Modified Rankin Scale and Short-Term Outcome in Cranial Neurosurgery: A Prospective and Unselected Cohort Study

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BACKGROUND: **The modified Rankin Scale (mRS) was developed to monitor functional recovery after stroke, but nowadays it is a treatment outcome measure in elective neurosurgery. Our objective was to study how mRS changes associate with short-term postoperative outcome.**

METHODS: **Preoperative, in-hospital, and 30-day mRS scores came from a prospective, consecutive and unselected cohort of 418 adult elective craniotomy patients enrolled between December 2011 and December 2012 in Helsinki, Finland. Recorded data included subjective and objective postoperative in-hospital complications as well as changes in mRS score after surgery.**

RESULTS: **Minor or major complications were detectable in 46% of the patients. In-hospital and 30-day postoperative increases in mRS score were inconsistent; among patients with no complications, 17% had a greater mRS score at discharge and 24% at 30 days, whereas 28% of the patients with major complications showed no increase in mRS score at discharge. Of individual complications, only new or worsened hemiparesis, silent stroke, and pneumonia were associated with postoperative increase (>2) in mRS score after multivariable analysis. For mRS-score difference > 1 at discharge in detecting major complications (including mortality), sensitivity was 45% and specificity 94%.**

CONCLUSIONS: **The mRS changes after elective cranial neurosurgery are inconsistent. The mRS seems to represent functional changes, which do not necessarily associate with detected in-hospital complications.**

INTRODUCTION

The modified Rankin Scale (mRS) originally was developed in the 1950s for the assessment of functional outcome in patients recovering from neurological deficits caused by a spontaneous stroke.[1] In the late 1980s, the mRS was modified to its current form of a 7-tier classification, in which 0 represents an asymptomatic and 6 a deceased patient.[2] In clinical practice, the mRS is a simple and widely applicable scale, and its interrater variability is low.[3-5] Neurosurgical society has adopted the mRS to assess outcomes after various neurosurgical treatments. Postoperative mRS scores are suggested to represent surgical outcome in cranial tumor surgery,[6-8] and perhaps even more so in cerebrovascular surgery.[9-26]

As an example of a widespread use of mRS in neurosurgery, most influential studies on cerebrovascular surgery, such as the first randomized treatment trial of unruptured brain arteriovenous malformations (A Randomized Trial of Unruptured Brain Arteriovenous Malformation [ARUBA]),[25] the International Study of Unruptured Intracranial Aneurysms (ISUIA),[26] and the International Subarachnoid Aneurysm Trial (ISAT)[22-24] have each reported outcomes and compared treatment results by the mRS. In the ARUBA and the ISUIA studies the mRS was assessed at postoperative follow-up visits or telephone contacts whereas in the ISAT study the mRS was assessed using a mailed questionnaire adapted from Lindley and colleagues.[27] A number of other outcome scores also are available in neurosurgery. For example, the Glasgow Outcome Scale is used for patients with brain injury/trauma[28] and the Karnofsky Performance Score[29] or Eastern Cooperative Oncology Group Performance Status score[30] for patients with brain tumors. These scores are only applicable for specific patient subgroups, however, unlike the mRS with its wide use in cranial neurosurgery.

In this prospective and unselected cohort study, we attempted to define the role of the mRS, recorded with methods similar to the ISUIA and ARUBA, in detecting various short-term outcomes in

Key words
- Craniotomy
- modified Rankin Scale
- Outcome

Abbreviations and Acronyms
ARUBA: A Randomized Trial of Unruptured Brain Arteriovenous Malformation
ISUIA: International Study of Unruptured Intracranial Aneurysms
mRS: Modified Rankin Scale
OR: Operating room

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elective cranial neurosurgery. Specifically, our aim was to determine which complications cause changes in postoperative mRS scores and whether postoperative changes in mRS scores represent the overall short-term surgical outcome of elective craniotomy patients.

MATERIALS AND METHODS

Ethical Statement

The Ethics Committee of the Hospital District of Helsinki and Uusimaa reviewed and approved the study. All subjects gave their written informed consent before enrollment.

Study Population and Data Collection

The cohort comprised consecutive and unselected adult patients (≥18 years) who underwent elective intracranial surgeries in Helsinki University Hospital between December 7, 2011, and December 31, 2012. The enrollment protocol has been described in a previous article.[31] Data collection included patient-reported health-related data collected through 2 questionnaires (1 preoperatively and 1 at hospital discharge), tailored for the purposes of this study. To minimize surgeon-related interpretation bias, a study anesthesiologist recorded the mRS score for each patient. In addition, the study anesthesiologist systematically recorded additional data on in-hospital complications and unplanned reoperations within 30 postoperative days. If the patient was still hospitalized on day 30, hospital discharge data also were recorded on day 30. For patients who were discharged and readmitted for an unplanned reoperation within the 30-day follow-up, the hospital discharge data were recorded at initial discharge. Hospital databases and the Population Register Center were checked for confirming mortality figures (in-hospital and 30-days). A more detailed description of data collection is available in an online supplement.

Postoperative Complications

Postoperative in-hospital major complications comprised mortality, new or worsened hemiparesis, silent stroke (radiological finding without clinical symptoms), deep-vein thrombosis, pulmonary embolism, acute myocardial infarction, and pneumonia. The hemipareses were recorded at discharge, but other major complications at any time during the hospital stay. Unplanned recraniotomies or endovascular interventions within 30 postoperative days also were considered major complications.

Recorded minor complications included subjective visual disturbances, minor infections, new or worsened facial nerve palsies, wound infections, meningitis (no neurological deterioration), subjective dysphagia, dysphasia/dysarthria, and unplanned cranial minor reoperations such as ventriculostomy and wound revision in the operating room (OR). These reoperations did not include tracheostomy, extracranial reoperations, or reoperations performed outside the OR (bedside). In-hospital complications data were retrieved from three sources: patient questionnaires, study forms filled by study anesthesiologists at hospital discharge, and hospital patient records.

mRS Assessments

The mRS score was recorded on admission, at discharge, and at 30 days after surgery. A face-to-face assessment occurred on admission and at discharge, whereas a structured telephone interview was used at 30 days.[3] The difference between the preoperative and postoperative mRS scores received the designation "mRS-score difference."

Statistical Analyses

For association analyses between mRS score and specific complications, we assigned each patient to one complication phenotype. Patients identified as having only one complication underwent separate association analyses. Ranking the significance of complications was done using Pearson chi-square test-based univariable analyses of all complications with mRS-score difference >2 between hospital discharge and preoperative mRS-scores. Significant (P values <0.05) complications in the univariable analyses were entered into logistic regression multivariable analysis, and the most significant complications were ranked in order. All statistically nonsignificant major and minor complications were ranked in order by frequency. This ranking order of complication phenotypes enabled assigning one patient to only one complication phenotype, when this was needed in further statistical analyses. Two-way (2 × 2) contingency tables provided means for sensitivity, specificity, and positive predictive value and negative predictive value calculations. The corresponding author (E.R.) conducted the statistical analyses with the IBM SPSS Statistics for Windows and Mac OX, Version 21.0 (IBM, Corp., Armonk, New York, USA).

RESULTS

Study Cohort and Craniotomies

Of the 418 study patients, 260 (62%) were female. Mean and median ages were 56.4 and 58.0 years (range 18–87). Surgical indications included vascular lesions (intracranial aneurysm or arteriovenous malformation) for 138 (33%), benign tumors for 134 (32%), and malignant tumors for 121 (29%) patients. One-quarter (25%) of the craniotomies were infratentorial.

In-Hospital Complications and 30-Day Mortality

Table 1 shows the recorded individual complications and the frequency of their combinations. The rates of individual complications have been described previously.[32] Of 418 patients, 194 (46%) had 1 or more in-hospital complications. Of the 194 patients, only 1 complication occurred in 120 (62%), whereas the remaining 38% (73 patients) had multiple complications. Four patients (1%) died (mRS = 6) in the hospital. The 30-day mortality rate was 2% (10 patients). One patient who died in the hospital had no recorded major or minor complications, but massive pulmonary embolism emerged in the autopsy.

Major Complications. In-hospital deaths excluded, the rate of major complications was 18%. The number of sole major complications was limited (35 of 76 patients). The three most frequent in-hospital major complications were new or worsened hemiparesis (10%), unplanned recraniotomy or endovascular intervention (4%), and pneumonia (3%).

Minor Complications. One or more in-hospital minor complications occurred in 159 (38%) of the surgical patients, of whom 118 (74%) had no major complications at all. The 3 most frequent minor

Table 1. Numbers of Patients with In-Hospital Complications

	Hemi	Unplanned re-CRT or EI	Silent Stroke	Pneumonia	AMI	PE	DVT	SVD	Speech	Minor Infections	Dysphagia	*N. facialis*	WI/Meningitis	Unplanned Minor Cranial Reoperation
Hemi	41	3	0	4	0	1	0	8	11	5	4	7	2	1
Unplanned re-CRT or EI	3	17	0	0	0	0	0	1	3	4	1	1	2	1
Silent stroke	0	0	6	2	1	0	0	3	2	2	1	0	1	0
Pneumonia	4	0	2	14	2	0	0	2	3	4	3	0	2	1
AMI	0	0	1	2	4	0	0	1	1	1	0	1	0	0
PE	1	0	0	0	0	3	0	0	0	1	0	0	0	0
DVT	0	0	0	0	0	0	2	0	0	0	0	0	0	0
SVD	8	1	3	2	1	0	0	76	13	9	11	5	2	0
Speech	11	3	2	3	1	0	0	13	49	5	9	7	0	0
Minor infections	5	4	2	4	1	1	0	9	5	39	2	1	2	0
Dysphagia	4	1	1	3	0	0	0	11	9	2	26	2	2	0
N. facialis	7	1	0	0	1	0	0	5	7	1	2	14	0	0
WI/meningitis	2	2	1	2	0	0	0	2	0	2	2	0	9	0
Unplanned minor cranial reoperation	1	1	0	1	0	0	0	0	0	0	0	0	0	3

Hemi, new or worsened hemiparesis; re-CRT, recraniotomy; EI, endovascular intervention; AMI, acute myocardial infarction; PE, pulmonary embolism; DVT, deep-vein thrombosis; SVD, subjective visual disturbance; N., nervus; WI, wound infection.

complications comprised subjective postoperative visual disturbance (18%), dysphasia/dysarthria (12%), and minor infections (9%).

Unplanned Reoperations. The rate of unplanned reoperations (including minor operations involving the head) was 5%: of these 19 patients; 16 underwent recraniotomy, 1 had an endovascular intervention, and 3 had minor cranial reoperations in the OR (2 ventriculostomies and 1 wound revision). In multivariable analysis for the assignment of individual complication phenotypes, only new hemiparesis ($P < 0.001$), silent stroke ($P < 0.001$), and pneumonia ($P = 0.005$) were associated with postoperative mRS-score difference >2.

Preoperative and Postoperative mRS

Supplementary Table 1 depicts mRS scores in patient subgroups. Preoperative mRS scores were available for 417 patients. The median preoperative mRS score was 1 (range 0–5). On admission, 374 (90%) patients were functionally independent (mRS score <3), and 267 (64%) had no significant functional symptoms (mRS score 0–1). For 12 patients (no deaths included), mRS score was not recorded at discharge, and thus mRS score was available for 406 patients (median 1, range 0–6, deaths included) at discharge. The number of patients with mRS score >2 doubled postoperatively as 92 (23%) patients had mRS score >2 at discharge. The rates of mRS scores ≤2 and >2 in various subgroups are presented in **Figure 1**.

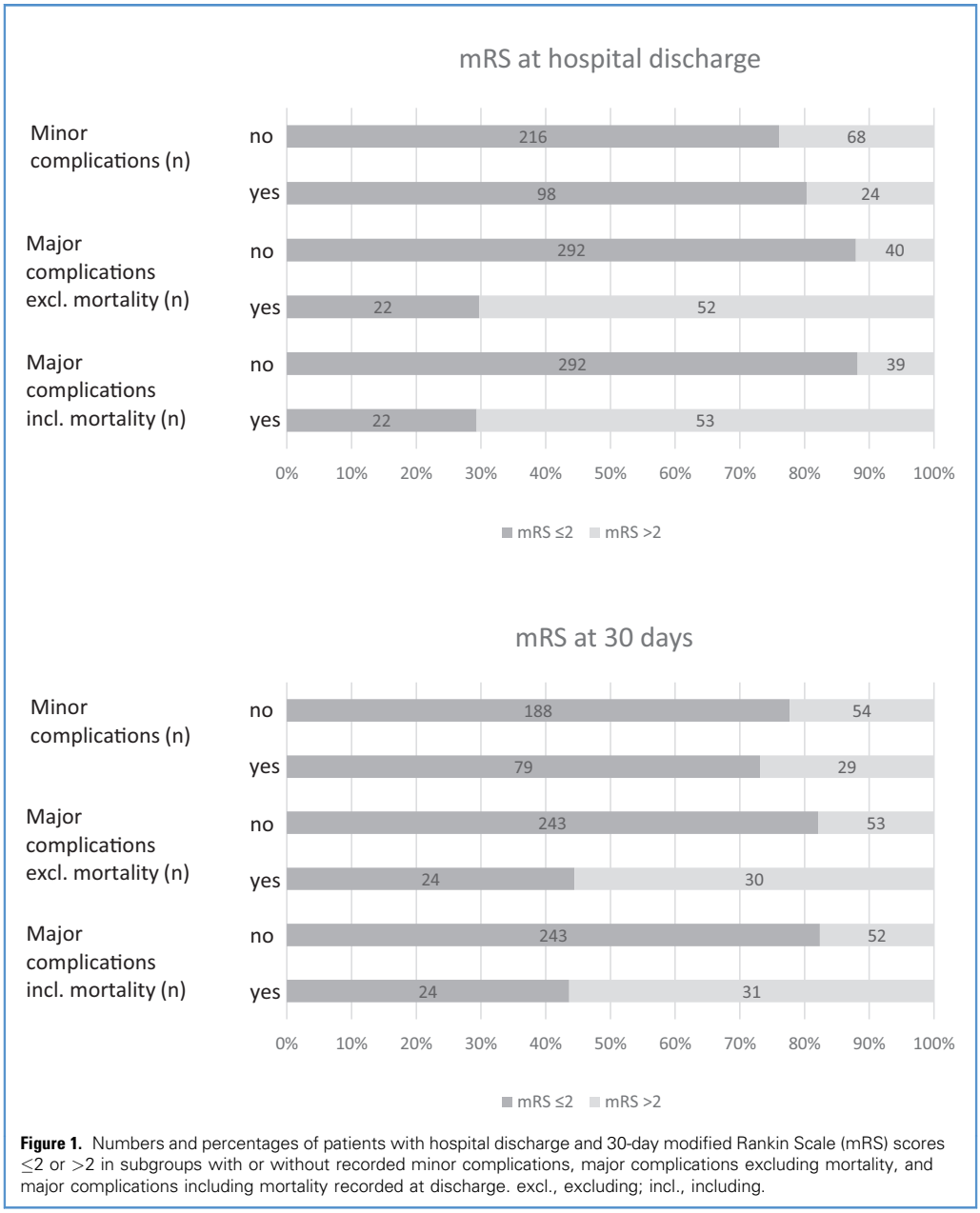

Figure 1. Numbers and percentages of patients with hospital discharge and 30-day modified Rankin Scale (mRS) scores ≤2 or >2 in subgroups with or without recorded minor complications, major complications excluding mortality, and major complications including mortality recorded at discharge. excl., excluding; incl., including.

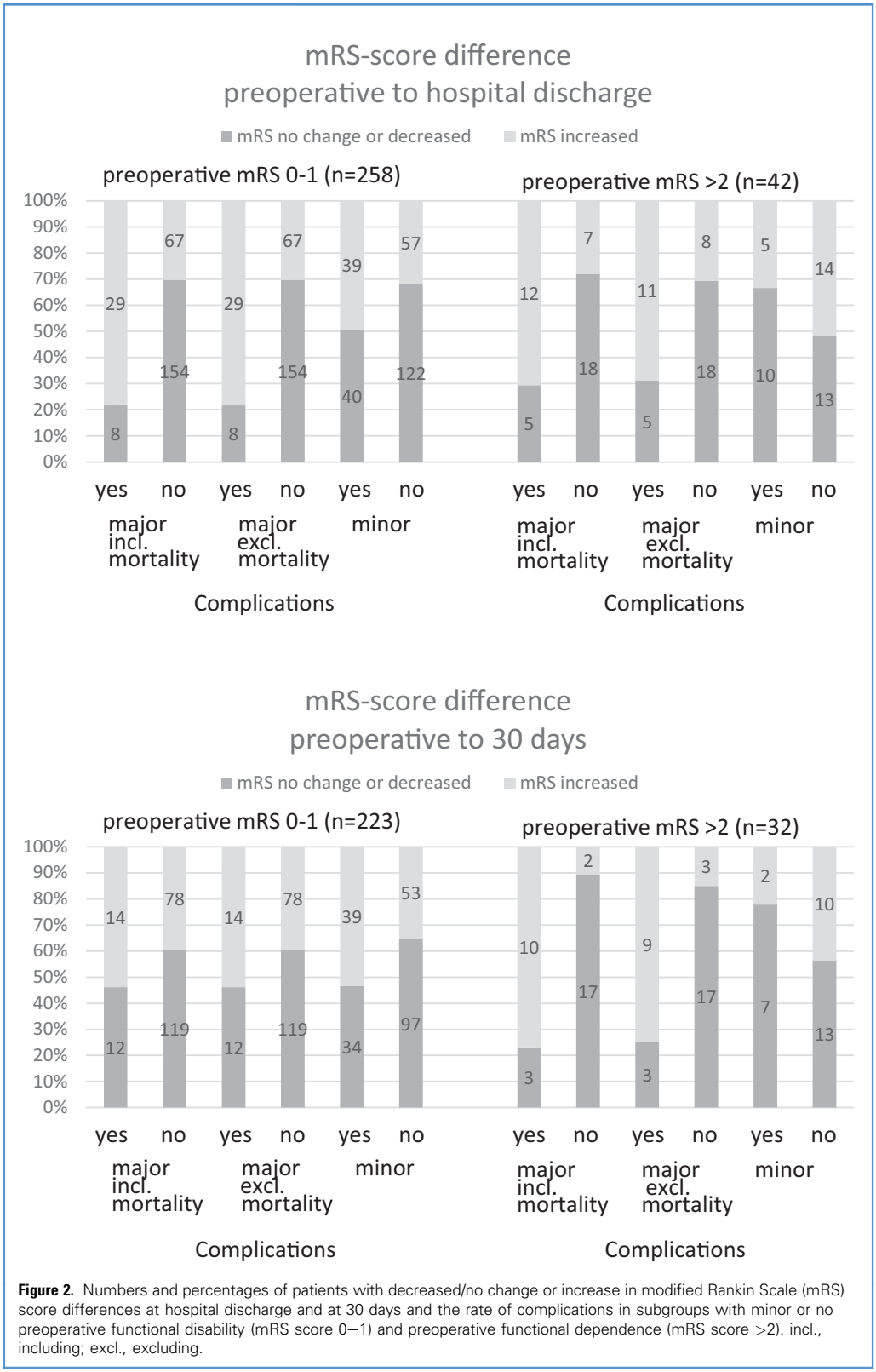

Figure 2. Numbers and percentages of patients with decreased/no change or increase in modified Rankin Scale (mRS) score differences at hospital discharge and at 30 days and the rate of complications in subgroups with minor or no preoperative functional disability (mRS score 0–1) and preoperative functional dependence (mRS score >2). incl., including; excl., excluding.

At 30-day follow-up, 340 patients (81%) answered the telephone interview. Including the 10 patients who died within 30 days after surgery, a total of 350 patients were included in the 30-day analyses. At 30 days, 267 (76%) of these patients were functionally independent (mRS score <3), and the median mRS score was 1.

mRS Score Differences and Complications

For the differences between preoperative and postoperative mRS scores, data were available for 405 patients at discharge and 349 at the 30-day follow-up. Figure 2 summarizes mRS-score differences between preoperative and postoperative mRS scores in patients with no or minor (mRS = 0–1) preoperative functional disability, as well as in preoperatively dependent (mRS score >2) patients. Overall, 138 (34%) and 54 (13%) patients had mRS-score differences >0 and >1 at discharge, respectively. Of 216 patients with no recorded in-hospital complications, mRS scores at discharge increased in 37 (17%). Especially patients with preoperative mRS scores 0 or 1 appeared to have deteriorating mRS scores at discharge without any objective complications (Figure 2). Additionally, 41 (55%) of 75 patients with major in-hospital complications (including mortality) did not have an mRS-score difference >1 at discharge (Supplementary Table 2).

At 30 days, 126 (36%) and 57 (16%) of the 349 patients had respective mRS score differences of >0 and >1. Interestingly, mRS scores worsened from discharge to 30 days in 45 (24%) of the 189 patients with no in-hospital complications. From discharge to 30 days, mRS scores improved in 101 (29%) of 349 patients and remained unchanged in 122 (35%). Anecdotally, 39 (42%) of 92 patients without preoperative functional impairments (mRS score = 0–1) and without in-hospital complications reported increased mRS scores at 30 days.

Two-thirds (66%) of the patients with the greatest ranked complication phenotype (new hemiparesis) had other major or minor complications as well. An mRS score worsening at 30 days was associated with the composite complication outcome measures, that is, the major ($P < 0.001$) and minor ($P = 0.030$) complications; however, the sensitivity, specificity, positive predictive value, and negative predictive value of the mRS-score differences, even for major and minor complications, were poor (Supplementary Table 3).

DISCUSSION

Nearly one-fifth of patients without any complications had increased mRS scores at discharge, and approximately three-fifths with minor complications had no mRS-score increase at all. At 30 postoperative days, the correlation further weakened, as one-fourth of the patients without complications had an mRS score difference >0. As only 35% of these patients underwent surgery for malignant intracranial tumors, neither early progression of the disease nor postoperative tumor treatment explain this observed trend.

In outcome and treatment comparisons, mRS-based outcome often is dichotomized into good (mRS ≤2) and poor (mRS >2). One-fifth (20%) of the cerebrovascular and one-fourth (25%) of all tumor patients had mRS scores >2 at discharge in our study. Of all these patients, roughly one-third (35%) already had an mRS score >2 preoperatively. Most surprisingly, only 57% of all patients with mRS score >2 at discharge had major complications.

The underlying reasons for the unpredictability of perioperative changes in the mRS scores with regard to recorded complications are probably complex. The possible effect of postoperative pain or fatigue may have led to perioperative loss of function (mRS-score difference >0) even in the absence of major complications, especially in the subgroup of patients who had none or mild symptoms preoperatively (mRS score 0–1). We have found previously that dependent functional status (mRS score ≥3) at 30 days associates with both patient-reported postoperative deterioration in subjective functional status as well as with patient-reported poor overall health.[33] Moreover, patients with preoperative mRS scores 0 and 1 may experience undefined functional impairments even without an objective evidence of postoperative complications as suggested by the presented results. In contrast, patients with high preoperative mRS scores may experience no changes in their well-being and functionality even after serious complications. In brief, postoperative functional changes in mRS are often unassociated with objectively recorded complications. Because psychosocial and cognitive factors may play a role in subjective postoperative functional status, the use of mRS as a surgical outcome measure is perhaps questionable.

Strengths and Limitations of the Study

The strengths of this unselected cohort study include its prospective design with tailored postoperative adverse event recording. Moreover, mRS scores were assessed by anesthesiologists who are unlikely to have any bias in reporting surgical outcome. Furthermore, mRS assessment protocol was similar to the ARUBA and ISUIA. In the ARUBA study, mRS scores were recorded at baseline and at each follow-up visit or telephone contact. In the ISUIA study, the mRS was recorded at each follow-up visit which were scheduled at 7 days, at discharge, at 30 days, and then at yearly intervals. The study has a number of limitations. First, a selection bias cannot be excluded, because only 76% of all eligible patients participated in the study. Second, the interrater variability of the mRS is relatively low[3-5] but cannot be excluded. Third, the response rate for the 30-day telephone interview was only 81%. We performed a posthoc analysis of the dropout effect relying on the outpatient hospital records, but the results remained unchanged (results not shown). Fourth, silent strokes were included in major complications, even though they are not expected to affect the functional status. When the analyses were repeated excluding the silent strokes, however, the results remained unchanged (results not shown). Fifth, our follow-up can be considered short. However, if mRS score does not change during short-term follow-up, or changes even without any observed complications, it is unlikely that a long-term follow-up would provide more reliable results. Sixth, the methods of measuring postoperative mRS differed at discharge (anesthesiologist's objective assessment) and at 30 days (patient's subjective reporting in a structured telephone interview), and subjectivity in the 30-day mRS scores cannot be excluded.

CONCLUSIONS

The mRS reflects the rate of postoperative hemiparesis to some extent, but hemiparesis only accounts for a small fraction of complications in cranial neurosurgery. The mRS score differences

associate poorly with the described complications in modern elective cranial neurosurgery, even if it measures subjective functional changes. The neurosurgical community could benefit from a consensus on more objective outcome measurements.[34]

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SUPPLEMENTAL METHODS

PREOPERATIVE DATA COLLECTION

Patient-Reported Data

Patient-reported data were collected with tailored patient questionnaires. If the patient was unable to read or write because of medical or age-related issues such as problems in eyesight, the data were collected through a personal interview during the preoperative visit. Preoperative nurses and study anesthesiologists provided help if the patient had difficulties in completing the questionnaires. The preoperative patient questionnaire consisted of the following questions:

1. Basic information:
   - Name
   - Social security number
   - Date of filling the questionnaire
   - Planned date for operation
   - Age
   - Weight, height
   - Place of residence before the operation (home, hospital, assisted residency, health care center, nursing home)
2. Previous health (no/yes; diagnosis and when diagnosed)
   - Heart condition
   - Arrhythmias
   - Dyspnea
   - Chronic lung illness
   - Atherosclerosis, carotid artery stenosis, claudication
   - Deep-vein thrombosis, pulmonary embolism, thrombogenic condition
   - Stroke, intracranial hemorrhage
   - Cancer
   - Diabetes
   - Epilepsy
   - Other significant illness
3. How do you rate your general health at the moment (excellent-good-average-poor-very poor), why?
4. Smoking
   - Never
   - Yes, how many cigarettes/day, how many years?
     - Stopped smoking, how many cigarettes/day, how many years, when stopped?
5. Alcohol consumption during past 7 days
   - None
   - Moderate: women 1–16 doses, men 1–24 doses
   - Excessive: women over 16 doses, men over 24 doses
6. How often do you exercise for at least 20 minutes, enough to feel short of breath and break a sweat?
   - Cannot exercise because of illness or condition
   - Less often than once a week
   - Once a week
   - 2–3 times a week
   - 4 times a week or more
7. How do you rate your physical fitness at the moment (excellent-good-average-poor-very poor)?
8. Can you climb to flights of stairs without stopping?
   - Yes
   - No, why?

Additionally, the patients were asked to fill a self-administered test for the detection of cognitive dysfunction called Test Your Memory (TYM).[1]

Anesthesiologist-Filled Study Form and Hospital Patient Records

At the time of the preoperative consultation, a study anesthesiologist filled a study form on each patient. Information was retrieved from hospital databases as necessary. If blood pressure and heart rate were not measured at preoperative consultation, we used the first measurements in the OR before the beginning of the anesthesia. The recorded data comprised:

- Date of operation
- Place of preoperative consultation
- Age
- Sex
- Weight (kg)
- Height (cm)
- Body mass index (kg/m^2)
- Use of anticoagulant medication
- Use of antithrombotic medication
- Preoperative blood pressure (mm Hg) and heart rate (beats per minute)
- Routine preoperative laboratory tests
  - hemoglobin (g/L)
  - thrombocyte count (10^9/L)
  - creatinine (μmol/L)
  - blood glucose (mmo/L) (not fasting)
  - Partial thromboplastin time (%)
  - C-reactive protein (mg/L)
  - Sodium (mmol/L)
  - Potassium (mmol/L)

- Charlson comorbidity score[2]
- American Society of Anesthesiologists physical status score[3]
- Helsinki American Society of Anesthesiologists score[4]
- modified Rankin Scale (mRS) score[5,6]
- Preoperative neurological symptoms

INTRAOPERATIVE DATA

Hospital Patient Records and Operating Room Management System Database

Recorded intraoperative variables from hospital patient records and operating room management system database included:

- Experience of the neurosurgeon
  - resident
  - specialist
- Experience of the anesthesiologist
  - resident
  - specialist
- Location of craniotomy
  - infratentorial
  - supratentorial
- Indication for surgery
  - vascular
  - benign tumor
  - malignant tumor
  - other
- Positioning during surgery
  - supine
  - prone
  - lateral park-bench position
  - sitting
  - other (supine with head elevated)
- Duration (min) of surgery from first surgical intervention (beginning of sterile skin preparation) to completion of wound dressings
- Duration (min) of anesthesia from first injection of an anesthetic agent to extubation or transfer to the intensive care unit (ICU)
- Time of extubation
  - in the operating room (OR)
  - in the ICU less than 6 hours after leaving the OR
  - in the ICU more than 6 hours after leaving the OR
- Blood loss during surgery (mL)
- Choice of anesthetic agent
  - intravenous (propofol)
  - volatile (sevoflurane or isoflurane)
  - both
- Use of nitrous oxide (yes or no)

IN-HOSPITAL DATA

Patient-Reported Data

Patients filled a second questionnaire on postoperative symptoms postoperatively at the neurosurgical ward. As with the preoperative questionnaire, they were assisted as necessary. The postoperative questionnaire included the following questions:

1. Basic information
   - Name
   - Social security number
2. Postoperative information
   - Date of operation
   - Date of hospital discharge (from Department of Neurosurgery)
   - Place of residence after hospital discharge (home, hospital, assisted residency, health care center, nursing home)
3. Postoperative neurological deficits/symptoms
   - Short description of symptoms
4. Postoperative symptoms (No/Yes, what?)
   - Postoperative visual impairment
   - Speaking difficulties (dysphasia, aphasia)
   - Swallowing difficulties (dysphagia)
   - Local wound infection, meningitis
   - Other infections
   - Stroke, cerebral ischemia
   - Pneumonia
   - Pulmonary embolism
   - Heart attack
5. Do you think your functional status has changed after the operation (No/Yes, how?)

Additionally, the patients filled a postoperative TYM test form, identical to the preoperative test.

Hospital Patient Records

Hospital patient records provided data on in-hospital complications. A study anesthesiologist manually extracted the following data for all study patients:

- Postoperative complications
  - neurological symptoms
  - stroke/ICH
  - Deep-vein thrombosis
  - Pulmonary embolism

- Acute myocardial infarction
- pneumonia
- wound infection/meningitis
- minor infections
- new or worsened facial nerve palsy
- subjective visual disturbances
- dysphasia/dysarthria
- dysphagia
- Reoperations involving the brain and their indications
  - recraniotomy or endovascular intervention
  - minor cranial reoperation

- length of stay in the ICU
- Hemoglobin on first postoperative day

HOSPITAL DISCHARGE DATA

Anesthesiologist-Filled Study Form and Hospital Patient Records

At the time of hospital discharge, a study anesthesiologist filled a second study form. Hospital databases provided additional data as necessary. The data collected at hospital discharge included:

- LOS in hospital
- New or worsened hemiparesis at hospital discharge
- Place the patient was discharged to
- mRS
- mortality

30-DAY FOLLOW-UP DATA

Telephone Interview, Hospital Patient Records, and Population Register Center Database

At 30 postoperative days, a study anesthesiologist conducted a structured telephone interview for each study patient. At least 3 attempts to reach the patient were made. The structured telephone interview consisted of the following questions:

1. Basic information
   - Patient name
   - Social security number
   - Date of call
2. Place of residence at the time of the interview (home, hospital, assisted residency, health care center, nursing home)
3. 30-day mRS according to a validated mRS telephone questionnaire[7]
4. How do you rate your general health at the moment (excellent-good-average-poor-very poor)?
5. Do you have any persisting postoperative symptoms? (No/Yes, what?) Are they severe/mild?
6. Which of the following best describes your overall satisfaction in the neurosurgical care during this hospitalization? Excellent, good, satisfactory, poor, or very poor.

A study anesthesiologist manually extracted data on reoperations involving the brain for the time period between hospital discharge and the end of 30-day follow-up.

The Population Register Center database provided mortality data for all study patients at 30-day follow-up.

MISSING DATA

Complete data were unavailable for some patients. Patient questionnaires and study forms were incompletely filled or not returned in 119 cases (28.5%). Objective variables, such as in-hospital complications were manually extracted from patient records as necessary. Thus, complete in-hospital complications data was available for all study patients. A total of 68 patients (16.3%) were lost to follow-up at 30 days. We obtained the 30-day mRS scores for 62 patients lost to follow-up for post hoc analyses.

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Supplementary Table 1. Preoperative, Hospital Discharge, and 30-Day mRS Values

mRS	Infratentorial, $n = 104$ (%)	Supratentorial, $n = 313$ (%)	Vascular, $n = 138$ (%)	Benign Tumor, $n = 135$ (%)	Malignant Tumor, $n = 120$ (%)	Other Indications, $n = 24$ (%)	Women, $n = 260$ (%)	Men, $n = 157$ (%)	≥65 years, $n = 124$ (%)	<65 years, $n = 293$ (%)
Preoperative, $n = 417$										
0	21 (20.2)	86 (27.5)	59 (42.8)	33 (24.4)	13 (10.8)	2 (8.3)	72 (27.7)	35 (22.3)	20 (16.1)	87 (29.7)
1	39 (37.5)	119 (38.0)	44 (31.9)	62 (45.9)	43 (35.8)	9 (37.5)	98 (37.7)	60 (38.2)	41 (33.1)	117 (39.9)
2	29 (27.9)	80 (25.6)	30 (21.8)	29 (21.5)	39 (32.5)	11 (45.8)	67 (25.8)	42 (26.8)	37 (29.8)	72 (24.6)
3	8 (7.7)	19 (6.1)	3 (2.2)	6 (4.4)	16 (13.3)	2 (8.3)	13 (5.0)	14 (8.9)	17 (13.7)	10 (3.4)
4	6 (5.8)	7 (2.2)	1 (0.7)	3 (2.2)	9 (7.5)	0 (0.0)	8 (3.1)	5 (3.2)	6 (4.8)	7 (2.4)
5	1 (1.0)	2 (0.6)	1 (0.7)	2 (1.5)	0 (0.0)	0 (0.0)	2 (0.8)	1 (0.6)	3 (2.4)	0 (0.0)
	Infratentorial, $n = 98$ (%)	**Supratentorial, $n = 308$ (%)**	**Vascular, $n = 133$ (%)**	**Benign Tumor, $n = 132$ (%)**	**Malignant Tumor, $n = 118$ (%)**	**Other Indications, $n = 23$ (%)**	**Women, $n = 255$ (%)**	**Men, $n = 151$ (%)**	**≥65 years, $n = 120$ (%)**	**<65 years, $n = 286$ (%)**
At hospital discharge, $n = 406$										
0	22 (22.4)	125 (40.6)	57 (42.9)	49 (37.1)	31 (26.3)	10 (43.5)	98 (38.4)	49 (32.5)	27 (22.5)	120 (42.0)
1	19 (19.4)	72 (23.4)	37 (27.8)	27 (20.5)	23 (19.5)	4 (17.4)	61 (23.9)	30 (19.9)	21 (17.5)	70 (24.5)
2	24 (24.5)	52 (16.9)	12 (9.0)	28 (21.2)	30 (25.4)	6 (26.1)	46 (18.0)	30 (19.9)	26 (21.7)	50 (17.5)
3	13 (13.3)	27 (8.8)	15 (11.3)	10 (7.6)	12 (10.2)	3 (13.0)	20 (7.8)	20 (13.2)	22 (18.3)	18 (6.3)
4	12 (12.2)	24 (7.8)	10 (7.5)	9 (6.8)	17 (14.4)	0 (0.0)	21 (8.2)	15 (9.9)	12 (10.0)	24 (8.4)
5	7 (7.1)	5 (1.6)	2 (1.5)	6 (4.5)	4 (3.4)	0 (0.0)	6 (2.4)	6 (4.0)	8 (6.7)	4 (1.4)
6	1 (1.0)	3 (1.0)	0 (0.0)	3 (2.3)	1 (0.8)	0 (0.0)	3 (1.2)	1 (0.7)	4 (3.3)	0 (0.0)
	Infratentorial, $n = 84$ (%)	**Supratentorial, $n = 266$ (%)**	**Vascular, $n = 113$ (%)**	**Benign Tumor, $n = 106$ (%)**	**Malignant Tumor, $n = 107$ (%)**	**Other Indications, $n = 24$ (%)**	**Women, $n = 219$ (%)**	**Men, $n = 131$ (%)**	**≥65 years, $n = 105$ (%)**	**<65 years, $n = 245$ (%)**
At 30 days, $n = 350$										
0	20 (23.8)	90 (33.8)	43 (38.1)	33 (31.1)	25 (23.4)	9 (37.5)	70 (32.0)	40 (30.5)	31 (29.5)	79 (32.2)
1	19 (22.6)	92 (34.6)	37 (32.7)	35 (33.0)	28 (26.2)	11 (45.8)	73 (33.3)	38 (29.0)	26 (24.8)	85 (34.7)
2	20 (23.8)	26 (9.8)	12 (10.6)	23 (21.7)	8 (7.5)	3 (12.5)	29 (13.2)	17 (13.0)	8 (7.6)	38 (15.5)
3	12 (14.3)	44 (16.5)	17 (15.0)	8 (7.5)	30 (28.0)	1 (4.2)	32 (14.6)	24 (18.3)	23 (21.9)	33 (13.5)
4	6 (7.1)	5 (1.9)	3 (2.7)	1 (0.9)	7 (6.5)	0 (0.0)	6 (2.7)	5 (3.8)	5 (4.8)	6 (2.4)
5	3 (3.6)	3 (1.1)	1 (0.9)	2 (1.9)	3 (2.8)	0 (0.0)	5 (2.3)	1 (0.8)	3 (2.9)	3 (1.2)
6	4 (4.8)	6 (2.3)	0 (0.0)	4 (3.8)	6 (5.6)	0 (0.0)	4 (1.8)	6 (4.6)	9 (8.6)	1 (0.4)

mRS, modified Rankin Scale.

Supplementary Table 2. Preoperative mRS Compared with In-Hospital and 30-day mRS

	mRS Score Difference <0				mRS Score Difference =0				mRS Score Difference >0				mRS Score Difference >1			
	Discharge, *n* = 405		30 days, *n* = 349		Discharge, *n* = 405		30 days, *n* = 349		Discharge, *n* = 405		30 days, *n* = 349		Discharge, *n* = 405		30 days, *n* = 349	
	Yes, *n* = 118	No, *n* = 287	Yes, *n* = 101	No, *n* = 248	Yes, *n* = 149	No, *n* = 256	Yes, *n* = 122	No, *n* = 227	Yes, *n* = 138	No, *n* = 267	Yes, *n* = 126	No, *n* = 223	Yes, *n* = 54	No, *n* = 351	Yes, *n* = 57	No, *n* = 292
Complication groups																
None	85	131	73	116	94	122	71	118	37	179	45	144	8	208	16	173
Major, including mortality	5	70	5	50	16	59	15	40	54	21	35	20	34	41	17	38
Major, excluding mortality	5	69	5	49	16	58	15	39	53	21	34	20	34	40	17	37
Minor	29	93	24	84	42	80	36	72	51	71	48	60	14	108	24	84
Complication phenotypes																
Hemi	2	38	4	25	5	35	9	20	33	7	16	13	22	18	8	21
Silent stroke	0	6	0	4	1	5	0	4	5	1	4	0	4	2	2	2
Pneumonia	0	8	0	4	0	8	0	4	8	0	4	0	2	6	3	1
Re-CRT/EI	3	11	1	10	8	6	4	7	3	11	6	5	3	11	1	10
AMI	0	2	0	2	0	2	1	1	2	0	1	1	2	0	1	1
PE	0	2	0	2	1	1	1	1	1	1	1	1	1	1	0	2
DVT	0	2	0	2	1	1	0	2	1	1	2	0	0	2	2	0
SVD	14	45	8	47	18	41	23	32	27	32	24	31	7	52	12	43
Speech	7	18	8	15	7	18	6	17	11	14	9	14	2	23	5	18
Minor infections	6	13	5	11	6	13	3	13	7	12	8	8	1	18	6	10
Dysphagia	0	7	1	6	6	1	3	4	1	6	3	4	1	6	1	6
N. facialis	0	2	0	2	2	0	1	1	0	2	1	1	0	2	0	2
WI/meningitis	1	1	1	1	0	2	0	2	1	1	1	1	1	1	0	2
Cranial minor reoperation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sole complications																
Hemi	1	13	2	9	2	12	2	9	11	3	7	4	7	7	2	9
Silent stroke	0	1	0	1	0	1	0	1	1	0	1	0	1	0	1	0
Pneumonia	0	3	0	3	0	3	0	3	3	0	3	0	0	3	2	1
Re-CRT/EI	2	6	0	8	5	3	4	4	1	7	4	4	1	7	1	7
AMI	0	1	0	1	0	1	0	1	1	0	1	0	0	1	1	0

PE	0	1	0	1	0	1	1	0	1	0	0	1	1	0	0	1
DVT	0	2	0	2	1	1	0	2	1	1	2	0	0	2	2	0
SVD	11	29	5	32	12	28	15	22	17	23	17	20	4	36	9	28
Speech	6	10	7	7	5	11	3	11	5	11	4	10	0	16	2	12
Minor infections	6	13	5	11	6	13	3	13	7	12	8	8	1	18	6	10
Dysphagia	0	7	1	6	6	1	3	4	1	6	3	4	1	6	1	6
N. facialis	0	2	0	2	2	0	1	1	0	2	1	1	0	2	0	2
WI/meningitis	1	1	1	1	0	2	0	2	1	1	1	1	1	1	0	2
Minor cranial reoperation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

mRS score difference <0 indicates functional improvement after surgery and mRS score difference = 0 implies the functional status has been unaffected by the surgery, mRS-score differences >0 and >1 indicate a decline in functional capacity after surgery. Complications are recorded at discharge.

mRS, modified Rankin Scale; Hemi, new or worsened hemiparesis; re-CRT, recraniotomy; EI, endovascular intervention; AMI, acute myocardial infarction; PE, pulmonary embolism; DVT, deep-vein thrombosis; WI, wound infection; SVD, subjective visual disturbance.

Supplementary Table 3. Sensitivity, Specificity, Positive Predictive Value, and Negative Predictive Value of mRS Score Differences >0 and >1 at Hospital Discharge and at 30-Day Follow-Up for Composite Complication Groups, Complication Phenotypes, and Patients Each with a Sole Complication

	mRS Score Difference>0								mRS Score Difference >1							
	Discharge, *n* = 405				30 days, *n* = 349				Discharge, *n* = 405				30 days, *n* = 349			
	Sens. (%)	Spec. (%)	PPV (%)	NPV (%)	Sens. (%).	Spec. (%)	PPV (%)	NPV (%)	Sens. (%)	Spec. (%)	PPV (%)	NPV (%)	Sens. (%)	Spec. (%)	PPV (%)	NPV (%)
Complication groups																
None	17.1	46.6	26.8	33.0	23.8	49.4	35.7	35.4	3.7	75.7	14.8	40.7	8.5	74.4	28.1	40.8
Major, incl. mortality	72.0	74.5	39.1	92.1	63.6	69.0	27.8	91.0	45.3	93.9	63.0	88.3	30.9	86.4	29.8	87.0
Major, excl. mortality	71.6	74.3	38.4	92.1	63.0	68.8	27.0	91.0	45.9	94.0	63.0	88.6	31.5	86.4	29.3	87.3
Minor	41.8	69.3	37.0	73.4	44.4	67.6	38.1	73.1	11.5	85.9	25.9	69.2	22.2	86.3	42.1	71.2
Complication phenotypes																
Hemi	82.5	71.2	23.9	97.4	55.2	65.6	12.7	94.2	55.0	91.2	40.7	94.9	27.6	84.7	14.0	92.8
Silent stroke	83.3	72.1	4.8	99.6	100.0	66.5	3.6	100.0	66.7	92.2	12.5	99.4	50.0	85.1	4.1	99.3
Pneumonia	100.0	73.8	8.0	100.0	100.0	67.3	3.8	100.0	25.0	92.6	7.1	98.2	75.0	85.9	6.4	99.6
Re-CRT/EI	21.4	73.6	3.3	95.8	54.5	68.1	5.9	97.6	21.4	93.2	11.5	96.6	9.1	85.7	2.3	96.3
SVD	45.8	78.7	31.8	87.0	43.6	71.7	26.1	84.7	11.9	95.2	35.0	83.3	21.8	88.3	30.0	83.1
Speech	44.0	81.0	19.0	93.5	39.1	72.8	13.2	91.9	8.0	95.5	15.4	91.1	21.7	89.4	17.9	91.5
Minor infections	36.8	82.5	14.9	94.0	50.0	74.6	13.6	94.9	5.3	95.6	9.1	92.4	37.5	91.5	26.1	94.8
Dysphagia	14.3	82.4	2.5	96.8	42.9	75.3	5.9	97.3	14.3	95.9	10.0	97.2	14.3	91.8	5.9	96.7
Sole complications																
Hemi	78.6	82.5	22.4	98.4	63.6	75.8	13.2	97.3	50.0	96.3	46.7	96.8	18.2	91.6	11.1	95.1
Re-CRT/EI	12.5	82.5	2.6	96.2	50.0	75.8	8.0	97.3	12.5	96.3	11.1	96.8	12.5	91.6	5.9	96.1
SVD	42.5	82.5	30.9	88.6	45.9	75.8	27.0	87.8	10.0	96.3	33.3	85.3	24.3	91.6	36.0	86.1
Speech	31.3	82.5	11.6	94.2	28.6	75.8	8.0	93.5	0.0	96.3	0.0	92.9	14.3	91.6	11.1	93.5
Minor infections	36.8	82.5	15.6	93.7	50.0	75.8	14.8	94.7	5.3	96.3	11.1	92.1	37.5	91.6	27.3	94.6
Dysphagia	14.3	82.5	2.6	96.8	42.9	75.8	6.1	97.3	14.3	96.3	11.1	97.2	14.3	91.6	5.9	96.7

Low patient counts (<5 patients) made sensitivity, specificity, and positive-, and negative predictive values not applicable for AMI, PE, DVT, *N. facialis*, WI/meningitis, and unplanned cranial minor reoperation complication phenotypes or sole complications, nor for pneumonia phenotype or silent stroke sole complication.

sens., sensitivity; spec., specificity; PPV, positive predictive value; NPV, negative predictive value, mRS, modified Rankin Scale; Hemi, new or worsened hemiparesis; Re-CRT; re-craniotomy; EI, endovascular intervention; SVD, subjective visual disturbance; AMI, acute myocardial infarction; PE, pulmonary embolism; DVT, deep-vein thrombosis; N., nervus; WI, wound infection; incl., including; excl., excluding.