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PROTOCOL

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Rehabilitation outcomes after comprehensive post-acute inpatient rehabilitation following moderate to severe acquired brain injury—study protocol for an overall prognosis study based on routinely collected health data

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Abstract

Background The initial theme of the PROGRESS framework for prognosis research is termed overall prognosis research. Its aim is to describe the most likely course of health conditions in the context of current care. These average group-level prognoses may be used to inform patients, health policies, trial designs, or further prognosis research. Acquired brain injury, such as stroke, traumatic brain injury or encephalopathy, is a major cause of disability and functional limitations, worldwide. Rehabilitation aims to maximize independent functioning and meaningful participation in society post-injury. While some observational studies can allow for an inference of the overall prognosis of the level of independent functioning, the context for the provision of rehabilitation is rarely described. The aim of this protocol is to provide a detailed account of the clinical context to aid the interpretation of our upcoming overall prognosis study.

Methods The study will occur at a Danish post-acute inpatient rehabilitation facility providing specialised inpatient rehabilitation for individuals with moderate to severe acquired brain injury. Routinely collected electronic health data will be extracted from the healthcare provider's database and deterministically linked on an individual level to construct the study cohort. The study period spans from March 2011 to December 2022. Four outcomes will measure the level of functioning. Rehabilitation needs will also be described. Outcomes and rehabilitation needs will be described for the entire cohort, across rehabilitation complexity levels and stratified for relevant demographic and clinical parameters. Descriptive statistics will be used to estimate average prognoses for the level of functioning at discharge from post-acute rehabilitation. The patterns of missing data will be investigated.

Discussion This protocol is intended to provide transparency in our upcoming study based on routinely collected clinical data. It will aid in the interpretation of the overall prognosis estimates within the context of our current clinical practice and the assessment of potential sources of bias independently.

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Keywords PROGRESS, Prognosis research, Overall prognosis, Acquired brain injury, Rehabilitation, Functional independence, Functioning, Stroke, Traumatic brain injury

Background

The Prognosis Research Framework (PROGRESS) defines four interrelated prognosis research themes. The initial theme is termed overall prognosis research aiming to describe the most likely course of health conditions in the context of current care [1]. Estimates of these average outcomes for people with certain health conditions can be used to inform numerous stakeholders including patients, public health policies, and trial designs [1, 2]. The current protocol is concerned with the overall prognosis of the level of independent functioning in people with moderate to severe acquired brain injury (ABI). This includes motor and cognitive functioning in activities of daily living. ABI covers several diagnoses including stroke, traumatic brain injury (TBI), subarachnoid hemorrhage, anoxic brain injury, and encephalopathy. These conditions have distinct aetiologies and contribute considerably to the accumulation of disability-adjusted life years worldwide [3, 4] and impact the lives of affected people similarly [5, 6]. Healthcare spending for people with ABI is substantial [7], with people with ABI being the third largest group in need of rehabilitation [8]. Rehabilitation may reduce the impact of ABI-related functional limitations and is considered both effective and cost-effective [9, 10]. Functional independence is associated with increased health-related quality of life and reduced caregiver burden [11–13]. In addition, the World Health Organization uses functioning as one of their three health indicators [14, 15].

There is a lack of overall prognosis studies in rehabilitation following moderate to severe ABI. Nevertheless, some existing observational studies provide information on the overall prognosis after ABI rehabilitation in Italy (stroke patients), Australia (stroke patients) [16, 17], and Canada (traumatic brain injury and hypoxic ischaemic patients) [18, 19]. Yet, overall prognosis estimates are context-dependent and based on current clinical practice and care (e.g. in diagnosing or treatment approaches). Most overall prognosis studies lack a detailed description of the contextual settings, which are recommended [1, 20]. A concise description of the clinical context may make the interpretation and application of the results from overall prognosis studies easier.

Objective

The aim of the current protocol is to aid the transparency and interpretability of an upcoming study in which the average prognosis for the level of independent functioning at discharge from comprehensive post-acute inpatient rehabilitation in a Danish inpatient rehabilitation facility will be estimated. The objective is to provide a detailed account of the setting, participants and planned analytical steps intended for the estimation of the overall prognosis in people with moderate to severe ABI receiving comprehensive post-acute ABI rehabilitation. The present protocol describes an overall prognosis study according to the PROGRESS framework [1].

Methods

Distinct guidelines for protocols in prognosis research are currently lacking but are in preparation [21]. The current protocol has been conducted based on the guidelines for transparency in prognosis research and reporting of studies based on routinely collected data [22–24].

Setting

ABI rehabilitation in Denmark

Denmark has a universal publicly funded healthcare system based on residency status (approximately 5.9 million inhabitants in 2023). Five administrative districts govern primary and secondary health care [25]. Comprehensive post-acute inpatient rehabilitation following moderate to severe ABI is organised in a national guideline on two service levels: (1) highly specialised service level (HSL) for severe ABI and (2) specialised service level (SSL) for moderate to severe ABI. Nationwide, two inpatient rehabilitation facilities provide rehabilitation for severe ABI (i.e. HSL), while 14 facilities provide rehabilitation for moderate to severe ABI (i.e. SSL) across the five administrative districts [26, 27]. In contrast, people with minor rehabilitation needs typically receive basic service level rehabilitation within neurological or general hospital wards treating the index ABI. Rehabilitation needs are individually assessed by a specialised, interdisciplinary team based on factors including the neurological severity of the brain injury, premorbid and post-ABI levels of functioning, specialised care or therapy needs, the expected ability to partake in rehabilitative therapy and the expected recovery potential. Since 2018, the Rehabilitation Complexity Scale-extended has been used as a referral and admission support tool ("Rehabilitation Complexity Scale-Extended" section) [28, 29].

Hammel Neurorehabilitation Centre and University Research Clinic

Hammel Neurorehabilitation Centre and University Research Clinic (HNC) is located in the Central Denmark Region, which also serves as the administrative district healthcare provider. HNC is an ABI-specialised inpatient rehabilitation facility providing comprehensive rehabilitation services at the highly specialised level for people residing in three Western administrative districts (i.e. North Jutland, Central Denmark, and Southern Denmark) which corresponds to approximately 3.1 Million inhabitants (53% of the Danish population) and the specialised level (i.e. Central Denmark, only) which corresponds to approximately 1.3 Million inhabitants (23% of the Danish population). Please see [30] for a graphical representation. HNC collaborates with educational institutions and is affiliated with Aarhus University. Hence, research and clinical education in specialised ABI rehabilitation must be performed at HNC. In 2019, 51 beds were designated for rehabilitation to people requiring highly specialised services and 67 beds were designated to people requiring specialised services. HNC has one designated ward for the rehabilitation of children and young adults. In 2022, HNC admitted a total of approximately 750 people who received a median of 49 days (IQR 29–71) of rehabilitation services. A research, quality assurance and educational unit are also maintained within HNC.

Provision of rehabilitation services

Rehabilitation services are provided by an interdisciplinary team of health professionals [31] which may include medical doctors (physicians and neurologists), nurses, occupational therapists, speech therapists, physiotherapists, social workers, specialised psychologists and dieticians (Table 1). The core rehabilitation team for each patient consists of at least a physiotherapist, an occupational therapist and a nurse. Rehabilitation services are patient-centred and distinctly tailored towards the expected potential and needs of the individual and their relatives [32]. The International Classification of Functioning, Disability and Health-framework (ICF) [33] is used as the underlying rehabilitation philosophy. Medical doctors are immediately available in the daytime and on-call at other times. All admitted patients are initially assessed for physical and cognitive functioning (including the performance of activities of daily living), nutritional status, mental health and comorbidities. On the specialised service level, the recommended aim for the rehabilitation intensity is at least 45 min of training per focus area on most days of the week [34, 35]. Due to the complex nature of severe ABI and the resulting symptoms, the intensity is higher at the highly specialised level. Therapy and training are recommended on all days, during and outside regular hours with therapists available in the evening and weekends [34, 35]. Discharge decisions are based on a professional interdisciplinary assessment of the individual's expected continued rehabilitation potential. Discharge is based on the potential to improve functioning during inpatient rehabilitation when considering factors such as personal goals, progress, ABI severity and pre-ABI level of functioning. If rehabilitation is required post-discharge, it usually continues on a municipal outpatient or inpatient basis where the individual resides. The municipal rehabilitation services focus particularly on reintegration into and participation in society [27]. People discharged to nursing home facilities do usually not receive any further rehabilitation.

Participants

ABI diagnoses eligible for specialised comprehensive rehabilitation covered by the national guidelines are defined by the Ministry of Health [27, 35]. The following conditions are included: ischaemic and haemorrhagic stroke, TBI, subarachnoid haemorrhage (SAH), encephalopathy (such as brain hypoxia or anoxic brain injury), infections (such as encephalitis or meningitis) and primary brain tumours (benign and malignant). Table A1 in the additional files provides the included referral ICD-10 codes for each condition. People with other ABI diagnoses related to the aforementioned diagnoses, but not explicitly defined in the national guidelines may be admitted when capacity permits an admission that is considered paramount for improvement (e.g. Guillain–Barré syndrome). These diagnoses are collected in a category termed 'other diagnoses'. Irrespective of the condition, people referred and admitted to HNC present with moderate to severe physical (motor or sensory) or cognitive functional limitations and require individually tailored complex rehabilitation services. For example, a previous report showed that 84% of Danish people with

Table 1 Therapy staff at RHN in 2023

Profession	MD	RN	PT	OT	Psy	Soc	SHCA	SpT	Diet
n	18	202	85	92	13	3	109	8	1

MD medical doctors, *RN* registered nurses, *PT* physiotherapists, *OT* occupational therapists, *Psy* psychologists, *Soc* social workers, *SHCA* social- and healthcare assistant, *SpT* speech therapists, *Diet* dietician

severe TBI received highly specialised rehabilitation [36]. Figure 1 shows the distribution of admitted diagnoses across service levels in 2019.

Inclusion criteria

All consecutively admitted people in the study period from 1st March 2011 to 31st December 2022 will be considered for inclusion. Preliminary inclusion criteria are the following: adults (age > 18 years), first-ever admission to HNC, consistent rehabilitation course (see definition below), complete referral information and alive at discharge. A consistent rehabilitation course may include a transfer from highly specialised to specialised service level which indicates improvement and less complex rehabilitation needs. The opposite indicates an inconsistent course due to an administrative or admission error. Functional deterioration during post-acute rehabilitation is seldom observed and is usually caused by another condition or comorbidity often causing the termination of rehabilitation. Complete referral information is required to classify diagnoses correctly. In addition, follow-up admissions are rare and excluded as these are unlikely comparable to the index admission. This also occurs for previous patients with a subsequent ABI (e.g. a TBI 5 years after a stroke). Nevertheless, the overall prognosis for people with inconsistent rehabilitation courses or secondary admissions may be investigated in a supplementary analysis. A minor sub-population of the sample started their rehabilitation at highly specialised level with a seamless subsequent transfer to specialised level rehabilitation and discharge (due to an in-hospital transfer between levels). These people will be considered on the specialised service level, as they were discharged from this service level.

Entry point and endpoint of the cohort

The entry point for the cohort is the admission to post-acute inpatient rehabilitation. There exists no 'time of prognostication' in overall prognosis studies [23]. In the present study, the estimates of the overall prognosis are most relevant for affected people and clinical staff at admission to rehabilitation as a crude indication of the individuals' rehabilitation potential and the basis for interdisciplinary rehabilitation planning and joint goal-setting with the patient. Therefore, estimates will be provided after stratification for relevant variables assessed at admission. The endpoint of the cohort is discharge from post-acute inpatient rehabilitation.

Data source

Data were collected during routine clinical practice using an electronic healthcare record-system (EHR). The EHR was introduced to HNC in 2011 and has been used to the present date. Other regional hospitals within the same administrative district introduced the same EHR approximately at the same time providing linkable data on treatment in the secondary healthcare sector (such as linking acute and subacute treatment). Hence, routinely collected health data for the entire hospital-based rehabilitation process are linkable and include all treatments, medical status, medication, comorbidities and mortality. The extraction, translation and loading process from raw EHR data is performed by the district healthcare provider's IT department in collaboration with an external third party. Data are loaded into the district's data warehouse where the IT department stages data into distinct relational tables and assigns unique identifiers for deterministic individual

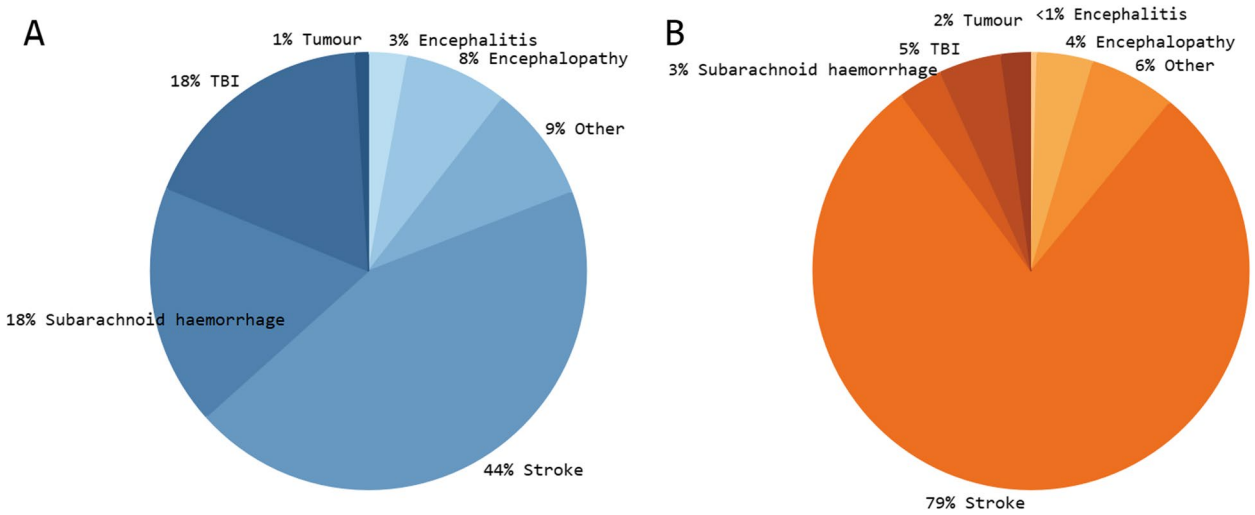

Fig. 1 Distribution of admitted diagnoses in 2019. **A** The proportion of patients across diagnoses on highly specialised service level. **B** The proportion of patients across diagnoses on specialised service level

linking of records across tables. This dimensional database model is commonly referred to as the 'star schema' [37]. For example, one table contains all hospital contacts and another contains all diagnoses. Through the assigned keys a deterministic linkage can identify data such as the referral diagnosis for a particular hospital admission. This form of data staging allows for flexible compilation of data records and extraction, without compromising unique linkages. HNC maintains a local database within the district's data warehouse wherein all inpatient rehabilitation admissions to HNC are identified based on administrative information such as the national personal identifier number, admission date, referral code and diagnosis. The patient administrative information is routinely validated by the medical secretaries at HNC. The local database is maintained by a team of data managers, including one author (UMP). The same author has access to the district's data warehouse within the range of the approval for this study and will perform all data management procedures. All data used will be managed, qualified (e.g. identifying missing data), and extracted using Microsoft SQL Server Management Studio 18 (Redmond, WA, USA) in the district's data warehouse. Administrative admission data will be deterministically linked with relevant clinical data such as the severity, level of functioning or blood biomarkers which concerns the rehabilitation services based on the aforementioned unique identifiers. In some people, information relevant to the study is not documented in the EHR. This information cannot be linked and is considered missing. For the current study, relevant information from eligible electronic patient records from between March 2011 and December 2022 will be compiled and extracted.

Sample size

The crude total cohort contains data from $n=7509$ rehabilitation admissions ($n=7119$ individuals) for the available study period (from 1st March 2011, until 31st December 2022). All available people matching the inclusion criteria will be considered for the descriptive analysis. There could be potential limitations of the final available sample size (e.g. bias induced by small strata) and this will be investigated and described [38–43]. After applying the inclusion criteria $n=6181$ individuals will be available. The HSL cohort and SSL cohort will contain $n=2302$ and $n=3879$ individuals, respectively. See Fig. 2 for the flow chart.

Outcomes

The overall prognosis at discharge from inpatient rehabilitation for the following rehabilitation outcome measures will be described: the (a) Functional Independence Measure® (FIM) [44], (b) Early Functional Ability scale (EFA) [45], (c) Ranchos Los Amigos Scale (RLAS) [46] and (d) Rehabilitation Complexity Scale-Extended (RCSE) [28]. Outcome assessments performed ≤7 days prior to discharge will be considered. Except for the RCSE, discharge assessments are generally performed within 7 days prior to discharge (Table 2 and Fig. 3). All clinicians performing the outcome assessment were sufficiently trained to perform the assessments. All discharge assessments were performed as routine clinical practice.

Functional Independence Measure

The FIM has displayed adequate psychometric properties in ABI populations and is a commonly used outcome measure in post-acute rehabilitation settings [47, 48]. The FIM consists of 18 clinically relevant items, covering motor and cognitive functions in activities of daily living [49, 50]. Items are scored on a 7-point scale, with higher scores indicating more independent functioning. The 13 motor-items and 5 cognitive items yield a score of between 18 and 126 points. Depending on the context, one to six dimensions of the FIM are acknowledged and frequently used [48, 51, 52]. Here, the FIM will be described with one (total FIM score), two (motor and cognitive domain scores) and four (self-care: 6-items; sphincter function: 2-items; mobility: 5-items; and executive control: 5-items) dimensions [52] (see Table 3).

The FIM will also be described using the Functional Independence staging grades, FIM efficiency, FIM effectiveness and proportion of people improving to a clinically meaningful level [53]. Functional Independence staging compiles the individual items into seven mutually exclusive hierarchical activity profiles ranging from requiring 'total assistance' (grade 1) to 'complete independence' (grade 7) [51, 54]. These seven profiles are based on the anticipated order of recovery across the individual items, taking into account the item difficulty, and represent the average score across all 18 items [54]. The FIM efficiency measures the improvement in the FIM per day of rehabilitation and is calculated as:

$$\text{FIM efficiency} = \frac{\text{discharge score} - \text{admission score}}{\text{rehabilitation length of stay}}$$

The FIM effectiveness measures the achieved proportion of the potential maximum improvement on the FIM. This is sometimes referred to as the 'relative functional gain':

$$\text{FIM effectiveness} = \frac{\text{discharge score} - \text{admission score}}{\text{maximum score} - \text{admission score}}$$

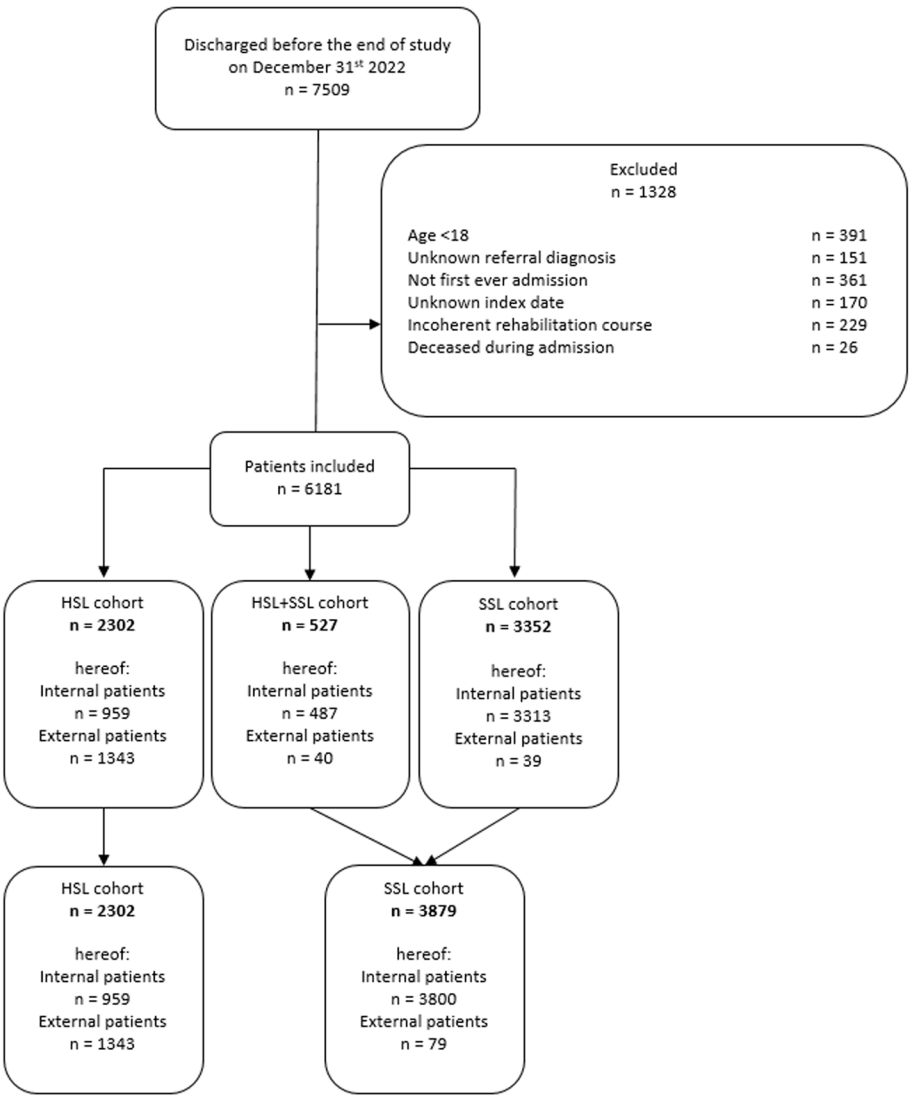

Fig. 2 Flowchart of excluded people based on the inclusion criteria. HSL highly specialised service level, SSL specialised service level, internal patient: referred from the Central Denmark Region, external patient: referred from any other Danish administrative district

Table 2 Number of timely assessments available at discharge and distinct time points during rehabilitation

Rehab. level	Outcome measure	Discharge	4 weeks	6 weeks	8 weeks	10 weeks	12 weeks
HSL	FIM	1714 (74)	1034	574	623	529	315
	EFA	1248 (54)	793	429	430	409	244
	RLAS	1659 (72)	1001	521	571	498	287
	RCSE	422 (18)	592	491	385	240	156
SSL	FIM	2571 (66)	1069	707	508	304	207
	EFA	15 (< 1)	111	61	38	43	24
	RLAS	21 (< 1)	168	87	57	46	25
	RCSE	405 (10)	473	307	172	109	62

HSL highly specialised service level, *SSL* specialised service level

All number are n (for Discharge *n* (% of total)); Weeks were calculated ± 3 days. Discharge includes assessment performed ≤ 7 days before discharge

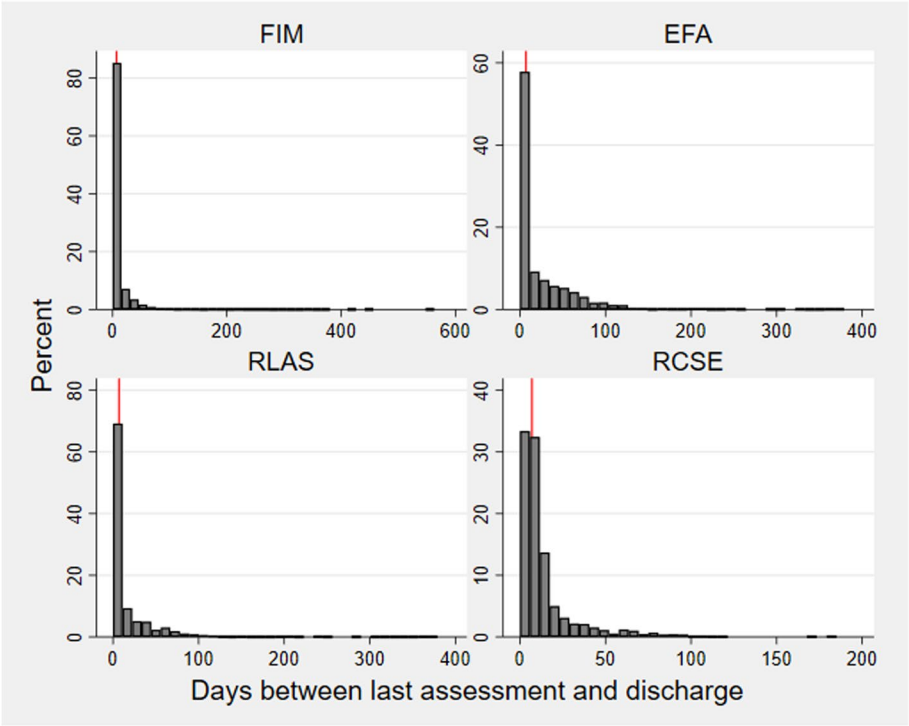

Fig. 3 Timeliness of discharge assessments. Vertical red line indicates 7 days; FIM Functional Independence Measure, EFA Early Functional Ability scale, RLAS Ranchos Los Amigos Scale, RCSE Rehabilitation Complexity Scale-Extended

Table 3 FIM dimensionality and contribution of individual items

FIM item	One-dimension	Two-dimensions	Four-dimensions
Eating	1	1	1
Grooming	1	1	1
Bathing	1	1	1
Upper-body dressing	1	1	1
Lower-body dressing	1	1	1
Toileting	1	1	1
Bladder management	1	1	2
Bowel	1	1	2
Chair transfer	1	1	3
Toilet transfer	1	1	3
Tub transfer	1	1	3
Walking or wheelchair	1	1	3
Stairs	1	1	3
Comprehension	1	2	4
Expression	1	2	4
Social interaction	1	2	4
Problem-solving	1	2	4
Memory	1	2	4

The minimal clinically important difference has been previously estimated in a post-stroke population as 22, 17 and 3 points for the total, motor and cognitive FIM, respectively [53]. The proportion of individuals achieving these benchmarks will be described.

Early Functional Ability Scale

In post-acute rehabilitation following ABI, it has been shown that the FIM is insensitive to total scores < 36 points [55, 56] and it has been recommended to use the EFA [45, 55–57]. This may be necessary for people with severe ABI admitted to highly specialised rehabilitation. The EFA consists of 20 items across the four domains: vegetative function (four items), oro-facial function (four items), sensorimotor abilities (seven items) and cognitive abilities (five items). Each item is rated on a five-point scale where a score of 1 indicates no function and a score of 5 indicates normal function. The total range of the EFA is 20–100 points, with higher scores indicating better functioning. The EFA has shown adequate reliability and validity in samples similar to the present cohort [58–60].

Ranchos Los Amigos Scale

The RLAS is one of the earlier developed outcome measures for cognitive function and behavioural patterns. It

is rated on a single-item ranging from 1 = no response to 8 = purposeful and appropriate behaviour [46]. The RLAS is adequately valid and reliable in ABI populations [61, 62] and is frequently used in clinical rehabilitation settings [63].

Rehabilitation Complexity Scale-Extended

The RCSE measures the complexity of rehabilitation needs. Items are (1) basic care needs, (2) risk (cognitive and behavioural needs), (3) skilled nursing needs, (4) medical needs, (5) number of therapy disciplines required, (6) therapy intensity and (7) equipment needs. All items are rated from 0 to 4, except for equipment needs (0–2), with higher scores indicating greater needs. The RCSE sum score is calculated as the sum of the five items: (3) skilled nursing needs, (4) medical needs, (5) number of therapy disciplines required, (6) therapy intensity and (7) equipment needs plus the highest score of either (1) basic care needs or the (2) risk item. The RCSE yields a sum score between 0 and 22 points [28]. The RCSE has shown satisfactory validity in Danish ABI populations [29, 64].

Candidate predictors

As this is an overall prognosis study, no candidate predictors are specified. The overall prognosis will be described for relevant cohort subgroups. The chosen subgroups partly reflect variables considered as candidate predictors for existing prognostic models [65] or which have been found to be frequently associated with the prognosis of function [66]. The prognosis for different outcomes will be stratified for the following subgroups: discharge year, ABI type, age groups, sex, initial global level of functioning (FIM and EFA) and blood biomarkers (Table 4). For admission level of functioning, only assessments conducted within 7 days of admission will be considered reflective of the functional level at admission (Fig. 4). Functional assessments were conducted during routine clinical practice by trained therapists based on local clinical guidelines. For blood biomarkers, only blood samples drawn within 3 days of admission will be considered. Blood samples were drawn by trained nurses and analysed with relevant standard procedures in one of the district healthcare provider's accredited laboratories (see Supplementary Table A2 in the additional files). See sections "Missing data" and "Considerations and limitations" for considerations on missing data. See Supplementary Tables A3 and A4 (in the additional files) for an extensive crude overview of the study population and variables.

Missing data

Some assessments may not have been performed for reasons such as patient status, inability to assess due to clinician workload, errors in transport or unusable samples. In addition, the clinical guidelines defining assessment time points have changed throughout the study period. Hence, missing admission and outcome data for some variables are likely. Missing data will be treated as missing and not imputed (as recommended in prognostic model research) as it may obscure the descriptive objective of this overall prognosis study. Instead, patterns of missingness will be described [67, 68] and the likelihood of missing variables and their association with other variables will be investigated. Admission and outcome assessments of functioning (i.e. FIM, EFA, RLAS, RCSE) that are not performed within 7 days of admission or discharge will be coded as missing. That ensures the assessment reflects the level of functioning at the respective time point. For the RCSE, a missing admission score may be substituted with the referral RCSE, if conducted within 7 days before admission. Currently, the default process for the translation of fundamental EHR data into the local dimensional database model (see "Data source" section) only allows

Table 4 Stratification of variables and resulting subgroups

Subgroup	Categories of stratified variables
ABI type[a]	Ischaemic stroke, haemorrhagic stroke, traumatic brain injury, subarachnoid haemorrhage, encephalitis, encephalopathy, tumours and 'other diagnoses'
Age	18–40 years, 41–65 years, > 65 years
Sex	Females, males
Functioning	a) Admission Functional Independence Staging grade: eight strata (grades 1–7, 'missing'), b) Total admission FIM score: 5 strata (18, 19–36, 37–90, 91–126, 'missing') c) Total admission EFA score: 5 strata (20–40, 41–60, 61–100, 'missing,''missing, yet FIM > 36'
Blood biomarkers	Based on the laboratories references intervals[b] three strata (under, within, over) for the biomarkers: albumin, C-reactive protein, glucose, calcium, potassium, sodium, haemoglobin, creatinine, leukocytes

[a] The ABI categories reflect the definition used by the Danish Health Authorities in the national guidelines (see Supplementary Table A1 for ICD-10 codes); 'other diagnoses': related ABI diagnoses not explicitly defined by the Ministry of Health in the national guideline on specialised comprehensive rehabilitation

[b] See Supplementary Table A2 in the additional files for the applied reference intervals

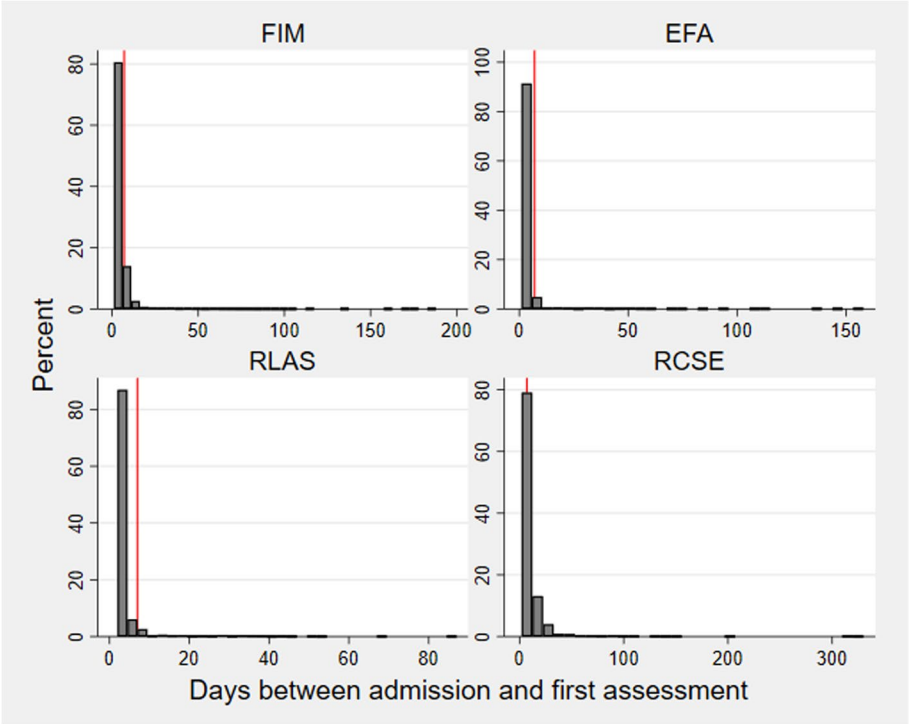

Fig. 4 Timeliness of admission assessments. Vertical red line indicates 7 days; FIM Functional Independence Measure, EFA Early Functional Ability scale, RLAS Ranchos Los Amigos Scale, RCSE Rehabilitation Complexity Scale-Extended

for complete assessments. Assessments missing one or more item scores (e.g. a FIM assessment with only 15 items assessed instead of the total 18 items) are considered errors and coded as missing. Table 5 provides a simple overview of the expected missing data per variable. Supplementary Table A5 in the additional files shows the basic patterns of some missing variables. Signalling questions of the 'Prediction model risk of bias assessment tool' (PROBAST) [69, 70] will be used to describe potential sources of bias in the presently described study, in regards to missing data, selection and information bias. An investigation of patterns of missingness will encompass both missing values from the point of origin (i.e. values not documented in the EHR) and values coded as missing (i.e. untimely assessments not accurately reflecting function at admission or discharge).

Statistical analysis

Statistical analyses will be performed in STATA 17 (College Station, TX, USA) and R (R Core Team, Vienna, Austria). Admission information will be described using the mean, median or proportions, including variances, where appropriate. The overall prognosis at discharge from post-acute rehabilitation for the four outcome measures FIM, EFA, RLAS and RCSE will be estimated using descriptive statistics. While none of the outcome scales are truly continuous, they will be treated as continuous variables for descriptive purposes. Estimates of the overall prognosis will be provided as medians (interquartile range) and ranges. For the RLAS, the proportion of people within each score (1–8) will be reported. The distribution of the outcomes will be presented graphically. The total FIM score and total EFA score may additionally be categorised to support clinical interpretation (Table 4). Outcome categories will be described with proportions (95% confidence intervals). As indicated in the "Outcomes" section, descriptive analyses will be repeated for relevant strata of variables (i.e. cohort subgroups).

The pattern of missing outcome data will be investigated using maximum-likelihood logistic regression with a dummy variable indicating missingness as the dependent variable. Clinical and demographic admission and administrative information will be used as independent variables. These may include ABI type, level of functioning on the FIM and the EFA, age, sex, onset-rehabilitation admission interval, rehabilitation length of stay and potentially blood biomarker levels. In supplementary analyses, we intend to provide estimates for individuals excluded from the primary analysis such as individuals with (a) a missing index diagnosis or date, (b) inconsistent rehabilitation courses and (c) secondary or follow-up admissions.

Table 5 Proportion (%) of missing values in selected variables taking a timely assessment into account

Variable	Total	HSL	SSL
BMI	24.8	29.3	22.2
Alcohol intake	75.2	78.0	73.5
Smoking status	48.6	51.0	47.1
NEWS score	24.3	23.8	24.6
Admission **total FIM score**[a]	21.7	10.0	28.7
Admission **FIS grade**[a]	21.7	10.0	28.7
Admission **EFA score**[a]	63.3	17.8	90.4
Admission **RCSE score**[a]	69.0	73.7	67.4
Admission **RLAS score**[a]	60.1	12.3	88.4
Admission **FOIS score**[a]	59.3	10.9	88.1
Discharge **total FIM score**[b]	30.7	25.5	33.7
Discharge **FIS grade**[b]	30.7	25.5	33.7
Discharge EFA score[b]	79.6	45.8	99.6
Discharge RCSE score[b]	86.6	81.6	89.6
Discharge RLAS score[b]	72.8	27.9	99.5
Discharge FOIS score[b]	72.1	26.3	99.3
Glucose[c]	59.1	37.2	72.1
Potassium[c]	41.9	22.3	53.5
Sodium[c]	41.7	22.1	53.4
Calcium[c]	52.0	24.4	68.4
Albumin[c]	43.8	22.2	56.6
Creatinine[c]	41.8	22.3	53.4
C-reactive protein[c]	53.7	32.5	66.2
Leukocytes[c]	43.0	21.8	55.7
Haemoglobin[c]	46.0	23.3	59.5

[a] Assessments performed later than 7 days after admission are coded as missing

[b] Assessments performed earlier than 7 days before discharge are coded as missing

[c] All blood samples were drawn within 3 days from admission

HSL highly specialised service level, *SSL* specialised service level, *NEWS* National Early Warning Score, *FIM* Functional Independence Measure, *FIS* Functional Independence Staging, *EFA* Early Functional Ability Score, *RCSE* Rehabilitation Complexity Scale–Extended, *RLAS* Ranchos Los Amigos Scale, *FOIS* Functional Oral Intake Scale

Results

We will provide estimates for the overall prognosis of the level of functioning at discharge from comprehensive post-acute inpatient rehabilitation based on the following outcome measures: FIM, EFA, RCSE and RLAS. Estimates will be provided for both cohorts (i.e. the highly specialised and the specialised service levels) and relevant subgroups described above. The demographics and clinical characteristics of the cohort and the current care approaches are described in detail to provide the necessary context for the interpretation of the estimates. Graphs of the distribution of the four outcome scores will be provided. The study manuscript will be drafted in accordance with the TRIPOD statement and PROBAST guidelines [23, 70], in addition to the consideration of guidelines for reporting clinical studies based on routinely gathered health data [24].

Discussion

The upcoming study intends to report the overall prognosis for functioning at discharge from a Danish ABI-specialised post-acute inpatient rehabilitation facility between 2011 and 2022. We agree with the authors of previous articles on the importance of research protocols in prognosis research to (a) increase transparency and reproducibility, and (b) support sound research design and methodological considerations [21, 22]. The results of our upcoming study will be useful as they can provide an indication of the overall prognosis for patients in clinical care and may support the setting of realistic goals. It may also be possible to use these results to compare with other countries with similar or dissimilar healthcare settings. Estimates can be discussed in relation to their importance in, for example, health service research, trial design and prognostic model research [1]. These may be particularly relevant from a research perspective, as the overall prognosis may describe the average outcome in a trial control group in similar settings and hence inform design and sample size requirements. In addition, the average prognosis on the group level also provides reference estimates, which can be improved upon using prognostic models for individual outcome prediction [2]. That is, if a prognostic model is not able to provide a more precise prognosis estimate for an individual than the crude group level average, it is unlikely clinically valuable. A previous report from our rehabilitation facility has compared the functional improvement between individuals with ischaemic, haemorrhagic strokes and subarachnoid haemorrhage [71]. We intend to extend this study and extend the overall prognosis to other ABI subgroups.

Considerations and limitations

There is missing data for particular variables on admission and discharge for the source data presented here. This is not uncommon in routinely collected data [24], and the patterns of missingness will be described and investigated. However, data are still missing and this may affect the overall prognosis estimates depending on the reason for its missingness [68, 72]. For missing data on admission, we expect potential information bias resulting from missing data to be non-differential based on the routine clinical documentation method. Potential information bias may result from the standard discharge procedures for some individuals admitted to HSL rehabilitation as HNC provides HSL rehabilitation for three Western administrative districts (North Jutland, Central Denmark and Southern Denmark). Referrals from

the two districts other than Central Denmark may differ in their discharge procedures (i.e., 'external' patients in Fig. 2). For these people, discharge from highly specialised rehabilitation is not necessarily grounded in the achievement of objective rehabilitation outcomes. Discharge may be related to a sufficiently improved functional level at which the referring administrative district is confident to assume rehabilitation responsibility again, including a transfer to another out-of-district inpatient rehabilitation facility. The presently used data source contains only information on healthcare services (including rehabilitation services) provided by one district, i.e., Central Denmark. Hence, the functional level 'at discharge' may not reflect the actual functional level at the conclusion of post-acute inpatient rehabilitation services, for these people. It will still reflect the functional level at discharge from the most comprehensive rehabilitation services (i.e., highly specialised level). As this practice is unlikely to change soon, from a clinical perspective, it is reasonable to describe all service levels and referrals to reflect the actual contextual clinical practice. The biomarkers were selected by an experienced neurologist. The choice of the nine selected biomarkers reflects their ability to identify disorders of the major organ groups such as albumin for liver function/metabolism, C-reactive protein for inflammation/infections or creatinine for kidney function. There are individuals in the cohort with a single assessment of functioning (e.g., FIM $n=782$). It may be assumed that the score on the FIM only changed marginally over very short rehabilitation courses, e.g., less than a week ($n=44$) or 2 weeks ($n=191$). In these instances, scores could be used as both admission and discharge scores. However, this assumption is incompatible with longer admissions ($n=591$). For these instances, only the score which was assessed timely with regards to admission and discharge (i.e., within 7 days) will be used, while the missing scores will be investigated. Finally, a missing demographic or clinical variable from admission does not necessarily indicate a truly missing assessment and may reflect challenges in uniform routine clinical documentation practice. For example, while 75% of the cohort have a missing value for alcohol intake, this proportion is unlikely reflective of actually missing assessments of dietary alcohol intake. Alcohol intake may have been documented in the written synopsis instead of inputted into the particular 'Alcohol intake' record pane. Unfortunately, we cannot identify all potential places where variables may have been documented in the electronic health records over the 10-year study period. This circumstance may contribute to information bias, which we assume is non-differential due to the routine clinical documentation practice.

Conclusion

This protocol provides an account of the methods intended to be applied in the upcoming study. Furthermore, the setting and patient population are described in detail to allow contextual interpretation of the study results. The upcoming study will provide a comprehensive description of the overall prognosis for the functional level at discharge from specialised post-acute inpatient rehabilitation, including estimates for relevant subgroups of people.

Abbreviations

PROGRESS	Prognosis research strategy
ABI	Acquired brain injury
TBI	Traumatic Brain Injury
FIM	Functional Independence Measure
HSL	Highly specialised service level
SSL	Specialised service level
HNC	Hammel Neurehabilitation Centre–University Research Clinic
ICD-10	International Classification of Disease 10th edition
EHR	Electronic healthcare record
EFA	Early Functional Ability Scale
RLAS	Ranchos Los Amigos Scale
RCSE	Rehabilitation Complexity Scale-Extended
TRIPOD	Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis
PROBAST	Prediction model Risk Of Bias ASsessment Tool

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41512-024-00183-3.

Additional file 1:Supplementary Table A1. International Classification of Disease-10th version (2019) codes and respective categories included in the cohort. Supplementary Table A2. Reference intervals for blood biomarkers. Supplementary Table A3. Crude overview over the sample cohort. Supplementary Table A4. Overview over blood biomarker values and availability. Supplementary Table A5. Overview over patterns of missing data.

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Authors' contributions

UMP: conceptualisation, methodology, project administration, investigation, formal analysis, writing-original draft, review and editing; PWS: conceptualisation, methodology, investigation, supervision, writing-original draft, review and editing; JFN: conceptualisation, supervision, writing—review and editing; All listed authors meet the ICMJE criteria for authorship and have approved the final manuscript.

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Data availability

The datasets generated and/or analysed for the current protocol and study are not publically available and must not be shared due to legal regulations (i.e. the Danish Health Act). The Structured Query Language (SQL) code used to generate the dataset and STATA and R scripts used for analyses is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Approval by the ethical committee is not required as the study is purely observational. The use of routinely collected personal health data (i.e. data extracted from electronic healthcare records) for the present investigations has been approved by the Regional Council of the Central Denmark Region as a responsible authority (Registration No.: 1–45-70–37-21) under the Danish Ministry of Health, and the respective hospital units where data was collected during treatment and rehabilitation.

Consent for publication

Not applicable.

Competing interests

UMP has received a grant from *Helsefonden* (Grant No. 20-B-0047) partially covering his salary during the PhD education, which this protocol and study represent a part of. Helsefonden had no influence on the preparation or execution of the present protocol or the study it describes. PWS and JFN declare no competing interest.

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References

1. Hemingway H, Croft P, Perel P, Hayden JA, Abrams K, Timmis A, et al. Prognosis research strategy (PROGRESS) 1: a framework for researching clinical outcomes. BMJ. 2013;346:e5595. https://doi.org/10.1136/bmj.e5595.
2. Van der Windt DA, Hemingway H, Croft P. Overall prognosis research. In: Riley RD, van der Windt DA, Croft P, Moons KG, editors. Prognosis Research in Healthcare Concepts. Methods, and Impact Oxford Oxford University Press; 2019. p. 87–106.
3. Feigin VL, Abajobir AA, Abate KH, Abd-Allah F, Abdulle AM, Vos T. Global, regional, and national burden of neurological disorders during 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet Neurol. 2017;16:877–97. https://doi.org/10.1016/S1474-4422(17)30299-5.
4. Johnson CO, Nguyen M, Roth GA, Nichols E, Feigin VL, Vos T, et al. Global, regional, and national burden of stroke, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol. 2019;18:439–58. https://doi.org/10.1016/S1474-4422(19)30034-1.
5. Gustavsson A, Svensson M, Jacobi F, Allgulander C, Alonso J, Beghi E, et al. Cost of disorders of the brain in Europe 2010. Eur Neuropsychopharmacol. 2011;21:718–79. https://doi.org/10.1016/j.euroneuro.2011.08.008.
6. Vestergaard SV, Rasmussen TB, Stallknecht S, Olsen J, Skipper N, Sørensen HT, et al. Occurrence, mortality and cost of brain disorders in Denmark: a population-based cohort study. BMJ Open. 2020;10:e037564. https://doi.org/10.1136/bmjopen-2020-037564.
7. Olesen J, Gustavsson A, Svensson M, Wittchen H-U, Jönsson B, group obotCs, et al. The economic cost of brain disorders in Europe. Eur J Neurol. 2012;19:155–62. https://doi.org/10.1111/j.1468-1331.2011.03590.x
8. Cieza A, Causey K, Kamenov K, Hanson SW, Chatterji S, Vos T. Global estimates of the need for rehabilitation based on the Global Burden of Disease study 2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet. 2020;396:2006–17. https://doi.org/10.1016/S0140-6736(20)32340-0.
9. Lorenz LS, Doonan M. Value and cost savings from access to multidisciplinary rehabilitation services after severe acquired brain injury. Front Public Health. 2021;9. https://doi.org/10.3389/fpubh.2021.753447
10. Turner-Stokes L, Pick A, Nair A, Disler PB, Wade DT. Multi-disciplinary rehabilitation for acquired brain injury in adults of working age. The Cochrane database of systematic reviews. 2015:Cd004170. https://doi.org/10.1002/14651858.CD004170.pub3
11. Doser K, Norup A. Caregiver burden in Danish family members of patients with severe brain injury: The chronic phase. Brain Inj. 2016;30:334–42. https://doi.org/10.3109/02699052.2015.1114143.
12. Verdugo MA, Fernandez M, Gomez LE, Amor AM, Aza A. Predictive factors of quality of life in acquired brain injury. Int J Clin Health Psychol. 2019;19:189–97. https://doi.org/10.1016/j.ijchp.2019.06.004.
13. Kohnen R, Lavrijsen J, Smals O, Gerritsen D, Koopmans R. Prevalence and characteristics of neuropsychiatric symptoms, quality of life and psychotropics in people with acquired brain injury in long-term care. J Adv Nurs. 2019. https://doi.org/10.1111/jan.14156.
14. Cieza A. Rehabilitation the health strategy of the 21st century, really? Arch Phys Med Rehabil. 2019;100:2212–4. https://doi.org/10.1016/j.apmr.2019.05.019.
15. Stucki G, Bickenbach J. Functioning: the third health indicator in the health system and the key indicator for rehabilitation. Eur J Physic Rehab Med. 2017;53:134–8. https://doi.org/10.23736/s1973-9087.17.04565-8
16. Scrutinio D, Monitillo V, Guida P, Nardulli R, Multari V, Monitillo F, et al. Functional gain after inpatient stroke rehabilitation: correlates and impact on long-term survival. Stroke. 2015;46:2976–80. https://doi.org/10.1161/strokeaha.115.010440.
17. Katrak PH, Black D, Peeva V. Do stroke patients with intracerebral hemorrhage have a better functional outcome than patients with cerebral infarction? PM&R. 2009;1:427–33. https://doi.org/10.1016/j.pmrj.2009.03.002.
18. Chan V, Sutton M, Mollayeva T, Escobar MD, Hurst M, Colantonio A. Data mining to understand how health status preceding traumatic brain injury affects functional outcome: a population-based sex-stratified study. Arch Phys Med Rehabil. 2020;101:1523–31. https://doi.org/10.1016/j.apmr.2020.05.017.
19. Stock D, Jacob B, Chan V, Colantonio A, Cullen N. Change in function over inpatient rehabilitation after hypoxic ischemic brain injury: a population-wide cohort study. Arch Phys Med Rehabil. 2019;100:1640–7. https://doi.org/10.1016/j.apmr.2019.01.012.
20. Collins GS, Reitsma JB, Altman DG, Moons KG. Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): the TRIPOD statement. BMJ. 2015;350:g7594. https://doi.org/10.1136/bmj.g7594.
21. Dhiman P, Whittle R, Van Calster B, Ghassemi M, Liu X, McCradden MD, et al. The TRIPOD-P reporting guideline for improving the integrity and transparency of predictive analytics in healthcare through study protocols. Nat Machine Intell. 2023;5:816–7. https://doi.org/10.1038/s42256-023-00705-6.
22. Peat G, Riley RD, Croft P, Morley KI, Kyzas PA, Moons KGM, et al. Improving the transparency of prognosis research: the role of reporting, data sharing, registration, and protocols. PLoS Med. 2014;11. https://doi.org/10.1371/journal.pmed.1001671
23. Moons KG, Altman DG, Reitsma JB, Ioannidis JP, Macaskill P, Steyerberg EW, et al. Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD): explanation and elaboration. Ann Intern Med. 2015;162:W1-73. https://doi.org/10.7326/m14-0698.
24. Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, et al. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. PLoS Med. 2015;12:e1001885. https://doi.org/10.1371/journal.pmed.1001885.
25. Schmidt M, Schmidt SAJ, Adelborg K, Sundbøll J, Laugesen K, Ehrenstein V, et al. The Danish health care system and epidemiological research: from health care contacts to database records. Clin Epidemiol. 2019;11:563–91. https://doi.org/10.2147/clep.S179083.
26. Danish Health Authority. Clinical guidelines for Neurology [Specialevejledning for neurologi] (in Danish). 2019.
27. Danish Health Authority. Organisation of rehabilitation for adults with acquired brain injury [Forløbsprogram for rehabilitering af voksne med erhvervet hjerneskade] (in Danish). Copenhagen: Danish Health Authority; 2011.
28. Turner-Stokes L, Scott H, Williams H, Siegert R. The Rehabilitation Complexity Scale – extended version: detection of patients with highly complex needs. Disabil Rehabil. 2012;34:715–20. https://doi.org/10.3109/09638288.2011.615880.

29. Pedersen AR, Nielsen JF, Jensen J, Maribo T. Referral decision support in patients with subacute brain injury: evaluation of the Rehabilitation Complexity Scale – Extended. Disabil Rehabil. 2017;39:1221–7. https://doi.org/10.1080/09638288.2016.1189610.
30. Pommerich UM, Kjeldsen SS, Hansen J, Skovbjerg F, Honoré H, Severinsen K, et al. Repurposing electronic health data for clinical research and beyond - experiences from a specialised neuorehabilitation clinic treating patients with acquired brain injury. Neurologie und Rehabilitation. 2023;29:S63-S4. https://doi.org/10.14624/NR23S2001
31. Langhammer B, Sunnerhagen KS, Lundgren-Nilsson A, Sallstrom S, Becker F, Stanghelle JK. Factors enhancing activities of daily living after stroke in specialized rehabilitation: an observational multicenter study within the Sunnaas International Network. Eur J Physic Rehab Med. 2017;53:725–34. https://doi.org/10.23736/s1973-9087.17.04489-6
32. Wade D. Rehabilitation - a new approach. Part four: a new paradigm, and its implications. Clin Rehabil. 2016;30:109–18. https://doi.org/10.1177/0269215515601177
33. WHO. The International Classification of Functioning, Disability and Health: ICF. Geneva: World Health Organization; 2001.
34. Danish Health Authority. Recommendations for cross-sectorial rehabilitation for adults with acquired brain injury [Anbefalinger for tværsektorielle forløb for voksne med erhvervet hjerneskade] (in Danish). Copenhagen: Danish Health Authority; 2020.
35. Danish Health Authority. Rehabilitation for acquired brain injury - a health technology assessment [Hjerneskaderehabilitering - en medicinisk teknologivurdering] (in Danish). Copenhagen: Danish Health Authority; 2011.
36. Odgaard L, Poulsen I, Kammersgaard LP, Johnsen SP, Nielsen JF. Surviving severe traumatic brain injury in Denmark: incidence and predictors of highly specialized rehabilitation. Clin Epidemiol. 2015;7:225–34. https://doi.org/10.2147/clep.s78141.
37. Kimball R, Ross M. The data warehouse toolkit : the definitive guide to dimensional modeling. 3rd ed. Indianapolis, US: John Wiley & Sons, Inc.; 2013.
38. Pate A, Riley DR, Collins GS, Van Smeden M, Van Calster B, Ensor J, et al. Minimum sample size for developing a multivariable prediction model using multinomial logistic regression. Stat Methods Med Res. 2023. https://doi.org/10.1177/09622802231151220.
39. Archer L, Snell KIE, Ensor J, Hudda MT, Collins GS, Riley RD. Minimum sample size for external validation of a clinical prediction model with a continuous outcome. Stat Med. 2021;40:133–46. https://doi.org/10.1002/sim.8766.
40. Riley RD, Ensor J, Snell KIE, Harrell FE, Martin GP, Reitsma JB, et al. Calculating the sample size required for developing a clinical prediction model. BMJ. 2020;368:m441. https://doi.org/10.1136/bmj.m441.
41. Riley RD, Snell KI, Ensor J, Burke DL, Harrell FE Jr, Moons KG, et al. Minimum sample size for developing a multivariable prediction model: PART II - binary and time-to-event outcomes. Stat Med. 2019;38:1276–96. https://doi.org/10.1002/sim.7992.
42. Riley RD, Snell KIE, Ensor J, Burke DL, Harrell FE Jr, Moons KGM, et al. Minimum sample size for developing a multivariable prediction model: Part I - Continuous outcomes. Stat Med. 2019;38:1262–75. https://doi.org/10.1002/sim.7993.
43. Ogundimu EO, Altman DG, Collins GS. Adequate sample size for developing prediction models is not simply related to events per variable. J Clin Epidemiol. 2016;76:175–82. https://doi.org/10.1016/j.jclinepi.2016.02.031.
44. Linacre JM, Heinemann AW, Wright BD, Granger CV, Hamilton BB. The structure and stability of the functional independence measure. Arch Phys Med Rehabil. 1994;75:127–32. https://doi.org/10.1016/0003-9993(94)90384-0.
45. Hankemeier A, Rollnik JD. The Early Functional Abilities (EFA) scale to assess neurological and neurosurgical early rehabilitation patients. BMC Neurol. 2015;15:207. https://doi.org/10.1186/s12883-015-0469-z.
46. Hagen C, Malkmus D, Durham P. Levels of cognitive functioning. In: Rehabilitation of the head-injured adult: Comprehensive physical management. Downey, CA: Professional Staff Association of Rancho Los Amigos Hospital, Inc.; 1979. p. 87–9.
47. Pretz CR, Kean J, Heinemann AW, Kozlowski AJ, Bode RK, Gebhardt E. A multidimensional rasch analysis of the functional independence measure based on the national institute on disability, independent living, and rehabilitation research traumatic brain injury model systems national database. J Neurotrauma. 2016;33:1358–62. https://doi.org/10.1089/neu.2015.4138.
48. Stineman MG, Shea JA, Jette A, Tassoni CJ, Ottenbacher KJ, Fiedler R, et al. The Functional Independence Measure: tests of scaling assumptions, structure, and reliability across 20 diverse impairment categories. Arch Phys Med Rehabil. 1996;77:1101–8. https://doi.org/10.1016/s0003-9993(96)90130-6.
49. Hobart JC, Lamping DL, Freeman JA, Langdon DW, McLellan DL, Greenwood RJ, et al. Evidence-based measurement: which disability scale for neurologic rehabilitation? Neurology. 2001;57:639–44. https://doi.org/10.1212/wnl.57.4.639.
50. Sangha H, Lipson D, Foley N, Salter K, Bhogal S, Pohani G, et al. A comparison of the Barthel Index and the Functional Independence Measure as outcome measures in stroke rehabilitation: patterns of disability scale usage in clinical trials. Int J Rehabil Res. 2005;28:135–9.
51. Stineman MG, Ross RN, Fiedler R, Granger CV, Maislin G. Functional independence staging: conceptual foundation, face validity, and empirical derivation. Arch Phys Med Rehabil. 2003;84:29–37. https://doi.org/10.1053/apmr.2003.50061.
52. Stineman MG, Jette A, Fiedler R, Granger C. Impairment-specific dimensions within the Functional Independence Measure. Arch Phys Med Rehabil. 1997;78:636–43. https://doi.org/10.1016/s0003-9993(97)90430-5.
53. Beninato M, Gill-Body KM, Salles S, Stark PC, Black-Schaffer RM, Stein J. Determination of the minimal clinically important difference in the FIM instrument in patients with stroke. Arch Phys Med Rehabil. 2006;87:32–9. https://doi.org/10.1016/j.apmr.2005.08.130.
54. Stineman MG, Ross RN, Fiedler R, Granger CV, Maislin G. Staging functional independence validity and applications. Arch Phys Med Rehabil. 2003;84:38–45. https://doi.org/10.1053/apmr.2003.50060.
55. Pedersen AR, Stubbs PW, Nielsen JF. Reducing redundant testing using the Functional Independence Measure and Early Functional Abilities scale during rehabilitation in patients with brain injury. Brain Inj. 2018;32:1090–5. https://doi.org/10.1080/02699052.2018.1482425.
56. Stubbs PW, Pallesen H, Pedersen AR, Nielsen JF. Using EFA and FIM rating scales could provide a more complete assessment of patients with acquired brain injury. Disabil Rehabil. 2014;36:2278–81. https://doi.org/10.3109/09638288.2014.904935.
57. Heck G, Steiger-Bachler G, Schmidt T. Early Functional Abilities (EFA) - eine Skala zur Evaluation von Behandlungsverläufen in der neurologischen Frührehabilitation. Neurol Rehabil. 2000;6:125–33.
58. Alvsåker K, Walther SM, Kleffelgård I, Mongs M, Drægebø RA, Keller A. Inter-rater reliability of the early functional abilities scale. J Rehabil Med. 2011;43:892–9. https://doi.org/10.2340/16501977-0855.
59. Poulsen I, Kreiner S, Engberg AW. Validation of the Early Functional Abilities scale: an assessment of four dimensions in early recovery after traumatic brain injury. J Rehabil Med. 2018;50:165–72. https://doi.org/10.2340/16501977-2300.
60. Boltzmann M, Schmidt SB, Gutenbrunner C, Krauss JK, Höglinger GU, Weimar C, et al. Validity of the Early Functional Ability scale (EFA) among critically ill patients undergoing early neurological rehabilitation. BMC Neurol. 2022;22:333. https://doi.org/10.1186/s12883-022-02855-3.
61. Gouvier WD, Blanton PD, LaPorte KK, Nepomuceno C. Reliability and validity of the Disability Rating Scale and the Levels of Cognitive Functioning Scale in monitoring recovery from severe head injury. Arch Phys Med Rehabil. 1987;68:94–7.
62. Hall KM, Hamilton BB, Gordon WA, Zasler ND. Characteristics and comparisons of functional assessment indices. J Head Trauma Rehabil. 1993;8:60–74.
63. Frantz A, Incio Serra N, Lopez Almendariz A, Duclos C, Owen AM, Blain-Moraes S. Assessing cognitive outcomes in coma survivors: a literature review. Brain Sci. 2023;13:96.
64. Maribo T, Pedersen AR, Jensen J, Nielsen JF. Assessment of primary rehabilitation needs in neurological rehabilitation: translation, adaptation and face validity of the Danish version of Rehabilitation Complexity Scale-Extended. BMC Neurol. 2016;16:205. https://doi.org/10.1186/s12883-016-0728-7.
65. Pommerich UM, Stubbs PW, Eggertsen PP, Fabricius J, Nielsen JF. Regression-based prognostic models for functional independence after post-acute brain injury rehabilitation are not transportable - a systematic review. J Clin Epidemiol. 2023. https://doi.org/10.1016/j.jclinepi.2023.02.009.

66. Meyer MJ, Pereira S, McClure A, Teasell R, Thind A, Koval J, et al. A systematic review of studies reporting multivariable models to predict functional outcomes after post-stroke inpatient rehabilitation. Disabil Rehabil. 2015;37:1316–23. https://doi.org/10.3109/09638288.2014.963706.
67. Steyerberg EW. Clinical Prediction Models A Practical Approach to Development, Validation, and Updating. 2nd ed. Cham: Springer Nature; 2019.
68. Donders AR, van der Heijden GJ, Stijnen T, Moons KG. Review: a gentle introduction to imputation of missing values. J Clin Epidemiol. 2006;59:1087–91. https://doi.org/10.1016/j.jclinepi.2006.01.014.
69. Wolff RF, Moons KGM, Riley RD, Whiting PF, Westwood M, Collins GS, et al. PROBAST: a tool to assess the risk of bias and applicability of prediction model studies. Ann Intern Med. 2019;170:51–8. https://doi.org/10.7326/m18-1376.
70. Moons KGM, Wolff RF, Riley RD, Whiting PF, Westwood M, Collins GS, et al. PROBAST: a tool to assess risk of bias and applicability of prediction model studies: explanation and elaboration. Ann Intern Med. 2019;170:W1-w33. https://doi.org/10.7326/m18-1377.
71. Stabel HH, Pedersen AR, Johnsen SP, Nielsen JF. Functional independence: a comparison of the changes during neurorehabilitation between patients with nontraumatic subarachnoid hemorrhage and patients with intracerebral hemorrhage or acute ischemic stroke. Arch Phys Med Rehabil. 2017;98:759–65. https://doi.org/10.1016/j.apmr.2016.11.010.
72. Moons KGM, Donders RART, Stijnen T, Harrell FE Jr. Using the outcome for imputation of missing predictor values was preferred. J Clin Epidemiol. 2006;59:1092–101. https://doi.org/10.1016/j.jclinepi.2006.01.009.

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