV; previous organ transplantation, oral anticoagulation, adipositas, malnutrition
surgical group. It is worth mentioning that a lower patient age (under 78 years) in the surgical group was associated to predict unplanned readmission. In addition, low PCCL (under 1) was found to be predisposing for unplanned readmission in the non-surgical group, although this relationship did not become statistically significant.

**Discussion**

**Placing our results into the literature context**

To the best of our knowledge, the present analysis constitutes the first attempt to address predictive factors for early readmission after treatment of intracranial lesions and to distinguish between surgical and non-surgical/interventional treatment.

Nearly half of the reasons for unplanned readmission were categorized as preventable (43.2%) and are mainly due to SSI. Looking at the surgical group, we found a readmission rate of 9.1% and a SSI rate of 34.4%. Similar rates of preventable readmissions (36.6%) have been published in neurosurgical patients [22].

In a comparable cohort of neurosurgical patients from Germany, a SSI rate of 4.1% in total and of 22.4% for unplanned readmitted patients was shown [19, 23]. Further studies from other disciplines reported SSI rate between 0.5% and 6.6% [10, 11, 16, 21]. However, it must be taken into account that neurosurgical patients are more readily hospitalized than other patients, because of the special nature of wound infections with their proximity to the central nervous system and the associated increased risk of complications, even in the case of superficial infections [22].

The second leading cause of readmission in our collective was new onset of seizures (14.2% of all readmissions, 1.9% of the complete population). Due to the nature of this adverse event, we categorized seizures as “readmission despite best practice”. A somewhat lower rate of newly occurring seizures was described in the literature with 3.69% of readmitted

| Table 2 | Patient demographics and hospital characteristics of the study population comparing non-surgical and surgical treatment. *p* values calculated by *t* test (mean values) or by Fisher exact test (frequencies) |
|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

| Complete study population *n* = 2486 | Non-surgical group *n* = 1074 | Surgery group *n* = 1412 | *p* value |
|-------------------------------------|-------------------------------|--------------------------|-----------|
| **Index admission diagnosis**       |                               |                          |           |
| Hydrocephalus                        | 64 (5.96)                     | 178 (12.61)              | 0.0001    |
| Functional disorders                 | 7 (0.65)                      | 80 (5.67)                | 0.0001    |
| Neoplasm                             | 243 (22.63)                   | 660 (46.74)              | 0.0001    |
| Other                                | 5 (0.47)                      | 7 (0.50)                 | 1.000     |
| Traumatic head injury                | 285 (26.54)                   | 123 (8.71)               | 0.0001    |
| Vascular disease                     | 470 (43.76)                   | 364 (25.78)              | 0.0001    |
| **Readmission rate**                |                               |                          |           |
|                                      | 55 (5.12)                     | 128 (9.07)               | 0.0002    |
| **Unplanned operation rate**        | 10 (0.93)                     | 68 (4.82)                | 0.0001    |
| **PCCL, index admission**           | 1.48                          | 3.3                      | < 0.0001  |
| **Discharge**                        |                               |                          |           |
| Home                                 | 960 (89.39)                   | 1207 (85.48)             | 0.0044    |
| Rehabilitation                       | 47 (4.38)                     | 117 (8.29)               | 0.0001    |
| Patients discretion                  | 14 (1.30)                     | 1 (0.07)                 | 0.0001    |
| **Gender**                           |                               |                          |           |
| Female                               | 568 (52.89)                   | 643 (45.54)              | 0.0003    |
| **LOS in days**                      |                               |                          |           |
| 1–8                                  | 838 (78.03)                   | 630 (44.62)              | 0.0001    |
| 9–16                                 | 171 (15.92)                   | 475 (33.64)              | 0.0001    |
| 17–24                                | 48 (4.47)                     | 192 (13.60)              | 0.0001    |
| ≥ 25–32                              | 17 (1.58)                     | 115 (8.14)               | 0.0001    |
| **Treatment at ICU**                |                               |                          |           |
|                                      | 61 (5.69)                     | 442 (31.30)              | 0.0001    |
| **Number transfer to ICU**          |                               |                          |           |
| 1                                    | 59 (96.72)                    | 391 (88.46)              | 0.0001    |
| 2                                    | 2 (3.28)                      | 42 (9.50)                | 0.0001    |
| **Number second diagnoses per case**|                               |                          |           |
|                                      | 6.11                          | 6.55                     | 0.045     |
| **Malignoma**                        | 150 (13.99)                   | 276 (19.55)              | 0.0003    |
| **Cerebrovascular disease**          | 325 (30.32)                   | 370 (26.20)              | 0.0271    |
| **Oral anticoagulation**             | 47 (4.38)                     | 26 (1.84)                | 0.0003    |

In italics corresponds to a *p* value < 0.05

*ICU* intensive care unit, *LOS* length of stay, *No.* number, *PCCL* patient clinical complexity level

*a* Unplanned operation rate: unplanned readmission and operation
patients [22]. Slight differences regarding the use of categorization classes (“preventable” versus “best practice”) can explain the high seizure rate in the present study.

In our cohort, we found a nosocomial infection rate of 2.2%, lower than in comparable publications (12.1%) [19]. Furthermore, venous thrombotic events were described as a major cause for preventable readmission [5], which were completely absent in our study. A potential explanation may be the high specialization of neurosurgical departments with wide catchment areas. Consequently, patients with thromboembolism are eventually readmitted to non-neurosurgical departments of other hospitals to treat thrombosis, close to the residence of the patients.

| Procedure-related readmission |
|--------------------------------|

Many readmission-associated factors can be explained by the previous surgery and the increased risk of intervention-related complications with an extended LOS. Prolonged LOS points to the presence of adverse events and to an increased complexity of the case, which both in consequence can lead to secondary unplanned readmission [19]. In addition to unplanned reoperations, seizures, catheter-associated infections, or thromboembolic events are risk factors related to surgery, which non-operated patients are less likely to encounter. In our study, the unplanned operation rate was with 4.8% significantly higher in the surgery group than in the nonsurgical group (0.9%). The indications for unplanned surgery

| Table 3 Patient demographics and hospital characteristics of the study population comparing with and without unplanned readmission. p values calculated by t test (mean values) or by Fisher exact test (frequencies) |
|-------------------------------------------------------------------------------------------------|
| Complete study population n = 2486                                                             |
| Without readmission n = 2303                                                                     |
| Unplanned readmission n = 183                                                                    |
| p value                                                                                         |
|                                                                                                  |
| Index admission diagnosis                                                                       |
| Hydrocephalus                                                                                    |
| 222 (9.64)                                                                                       |
| 20 (10.93)                                                                                      |
| 0.6035                                                                                            |
| Functional disorders                                                                            |
| 80 (3.47)                                                                                        |
| 7 (3.83)                                                                                        |
| 0.8332                                                                                            |
| Neoplasm                                                                                         |
| 820 (35.61)                                                                                      |
| 83 (45.36)                                                                                      |
| 0.0104                                                                                            |
| Other                                                                                           |
| 12 (0.52)                                                                                       |
| 0 (0.00)                                                                                        |
| 1.000                                                                                            |
| Traumatic head injury                                                                           |
| 383 (16.63)                                                                                      |
| 25 (13.66)                                                                                      |
| 0.3504                                                                                            |
| Vascular disease                                                                                 |
| 786 (34.13)                                                                                      |
| 48 (26.23)                                                                                      |
| 0.0342                                                                                            |
| PCCL                                                                                            |
| 2.85                                                                                             |
| 3.07                                                                                            |
| 0.323                                                                                            |
| Age in years                                                                                    |
| 60.40                                                                                            |
| 57.65                                                                                            |
| 0.053                                                                                            |
| Gender                                                                                          |
| Female                                                                                          |
| 1134 (49.24)                                                                                     |
| 77 (42.08)                                                                                      |
| 0.0653                                                                                            |
| LOS in days                                                                                     |
| 9.39                                                                                            |
| 12.24                                                                                            |
| <0.0001                                                                                          |
| LOS in days                                                                                     |
| 1–8                                                                                             |
| 1395 (60.57)                                                                                     |
| 73 (39.89)                                                                                      |
| 0.0001                                                                                            |
| 9–16                                                                                           |
| 580 (25.18)                                                                                     |
| 66 (36.07)                                                                                      |
| 0.0021                                                                                            |
| 17–24                                                                                           |
| 210 (9.12)                                                                                      |
| 30 (16.39)                                                                                      |
| 0.0026                                                                                            |
| ≥ 25–32                                                                                        |
| 118 (5.12)                                                                                      |
| 15 (8.20)                                                                                        |
| 0.0861                                                                                            |
| Treatment at ICU at index admission                                                            |
| 456 (19.80)                                                                                      |
| 47 (25.68)                                                                                      |
| 0.0687                                                                                            |
| Number transfer to ICU                                                                          |
| 1                                                                                               |
| 408 (89.47)                                                                                     |
| 42 (89.36)                                                                                      |
| 1.000                                                                                            |
| 2                                                                                               |
| 39 (8.55)                                                                                       |
| 5 (10.64)                                                                                        |
| 0.5890                                                                                            |
| ≥ 3                                                                                             |
| 9 (0.39)                                                                                         |
| 0 (0.00)                                                                                         |
| 1.000                                                                                            |
| Surgical treatment at index admission                                                          |
| 1284 (55.75)                                                                                     |
| 128 (69.95)                                                                                      |
| 0.001                                                                                            |
| Number surgeries per case                                                                       |
| 0.67                                                                                             |
| 0.896                                                                                            |
| 0.0001                                                                                            |
| Number second diagnoses per case                                                                |
| 6.30                                                                                             |
| 7.20                                                                                            |
| 0.013                                                                                            |
| Comorbiditya                                                                                    |
| 1196 (51.93)                                                                                     |
| 121 (66.12)                                                                                      |
| 0.0002                                                                                            |
| All cardiac diseasesb                                                                          |
| 652 (28.31)                                                                                      |
| 67 (36.61)                                                                                       |
| 0.0219                                                                                            |
| Malignoma                                                                                        |
| 367 (15.94)                                                                                      |
| 59 (32.24)                                                                                       |
| 0.0001                                                                                            |
| Oral anticoagulation                                                                            |
| 69 (3.00)                                                                                        |
| 4 (2.19)                                                                                         |
| 0.8184                                                                                            |

In italics corresponds to a p value < 0.05

ICU intensive care unit, LOS length of stay, No. number, PCCL patient clinical complexity level

a comorbidity: yes in the case of three or more side diagnoses

b All cardiac diseases: ischemic heart diseases, pulmonic heart diseases, other heart diseases, cardiovascular diseases, cardiovascular devices
in the non-surgical group occurred, when enlarging or recurring subdural hematoma, as well as SSI in a first attempt had been treated conservatively, but then needed operation after further observation. Very similar to our results, unplanned operation rates of 3.1% due to postoperative bleeding, SSI, re-resection of a tumor, or CSF leakage have been published [4].

Readmission was significantly more often categorized as preventable in the surgical group than in the non-surgical group.

The unplanned readmissions in the non-surgical group were mainly due to unspecific complaints such as neurological deterioration and vertigo belonging to the category “natural progression”. In addition, significantly more patients from the non-surgical group were readmitted multiple times. We suppose that the unplanned readmissions in this group are mainly due to home care and nursing problems.

The readmitted patients in the non-surgical group are significantly older (> 65 years) and suffer from more secondary diagnoses than the patients in the surgical group, whereas the PCCL score of severity lies significantly lower (Table 5). It must be taken into account that the PCCL is a mixed value between the severity of the patient’s previous illnesses and the severity of the inpatient stay, whereby invasive procedures or complications have a higher influence. This mirrors that the unplanned readmissions in the operated group are due to a majority of young, mainly male patients after severe traumatic brain injury, as has been supposed before [18].

Our study shows that patients with previous cardiac diseases in particular were more likely to be unplannedly readmitted. This was striking in both study groups (Tables 6 and 7). For the non-surgical group, patients with diabetes mellitus and malignoma as secondary diagnoses were significantly more frequently readmitted. On the one hand, due to the higher patient age and on the other hand due to the abundance of secondary diseases, this is why non-surgical treatment may have been favored at the index admission.
Main predictors for an unplanned 30-day readmission in the surgical group were a higher number of side diagnoses (> 3), presence of certain secondary diseases, and patient age, while the presence of a malignant tumor as side diagnosis showed a highly significant impact in both study groups. This is in good accordance with most comparable studies [7, 13, 15]. Other second diagnoses with implications on readmission are cerebral metastasis, congestive heart failure, peripheral arterial disease [15, 19], myocardial infarction [13], hypertension [4], or coagulopathy [15]. In the literature, the number of side diagnoses correlates significantly with an increased risk of 30-day reoperations, readmissions, mortality, and infections [20], similar to the results presented here.

In the present study population, further reported patient characteristics such as male gender [4], type of health insurance [7], income [17], or race [15] were not confirmed. In the non-surgical group, we identified mainly treatment-related factors to be predictive for 30-day readmission, such as longer LOS and the need for ICU treatment.

A longer LOS was predictive for unplanned readmission after neurosurgical treatment in the non-surgical cohort. A previous study had found that a longer LOS is associated with an increased likelihood of unplanned readmission [9].

Treatment-dependent factors (LOS, ICU) predicted unplanned re-hospitalization in non-operated patients, whereas...
patient-dependent factors (age and second diagnoses) dominated in the surgical group. Knowledge about modifiable predictors for unplanned readmission in non-surgical patients is new and essential for early identification and protection of patients with increased risk. It remains to be elucidated, in how far the surgical indication, the LOS, and the intensive care unit treatment are modifiable factors subjected to medical decisions, or if they rather constitute indicators for a complex clinical course, entailing more severe sequelae and a higher risk for 30-day readmission.

Identification of risk factors for 30-day readmission in these conservatively treated patients is of clinical relevance, not only to know the baseline readmission rate the neurosurgeon has to compete with, but also to be aware of factors putting the patient at risk already at the time of first patient counseling.

Strategies for reducing preventable unplanned readmission due to modifiable factors are the subject of current research. A modification of care upon discharge and post-discharge follow-up is being discussed [5]. Similar to the results described by Marcus et al., we determined a high frequency of unplanned readmissions caused by seizures and surgical site infections. A strict anticonvulsive prophylaxis and continued antibiotic regimes can help to reduce readmission rates [13]. A detailed discharge bundle and frequent follow-up appointments may reduce readmission rates and improve outcome.

### Limitations

Among the limitations of the study are the retrospective character and the data collection based on hospital documentation and coding systems. In addition, only patients who were rehospitalized to the Leipzig University Hospital could be tracked. Even though 183 readmitted patients were identified, the numbers of patients become very small after subdivision, thus lowering the statistical power. The classification of different diseases into five diagnosis groups (Table S1) conceals

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**Table 6** Patient demographics and hospital characteristics in unplanned readmitted patients and patients without unplanned readmission in the surgically treated group. *p* values calculated by *t*-test (mean values) or by Fisher exact test

|                      | Unreadmitted surgery group *n* = 1284 Average/No. (%) | Readmitted surgery group *n* = 128 Average/No. (%) | *p* value |
|----------------------|------------------------------------------------------|---------------------------------------------------|-----------|
| Age in years         | 60.50                                                | 55.91                                             | 0.0029    |
| Age in years > 65    | 571 (44.47)                                          | 45 (35.16)                                        | 0.0494    |
| LOS index admission  | 12.24                                                | 14.21                                             | 0.0258    |
| LOS in days 1–8      | 595 (46.34)                                          | 35 (27.34)                                        | 0.0001    |
| Comorbidity *a*      | 699 (54.44)                                          | 84 (65.63)                                        | 0.0154    |
| Pulmonic heart disease | 11 (0.86)                                          | 4 (3.13)                                          | 0.0400    |
| Malignoma            | 232 (18.07)                                          | 44 (34.38)                                        | 0.0001    |

In italics corresponds to a *p* value < 0.05

*LOS* length of stay, *No.* number

*a* Comorbidity: yes in the case of three or more side diagnoses

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**Table 7** Patient demographics and hospital characteristics in unplanned readmitted patients and patients without unplanned readmission in the non-surgically treated group. *p* values calculated by *t*-test (mean values) or by Fisher exact test

|                      | Unreadmitted non-surgical group *n* = 1019 Average/No. (%) | Readmitted non-surgical group *n* = 55 Average/No. (%) | *p* value |
|----------------------|------------------------------------------------------|---------------------------------------------------|-----------|
| LOS in days          | 5.79                                                 | 7.64                                              | 0.0281    |
| Treatment at ICU at index admission | 47 (4.61)                                          | 7 (12.73)                                         | 0.0169    |
| Transfer to ICU      | 1                                                    | 45 (95.74)                                        | 0.0196    |
|                      | ≥ 2                                                  | 2 (4.26)                                          | 1.00      |
| Other heart diseases | 102 (10.01)                                         | 11 (20.00)                                        | 0.0379    |
| Cardiovascular disease | 141 (13.84)                                        | 14 (25.46)                                        | 0.0277    |
| All cardiac diseases *a* | 53 (5.20)                                           | 39 (70.91)                                        | 0.0001    |
| Diabetes mellitus    | 134 (13.15)                                         | 13 (23.64)                                        | 0.0411    |
| Malignoma            | 135 (13.25)                                         | 15 (27.27)                                        | 0.0079    |

In italics corresponds to a *p* value < 0.05

*ICU* intensive care unit, *LOS* length of stay, *No.* number

*a* All cardiac diseases: ischemic heart diseases, pulmonic heart diseases, other heart diseases, cardiovascular diseases, cardiovascular devices
certain important aspects, e.g., tumor entities or acute versus chronic hemorrhages. To address this, our ongoing research deals with detailed investigation of subentities and further reports are in preparation.

**Conclusions**

The present study provides a comprehensive look at 30-day all-cause readmissions after neurosurgical treatment. Factors associated with an increased readmission rate are a younger patient age (<65 years), longer LOS, and comorbidities. Patients who have undergone surgery have to be readmitted more frequently, often due to surgical site infection or seizures. Non-surgically or interventionally treated patients are most likely to be readmitted with neurological deterioration and unspecified complaints due to natural progression of the index diagnosis.

In operated patients, main predictors for readmission were non-modifiable, such as age and comorbidities, whereas in non-surgically treated patients, the seemingly modifiable predictors LOS and intensive care unit treatment were identified. In both groups, the presence of a malignant disease as side diagnosis strongly predicted 30-day readmission. Patient counseling and information to relatives have to consider the non-modifiable factors at the beginning of the treatment, especially for neurosurgical decision making.

The analysis of readmission rates and established risk factors is the beginning of individualized risk adjustment and will help to form quality improvement programs in the future.

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### Table 8 Predictors for unplanned readmission. Multivariate binary logistic regression analysis for unplanned readmission in the study population. Factors with a p value of 0.20 or lower at the univariate level were integrated into the model. Threshold of continuous variables was estimated using the area under the curve

| Predictor                                    | Surgical group (n = 1412) | Non-surgical group (n = 1074) |
|----------------------------------------------|---------------------------|-------------------------------|
| Higher age                                   | 0.98 (0.970–0.995)        | 1.35 (0.760–2.407)            |
| Age > 77 years                                | 0.89 (0.423–1.858)        | 0.78 (0.578–1.054)            |
| Higher number of second diagnoses            | 0.97 (0.923–1.018)        | 0.66 (0.295–1.366)            |
| Number of second diagnoses > 3               | 2.79 (1.478–5.273)        | 0.95 (0.879–1.024)            |
| Presence of comorbidity                      | 1.16 (0.662–2.038)        | 1.07 (1.001–1.14)             |
| Presence of pulmonic heart disease           | 3.73 (1.072–12.999)       | 2.63 (0.963–7.180)            |
| Presence of malignoma                        | 2.44 (1.592–3.724)        | 1.73 (1.106–2.701)            |
| Presence of cerebrovascular disease          |                           | 1.32 (0.556–3.124)            |
| Gender, male                                 |                           |                               |
| Higher PCCL                                   | 0.98 (0.970–0.995)        | 1.35 (0.760–2.407)            |
| PCCL > 1                                     | 0.89 (0.423–1.858)        | 0.78 (0.578–1.054)            |
| Longer LOS                                    | 0.97 (0.923–1.018)        | 0.66 (0.295–1.366)            |
| LOS > 5 days                                  | 2.79 (1.478–5.273)        | 0.95 (0.879–1.024)            |
| Presence of comorbidity                      | 1.16 (0.662–2.038)        | 1.07 (1.001–1.14)             |
| Presence of ischemic heart disease           | 3.73 (1.072–12.999)       | 2.63 (0.963–7.180)            |
| Presence of other heart diseases             | 4.70 (0.832–26.566)       | 1.73 (1.106–2.701)            |
| Presence of cardiovascular disease           | 2.55 (0.399–16.222)       | 1.32 (0.556–3.124)            |
| Presence of diabetes mellitus                | 1.64 (0.784–3.449)        | 1.73 (1.106–2.701)            |
| Presence of malignoma                        | 2.53 (1.287–4.979)        | 2.44 (1.592–3.724)            |
| Presence of chronic obstructive lung disease | 2.08 (0.759–5.715)        | 1.32 (0.556–3.124)            |
| Previous organ transplantation               | 22.15 (1.209–405.746)     | 1.32 (0.556–3.124)            |

In italics corresponds to a p value < 0.05

CI 95% confidence interval, LOS length of stay, ICU intensive care unit, OR odds ratio, PCCL patient clinical complexity level

*a Comorbidity: yes in the case of three or more side diagnoses
performed by CS, HO, KS, ND, UN, and JM. The first draft of the manuscript was written by CS, revised by CS and UN, and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

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**Compliance with ethical standards**

This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The ethical committee of Medical Faculty, University of Leipzig (167/18-ek) approved this study.

**Conflict of interest** All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

**Consent to publish** For this type of study formal consent is not required.

**Abbreviations** CSF, Cerebrospinal fluid; CI, Confidence interval; e.g., Example given; HIV, Human immunodeficiency virus; ICU, Intensive care unit; ICD-10-GM, Classification of Diseases and Related Health Problems, 10th Revision, German Modification; LOS, Length of stay; n.a., Not applicable; No., Number; OR, Odds ratio; PCCL, Patient clinical complexity level; USA, United States of America

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