

## ORIGINAL REPORT

## REFERRALS TO EARLY SPECIALIZED REHABILITATION AFTER TRAUMATIC BRAIN INJURY DURING THE COVID-19 PANDEMIC

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**Objective:** To quantify potential changes in direct referral to early specialized rehabilitation during the COVID-19 pandemic and the injury pattern of patients hospitalized with traumatic brain injury (TBI) at a level 1 trauma centre.

**Methods:** In this registry-based study, data were retrieved from the Oslo TBI Registry-Neurosurgery and included adult patients with injury-related intracranial findings admitted to Oslo University Hospital (OUH). The study focused on a period of time when OUH was in any level of preparedness because of the COVID-19 pandemic; March 2020 to August 2021. For comparison, the study used patients hospitalized for TBI in 2018 and 2019.

**Results:** A total of 1,310 hospitalized patients with TBI were divided into 2 groups; pre-pandemic and pandemic. Direct referral to early rehabilitation was maintained. Patient volume remained stable, and there were no differences between the groups regarding patient characteristics and acute management, although there was a significantly higher proportion of TBIs secondary to electric scooter accidents in the pandemic group. Results from univariable and multivariable logistic regression showed a multifaceted reality, but younger age, none or mild pre-injury comorbidity and severe disability due to TBI at discharge from acute care remained stable strong predictors of direct referral to rehabilitation.

**Conclusion:** For patients with moderate-severe TBI, the direct pathway to early specialized rehabilitation was maintained during 2020–21. However, the pandemic continued and the long-term impact for rehabilitation services is not yet known.

**Key words:** traumatic brain injury; pathway; early specialized rehabilitation; COVID-19; trauma centre.

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## LAY ABSTRACT

After traumatic brain injury, early rehabilitation is important in order to achieve optimal functional outcome. The COVID-19 pandemic has put the health services under pressure, and hospitals in Norway were reorganized to be able to treat a large number of patients with COVID-19. Therefore, this study investigated to what extent the transfer to early rehabilitation has been affected and whether there have been changes in volume and characteristics of patients admitted to hospital with traumatic brain injury. In conclusion, the direct pathway to early rehabilitation was maintained during the pandemic years 2020 and 2021. Moreover, there was no change in the number of hospital admissions or patient characteristics, and acute management was maintained. However, the true long-term consequences for rehabilitation are not yet known.

The COVID-19 pandemic, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) incited a global public health response through government, commercial, and behaviour protocols aimed at reducing spread of the disease. The 2 first cases of COVID-19 in Oslo, the capital of Norway, were confirmed on 27 February 2020. On 28 February 2020, the City Government was on emergency alert, and on 13 March 2020, the Norwegian national authorities decided to implement strict national interventions. On 11 March 2020, Oslo University Hospital's (OUH) preparedness response to COVID-19 was to postpone non-urgent operations, reorganize services and reallocate medical staff. This included converting the early rehabilitation ward to a COVID-19 ward and transferring the rehabilitation of patients with traumatic brain injury (TBI) to the neurosurgery ward.

Comparing TBI referrals during lockdown with previous years, many studies showed a decrease in the incidence of referrals and admissions during lockdown periods (1–6). However, the relief of lockdown measures was accompanied by increases in TBIs (2, 7). The observed changes may be explained by lockdown measures resulting in people staying at home, which led to global

reductions in road traffic accidents (RTAs) (1, 8–10). Neurotrauma was more likely to take place indoors at private residences, accompanied by increases in falls, which were seen among >65-year-olds (6). Regarding management of TBI, Manivannan et al. (9) found a significant decrease in surgical management of TBI, with a comparable increase in conservative management. This may be a reflection of a change towards milder TBI during the pandemic. However, Goyal et al. (8) similarly experienced a significant increase in the proportion of conservatively managed TBI, despite significant increases in severity of TBI. There is a considerable variation between countries (11), and the eventual impact on unmet service needs for the patients with TBI during the pandemic is largely unexplored.

Depending on its severity, TBIs can result in cognitive, social, emotional and motor deficits requiring extensive rehabilitative therapy. Early initiation of a continuous care and rehabilitation pathway can improve functional outcomes and reduce hospitalization costs for patients with severe TBI (12, 13). Hence, a continuous care pathway including specialized rehabilitation has been a goal for the services over the last years (14). However, during the COVID-19 pandemic, both the non-urgent neurosurgical and the rehabilitation services were downscaled. Combining trauma referral and TBI severity with referral to specialized rehabilitation provides the opportunity to explore the pandemic's impact on the patients' needs. Therefore, the aim of this study was to quantify potential changes in direct referral to early specialized rehabilitation during the COVID-19 pandemic. The study also aimed to evaluate changes in injury pattern and severity of patients with TBI and neurosurgical treatment at OUH during the pandemic period.

## METHODS

### *Study setting and participants*

Oslo University Hospital (OUH) is the only level 1 trauma centre with neurosurgical services in the south-east region of Norway and the primary trauma referral hospital for Oslo residents. Thus, all neurosurgery in the region is performed solely at OUH. Patients with TBI are transported directly to OUH if they are in need of emergency neurosurgical procedures or neurosurgical evaluation. After treatment at the acute care units (intensive care unit (ICU) and/or neurosurgical ward), the patient can be discharged to specialized rehabilitation, to their local hospital or home.

The patient cohort in this study was retrieved from the Oslo TBI Registry-Neurosurgery, a quality control registry maintained by the neurosurgical department at OUH. The registration is prospective, and data are

derived manually from electronic medical records and stored in a Medinsight database (15). Inclusion criteria for Oslo TBI Registry – Neurosurgery are: (i) TBI; (ii) cerebral-computed tomography (CT)/CT angiography (CTA), or cerebral-magnetic resonance imaging (MRI)/ magnetic resonance angiography (MRA) with findings of acute trauma (haemorrhage, fracture, traumatic axonal injury (TAI) vascular injury); (iii) admitted to OUH within 7 days post-injury; and (iv) Norwegian social security number.

This study included patients admitted to OUH in the period when the hospital was in a level of preparedness because of the COVID-19 pandemic; 11 March 2020 was the start-date for change in preparedness level at OUH and 17 August 2021 was the end-date. Subgroup analyses were performed on patients hospitalized and discharged between 27 March 2020 and 4 May 2020, and 29 March 2021 and 26 April 2021 because of further increased preparedness level, and the rehabilitation ward in these periods was converted to a COVID-19 ward. Patients admitted between 1 January 2018 and 31 December 2019 were used for comparison. This study included adult patients (age  $\geq 18$  years), alive at discharge and resident in the south-east region of Norway.

### *Endpoint*

The study endpoint was the discharge destination from acute care units at OUH. Discharge destinations are categorized as home, specialized rehabilitation, local hospital, general rehabilitation, nursing home and other. The endpoint variable is binary; either direct transfer to specialized rehabilitation or not. Patients discharged to specialized inpatient rehabilitation are categorized as “yes”. All other discharge places are considered as “no”. The specialized inpatient rehabilitation programme focusses on reducing the extent of the brain injury, preventing complications, promoting functional recovery and reducing impairment, as well as minimizing the distress of the patient and caregivers (12). The treatment includes medical assessment and treatment of post-traumatic amnesia, physiotherapy, cognitive assessment and training, occupational therapy, speech therapy, nutrition, dietary services and psycho-social support.

### *Demographics, pre-injury comorbidity, injury characteristics and functional outcome*

Age was stratified into 18–29 years, 30–49 years, 50–64 years, 65–79 years, 80+ years and sex into male/female. Living status was recorded as: independently at home, home with assistance, institution or other, and further dichotomized into living independently at home

or not. Trauma mechanism was divided into falls, RTA or other. High-energy trauma was defined as falls from a height  $\geq 3$  m, RTAs or other high-energy accidents. The Glasgow Coma Scale score (GCS) was defined as the lowest score documented prior to intubation or admission to OUH. TBI severity was measured by Head Injury Severity Score (HISS) (minimal: GCS 15 and no loss of consciousness or amnesia, mild: GCS 14 or 15 plus amnesia, or brief loss of consciousness ( $< 5$  min), or impaired alertness or memory, moderate: GCS 9–13 or loss of consciousness  $\geq 5$  min or focal neurological deficit, or severe: GCS  $\leq 8$ ) (16). Pre-injury comorbidity was classified by the American Society of Anaesthesiologists Physical Status Classification System (ASA-PS) (17). Assigning a Physical Status classification level is a clinical decision based on multiple factors. Here we report on classification from 1 = normal healthy, 2 = mild systemic, 3 = severe systemic, 4 = life-threatening. The Glasgow Outcome Score (GOS) on the day of discharge was based on information from multidisciplinary medical records. The GOS is divided into 5 categories: GOS 1 dead (D), GOS 2 vegetative state (VS), GOS 3 severe disability (SD), GOS 4 moderate disability (MD) or GOS 5 good recovery (GR) (18), and only 2 through 5 were applicable in the current study population. The reasons for reduced GOS were grouped into: (i) TBI, (ii) TBI in combination with extracranial injury and/or comorbidity, and (iii) other.

#### *Hospital management*

The hospital's management strategy was divided into conservative management (no surgery required), insertion of intracranial pressure (ICP) sensor, or intracranial procedures. Intracranial procedures included evacuation of mass lesion (haematoma/haemorrhage), cerebrospinal fluid drainage, decompressive hemicraniectomy, repair of dura or fractured skull (duraplasty/cranioplasty), and vascular surgery. Calculation of length of stay (LOS) is based on dates and each date counted as a full day.

#### *Statistical analysis*

Patient characteristics are reported as frequency (percentage), mean (standard deviation; SD), or median (interquartile range; IQR) depending on distribution. For comparison between groups, we used Student's test or Mann–Whitney *U* test for continuous variables, and  $\chi^2$  tests or Fisher's exact test for categorical variables, as appropriate. All tests were 2-sided and set 5% significant level. The statistical procedure and selection of variables for the multivariable logistic regression models was built on a previous study from OUH (14). In brief, univariable and multivariable

logistic regressions were performed to examine possible risk factors of differentiating between patients discharged to specialized rehabilitation and patients discharged elsewhere. The possible risk factors were selected based on previous literature and clinical relevance, and possible multicollinearity examined using Pearson correlation analyses, correlating variables were not included ( $r$  upper limit 0.7). The model was assessed by calibration and discrimination, and calibration evaluated by the Hosmer and Lemeshow goodness-of-fit test. Discrimination was evaluated by analysis of the area under the receiver operating characteristic curve (AUC ROC). Results are presented with odds ratio (OR), 95% confidence interval (95% CI) and *p*-value, and data were analysed with IBM SPSS Statistics, Version 26.0. Armonk, NY, USA: IBM Corp.

#### *Ethics*

OUH data protection officer (DPO) has approved Medinsight database (approval number 2016/17569), this study was applied to OUH DPO and approved on 5 October 2021.

## RESULTS

#### *Patient cohort*

A total of 1,310 patients with TBI fulfilling the inclusion criteria were divided in 2 groups based on admission dates. The pre-pandemic group covered a time-period of 24 months and included 758 patients. The pandemic group covered a period of 18 months and included 552 patients. A comparison of patient and injury characteristics in pre-pandemic and pandemic period is shown in Table I. There were no significant differences in the characteristics between the groups with respect to mean age (58 years in both groups (SD 20)), and sex (65–68% male). The majority were healthy, with ASA-PS score of 1–2. However, there was a difference in pre-injury ASA-PS score; the pandemic group had a higher proportion of patients with ASA-PS  $\geq 3$  (43–33%). The majority lived independently at home in both groups (84–85%). The trauma mechanisms were similar with falls as a dominating cause (58–56% of the cases). The major difference between the groups was the proportion of injured electric scooter riders (1–8%). The distribution of TBI severity was similar across the periods.

#### *Referral patterns*

By comparing TBI referrals, acute treatment, and discharge destination, no difference was found between the pre-pandemic and pandemic groups



**Table I.** Summary of patient cohort from pre-pandemic and pandemic groups and statistical Comparisons

	Pre-pandemic <sup>a</sup> n (%) 758 (100)	Pandemic <sup>b</sup> n (%) 552 (100)	Differences p-value
Age			
In years, mean (SD)	58 (20)	58 (20)	0.61
Age strata, years			0.63
18–29	91 (12.0)	61 (11.1)	
30–49	148 (19.5)	116 (21.0)	
50–64	195 (25.7)	146 (26.4)	
65–79	197 (26.0)	152 (27.5)	
80+	127 (16.8)	77 (13.9)	
Male	516 (68.1)	360 (65.2)	0.28
ASA-PS			>.001
1 Normal healthy	272 (35.9)	177 (32.1)	
2 Mild systemic	239 (31.5)	140 (25.4)	
3 Severe systemic	238 (31.4)	217 (39.3)	
4 Life threatening	9 (1.2)	18 (3.3)	
Living status			0.41
Home independent	634 (83.6)	471 (85.3)	
Substance dependence	129 (17)	110 (19.9)	0.18
Trauma mechanism			>.001
Fall	438 (57.8)	310 (56.2)	
Motor vehicle	67 (8.8)	34 (6.2)	
Pedestrian	20 (2.6)	11 (2.0)	
Bicycle	71 (9.4)	62 (11.2)	
Electric scooter	5 (0.7)	42 (7.6)	
Sports	34 (4.5)	12 (2.2)	
Violence	48 (6.3)	29 (5.3)	
Self-harm	23 (3.0)	6 (1.1)	
Other/unknown	53 (6.9)	46 (8.3)	
Alcohol at time of injury	224 (29.6)	167 (30.3)	0.78
Head Injury Severity Scale			0.47
Minimal	44 (5.8)	43 (7.8)	
Mild	333 (43.9)	228 (41.3)	
Moderate	251 (33.1)	188 (34.1)	
Severe	130 (17.2)	93 (16.8)	
High-Energy trauma (yes)	250 (33)	196 (35.5)	0.34
Isolated TBI	401 (52.9)	293 (53.1)	0.95

<sup>a</sup>Admitted to OUH from 1 January 2018 to 31 December 2019

<sup>b</sup>Admitted to OUH from 11 March 2020 to 17 August 2021

ASA-PS: American Society of Anaesthesiologists Physical Status Classification System, SD: standard deviation, TBI: traumatic brain injury.

(Table II). The monthly number of hospital admitted patients with TBI to OUH remained stable with natural fluctuation during both periods (Fig. 1). Of the 117 discharged directly to specialized rehabilitation in the pandemic group, 16% (19 patients) was admitted with mild TBI, 39% with moderate TBI (46 patients) and 44% with severe TBI (52 patients). A similar proportion was found in the pre-pandemic group; mild TBI 14%, moderate TBI 42% and severe TBI 44%. The proportion of direct discharge to specialized rehabilitation was similar when comparing the 2 groups (19–21%, Table II). When selecting patients with moderate-severe TBI (upon admission), the proportion was similar (32–35%). The monthly proportion of patients with moderate-severe TBI discharged to specialized rehabilitation is shown in Fig. 2. In a subgroup analysis, we found a decrease in the number of patients getting specialized rehabilitation during the second period in which the rehabilitation ward was converted to a COVID-19 ward (April 2021) (Fig. 2)

**Table II.** Treatment and referral patterns during the pandemic; pre-pandemic and pandemic groups

	Pre-pandemic <sup>a</sup> n = 758 (100%)	Pandemic <sup>b</sup> n = 552 (100%)	p-value
Referral			0.46
Primary	265 (35.0)	178 (32.2)	
Secondary	253 (33.4)	201 (36.4)	
Emergency department/other	240 (31.7)	173 (31.1)	
Intensive care unit admission (yes)	456 (60.2)	349 (63.2)	0.26
Length of stay at intensive care unit			0.07
Days (median, interquartile range)	3 (2-7.75)	3 (2-9)	
Treatment TBI			
Conservative	577 (76.1)	426 (77.2)	0.66
Any neurosurgical procedure	181 (23.9)	126 (22.8)	0.66
Intracranial pressure sensor	128 (16.9)	94 (17.0)	0.95
Evacuation of mass lesion	89 (11.7)	65 (11.8)	0.99
Intracranial surgery <sup>c</sup>	132 (17.4)	94 (17.0)	0.86
Extracranial surgery (yes)	147 (19.4)	104 (18.8)	0.80
Discharge destination			0.67
Home	259 (34.2)	174 (31.5)	
Local hospital	296 (39.1)	222 (40.2)	
Specialized rehabilitation	143 (18.9)	117 (21.1)	
Nursing home	46 (6.1)	32 (5.8)	
Other	14 (1.8)	7 (1.3)	
GCS 15 at discharge	510 (67.3)	348 (63.0)	0.11
Glasgow outcome score (at day of discharge)			0.08
Vegetative state	25 (3.3)	25 (4.5)	
Severe disability	348 (45.9)	282 (51.1)	
Moderate disability	345 (45.5)	227 (41.1)	
Good recovery	37 (4.9)	15 (2.7)	
Reason reduced function			0.46
TBI	372 (49.1)	272 (49.3)	
TBI + extracranial injury/comorbidity	254 (33.5)	197 (35.7)	
Other	132 (17.4)	83 (15.0)	

<sup>a</sup>Admitted to OUH from 1 January 2018 to 31 December 2019.

<sup>b</sup>Admitted to OUH from 11 March 2020 to 17 August 2021.

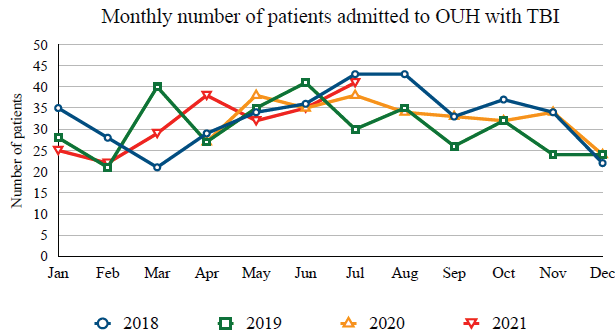
<sup>c</sup>Includes evacuation of mass lesion (haematoma/haemorrhage), cerebrospinal fluid drainage, decompressive hemicraniectomy, repair of dura or fractured skull (duraplasty/cranioplasty) and vascular surgery.

GCS: Glasgow Coma Scale score, TBI: traumatic brain injury.

compared with the first period (April 2020). However, due to the relatively short time and a low number of patients with moderate or severe TBI in both periods ( $n=21$ ), this was not investigated further. An overall summary of the patient cohort from both subgroups is shown in Table SI.

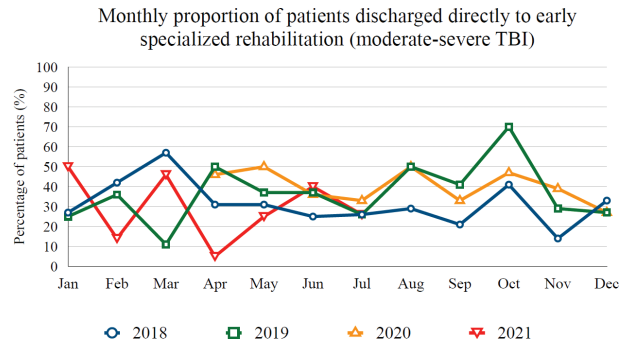
### Predictors

Tables III and IV contain a comparison of predictors for discharge directly to specialized rehabilitation between the pre-pandemic and pandemic period. Results from univariable logistic regression analysis show that strong positive predictive factors for discharge to specialized rehabilitation in both pre-pandemic and pandemic groups were: younger age, ASA-PS of 1 or 2, moderate or severe TBI, intracranial surgery, insertion of ICP-sensor (surrogate for neurointensive management), extracranial surgery, and severe disability upon discharge from acute care units due to TBI (Table III). Being male was associated with discharge to specialist rehabilitation in the pre-pandemic



**Fig. 1.** Admission rate of patients hospitalized with traumatic brain injury (TBI) identified with neuroimaging ( $n=1,310$ ). The dates 2018 and 2019 represent pre-pandemic years, 2020 and 2021 represent pandemic years and include patients admitted from April 2020 to July 2021 (March 2020 and August 2021 are excluded from this graph, as they were partial months).

(OR 2.19, 95% CI 1.4, 3.42,  $p=0.001$ ), but not in the pandemic group (OR 1.55, 95% CI 0.99, 2.43,  $p=0.058$ ), similar trend was found in multivariable model (Table IV). In multivariable logistic regression analysis (Table IV), younger age (<65 years) remained as a strong positive predictor, along with pre-injury ASA-PS of 1–2, severe disability upon



**Fig. 2.** Proportion of patients with moderate-severe traumatic brain injury (TBI) ( $n=662$ ) who were discharged directly to early specialized rehabilitation. The dates 2018 and 2019 represent pre-pandemic years, 2020 and 2021 are pandemic years and include patients discharged in the period April 2020 to July 2021 (March 2020 and August 2021 are excluded from this graph, as they were partial months). It includes the 2 periods when the rehabilitation ward was converted to a COVID-19 ward (27 March 2020 to 4 May 2020, and 29 March 2021 to 26 April 2021).

discharge due to TBI in both pre-pandemic and pandemic groups. In neither group was intracranial surgery, insertion of ICP-sensor or extracranial surgery a significant predictor. Severity of the injury was a strong predictor factor in both pre-pandemic

**Table III.** Univariable analysis examining predictors associated with discharge directly to a rehabilitation unit during pre-pandemic and pandemic periods

Variable	Pre-pandemic			Pandemic		
	OR	95% CI	$p$ -value	OR	95% CI	$p$ -value
Age strata, years						
18–29	1			1		
30–49	0.792	0.45, 1.40	0.423	1.469	0.75, 2.89	0.265
50–64	0.819	0.48, 1.41	0.469	0.977	0.50, 1.90	0.945
65–79	0.215	0.11, 0.41	<.001	0.326	0.15, 0.69	0.004
80+	0.034	0.01, 0.15	<.001	0.034	0.004, 0.27	0.001
Sex						
Female	1			1		
Male	2.192	1.40, 3.42	0.001	1.545	0.99, 2.43	0.058
Pre-injury ASA						
1–2	1			1		
3–4	0.296	0.18, 0.48	<.001	0.291	0.18, 0.47	<.001
Head injury severity score						
Mild	1			1		
Moderate	5.607	3.28, 9.58	<.001	4.297	2.42, 7.62	<.001
Severe	16.784	9.52, 29.58	<.001	16.822	9.05, 31.29	<.001
Intracranial surgery						
No	1			1		
Yes	2.917	1.92, 4.43	<.001	3.067	1.90, 4.95	<.001
ICP-sensor						
No	1			1		
Yes	6.663	4.39, 10.13	<.001	6.632	4.10, 10.73	<.001
Extracranial surgery						
No	1			1		
Yes	2.020	1.33, 3.06	0.001	1.682	1.04, 2.73	0.035
GOS at discharge						
Moderate disability	1			1		
Severe disability	5.823	3.68, 9.21	<.001	6.700	3.81, 11.79	<.001
Vegetative state	3.067	1.06, 8.839	0.038	4.164	1.46, 11.89	0.008
Reason reduced GOS						
Other	1			1		
TBI	4.671	2.36, 9.25	<.001	6.559	2.75, 15.62	<.001
TBI + extracranial injury/comorbidity	1.634	0.77, 3.45	0.199	1.370	0.53, 3.56	0.519

ASA-PS: American Society of Anaesthesiologists Physical Status Classification System, 95% CI: 95% confidence interval, GCS: Glasgow Coma Scale score, GOS: Glasgow Outcome Score, ICP: intracranial pressure, OR: odds ratio, TBI: traumatic brain injury.

**Table IV.** Multivariable logistic regression model examining the predictors associated with discharge directly to a rehabilitation unit during pre-pandemic and pandemic periods

Variable	Pre-pandemic <sup>a</sup>			Pandemic <sup>b</sup>		
	OR	95% CI	p-value	OR	95% CI	p-value
Age strata, years						
18–29	1			1		
30–49	0.69	0.30, 1.43	0.314	1.44	0.58, 3.57	0.433
50–64	0.65	0.32, 1.33	0.238	0.92	0.37, 2.29	0.860
65–79	0.21	0.09, 0.48	<.001	0.29	0.10, 0.80	0.017
80+	0.04	0.01, 0.20	<.001	0.04	0.01, 0.41	0.006
Sex						
Female	1			1		
Male	1.75	1.00, 3.07	0.051	0.80	0.43, 1.49	0.484
Pre-injury ASA						
1–2	1					
3–4	0.38	0.20, 0.74	0.004	0.35	0.18, 0.69	0.002
Head injury severity score						
Mild	1			1		
Moderate	2.13	1.12, 4.06	0.021	1.50	0.70, 3.20	0.297
Severe	4.67	1.95, 11.20	0.001	2.57	0.96, 6.89	0.062
Intracranial surgery						
No	1			1		
Yes	0.78	0.39, 1.55	0.479	0.79	0.36, 1.71	0.547
ICP-sensor						
No	1			1		
Yes	1.04	0.46, 2.31	0.479	2.28	0.91, 5.73	0.081
Extracranial surgery						
No	1			1		
Yes	1.24	0.60, 2.55	0.563	1.78	0.78, 4.08	0.172
GOS at discharge						
Moderate disability	1			1		
Severe disability	9.03	4.65, 17.52	<.001	8.89	4.09, 19.3	<.001
Vegetative state	1.86	0.48, 7.24	0.374	1.34	0.33, 5.51	0.686
Reason reduced GOS						
Other	1			1		
TBI	3.44	1.21, 9.80	0.021	5.03	1.39, 18.3	0.014
TBI + extracranial injury/comorbidity	1.16	0.44, 3.05	0.764	1.10	0.33, 3.60	0.879

<sup>a</sup>Pre-pandemic: 718 patients included analysis. Missing 40 patients; 37 discharged as GOS GR, 3 discharged as GOS NA. The Hosmer and Lemeshow goodness-of-fit test was not significant indicating a satisfactory fit of the model ( $\chi^2=7.15$ ,  $df=8$ ,  $p=0.52$ ). The area under the ROC curve was 0.88 (95% CI: 0.86–0.91) indicating a good discriminative ability.

<sup>b</sup>Pandemic: 534 patients included analysis. Missing 18 patients; 15 discharged as GOS GR, 3 discharged as GOS NA. The Hosmer and Lemeshow goodness-of-fit test was not significant indicating a satisfactory fit of the model ( $\chi^2=3.12$ ,  $df=8$ ,  $p=0.93$ ). The area under the ROC curve was 0.89 (95% CI: 0.86–0.92) indicating a good discriminative ability.

ASA-PS: American Society of Anaesthesiologists Physical Status Classification System, 95% CI: 95% confidence interval, GCS: Glasgow Coma Scale score, GOS: Glasgow Outcome Score, ICP: intracranial pressure, OR: odds ratio, TBI: traumatic brain injury; GR: good recovery; NA: not available; ROC: Receiver Operating Characteristic.

and pandemic groups, with OR for direct transfer 1.5 for moderate injury and 2.5 for severe injury in the pandemic group.

## DISCUSSION

This study examined the consequences for patients regarding early specialized rehabilitation following acute TBI during an 18-month period during which COVID-19 infections spread throughout south-east Norway. The continuous rehabilitation pathway for patients with moderate and severe TBI was maintained in 2020 and 2021. The TBI patient composition did not change due to the impact of the pandemic, and acute care management appears to have been maintained at OUH.

There is consensus that the COVID-19 pandemic in its early phases contributed to changes in neurosurgical

referrals for TBI worldwide. Retrospective single-centre studies comparing TBI referral volumes during lockdown with previous years have shown a decrease in the incidence of TBI referrals and admission during lockdown periods (1–7, 19). In contrast, no change was found in TBI referrals in the study material. One reason could be the length of period included in this study. We report here on a prolonged period with abnormal preparedness level at the hospital, while other studies report on shorter lockdown periods. Despite seeing decreases in TBI referrals and admissions associated with the implementation of lockdowns, several studies show that the relaxation of such measures was accompanied by increases in TBIs (2, 7, 20).

The current study did not find a decline in the direct pathway to specialized rehabilitation. In contrast, the results show that the positive trend from 2015 to 2019 reported by Tverdal et al. (14) continued in 2020–21. At the start of the pandemic, the discharge may even

have been accelerated because of the pressure in the ICU and neurosurgical wards. In addition, an explanation could be the medical staffs' willingness to make extra efforts at the onset of the pandemic. These findings reinforce the feasibility and preparedness of the rehabilitation ward to manage patients with TBI during a pandemic. Maintaining rehabilitation pathways can have major consequences for the individual patient as well as potential socio-economic consequences. The early specialized rehabilitation ward is essential to durable outcomes, as they prevent readmissions and promote hospital bed-availability.

In previous years, falls and RTAs predominated as the main cause of TBI worldwide (21–24). The restrictions on movement imposed by COVID-19 lockdown measures resulted in people staying at home. Working from home and school closures resulted in global reductions in road traffic levels, leading to a decrease in TBIs due to RTAs. However, during the latter stages of lockdown, studies from India and the United States show that rates of RTA associated TBIs increased to levels above those experienced before COVID-19 (8, 25, 26). The current study did not find any major change in mechanism of injury, except for electric scooters. In 2020, electric scooters became publicly available in the city centre of Oslo (unrelated to the pandemic), meanwhile electric scooters also gained popularity in the private market. Before the pandemic, electric scooters were available to a small extent; however, COVID-19 infection control and preventive measures recommended avoiding public transport and may have strengthened their use even further. Fall was the dominant trauma mechanism, similar to the European population (21, 27). The current study also found no change in length of stay in the ICU and/or neurosurgery ward despite pressure to discharge patients due to an increase in the number of COVID-19 patients. One reason may be that the current analyses were based on a longer preparedness level period of 18 months and variation in admissions occurred due to COVID-19 in this period.

No significant epidemiological changes in TBI resulting from the pandemic were found in this study; however, the study supports the substantial variability in TBI admittance to the trauma hospitals. Evidence of significant sex differences is limited, and there is a conflicting picture (10, 25, 26), probably due to regional variation. The study by Algattas et al. (6) found no differences in the mean and median age of neurotrauma patients, but significant differences in age distribution. This highlights the need for an accurate analysis of the age distribution of TBI. Despite stratifying by different age groups, no significant change in TBI by age before and during the pandemic was found. In addition, this study did not include patients younger than 18 years

of age. A difference in ASA-PS score was found, with higher scores in the pandemic group; however, the study does not explain whether this is affected by the pandemic or is an overall trend.

At the start of the pandemic, the aim of keeping hospital admissions to a minimum led to the suspension of elective surgical procedures and an emphasis on surgical prioritization. The current study reports the referral patterns, management and direct pathway to early specialized rehabilitation from a level 1 trauma centre that covers the south-east region of Norway representing more than half of the Norwegian population. The data show that TBI continued to be treated with the highest priority and its neurosurgical management remained largely unchanged. This is in contrast to other studies showing that TBI was more likely to be managed conservatively during the pandemic (8, 9, 26). Although stretched, this could reflect that the healthcare system at OUH was able to prioritize patients with TBI in need of neurosurgery and prioritized the rehabilitation for severe TBI by moving the early rehabilitation to the neurosurgical ward. The results must be interpreted in the light of Norway being a high-income country with a well-organized healthcare system and government-funded universal health coverage. During the pandemic, the national government chose a strategy with constantly adjusting measures of social restrictions to keep the spread of the virus under control, in order to maintain adequate healthcare services, and to prevent the healthcare system being overwhelmed. Across Europe, it also seems that TBI has been adequately treated. A multicentre study showed no increase in 30-day mortality of patients with TBI during 2020 compared with previous years (19). Yet, mortality is a crude outcome, and data on rehabilitation services in Norway indicate large regional variations (28). Hence, patients may have suffered from altered early rehabilitation in other regions of Norway, as well as downscaling of long-term rehabilitation services, with impacts on functional outcome and quality of life.

When comparing factors predicting the direct pathway to rehabilitation, univariable analysis showed several significant factors, in contrast to the multivariable model. In the multivariable model, strong positive factors in both groups were younger age, pre-injury ASA-score 1–2, severe TBI, severe disability due to TBI upon discharge, in line with a previous study (14). We cannot fully explain the variation regarding male sex, but contributing factors may be that in younger TBI patients, males are over-represented and males more often need emergency neurosurgery (29, 30). Interestingly, we found a difference in favour of the group who received neurosurgical procedure with ICP-sensor insertion in the pandemic group, although the difference was not statistically significant. Severity



of the injury was a strong predictor factor in both pre-pandemic and pandemic group with OR for direct transfer 1.5 for moderate and 2.5 for severe injury in the pandemic group. TBI as reason for reduced function upon discharge was a stronger factor for the pandemic group; this may suggest a trend towards priority given to patients with severe TBI treated at the intensive unit. Possible explanatory factors for this difference can be an internal pressure at OUH to release bed capacity for COVID-19 patients at ICU, or a situation with no alternative discharge place as the receiving local hospitals did not have any available beds because of COVID-19 patients.

The strength of this study is the sample size and the use of register data minimizing the effect of selection bias due to non-response and loss to follow-up. In addition, the collection of the data was performed independently of the study. However, some limitations must be addressed, the data are pre-collected and the Oslo TBI Registry-Neurosurgery lacks detailed information, such as comorbid conditions and regarding length or intensity of rehabilitation. The current study also had no information regarding where patients were discharged to from early rehabilitation, their subsequent access to rehabilitation, or long-term outcomes.

### CONCLUSION

The COVID-19 pandemic has not resulted in any notable reduction in the number of TBI referrals, or influenced the direct pathway to early, specialized rehabilitation. This study did not find evidence of a change in acute care management, although the full consequences of the pandemic for the rehabilitation of patients with TBI may not be realized for years to come.

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