JNS

CLINICAL ARTICLE

J Neurosurg 139:892–900, 2023

Epidemiology and practice variations of shunt surgery for hydrocephalus: a nationwide registry–based study

Nadia Mansoor, MD,[1,2] Sasha Gulati, MD, PhD,[1,2] Oddrun A. Fredriksli, MD,[1,2] Øyvind Salvesen, MSc, PhD,[3] and Ole Solheim, MD, PhD[1,2]

[1]Department of Neurosurgery, St. Olavs University Hospital, Trondheim; and Departments of [2]Neuroscience and [3]Public Health and General Practice, Norwegian University of Science and Technology, Trondheim, Norway

OBJECTIVE Indications for surgical treatment of hydrocephalus (HC) can vary across centers. The authors sought to investigate the frequencies of surgically treated HC disorders and to study variations in the practice of shunt surgery in Norway, a country with universal and free healthcare.

METHODS This is a nationwide registry–based study using data from the Norwegian Patient Registry. Four neurosurgical centers serve exclusively in 4 defined geographic regions. All patients who underwent shunt surgery in Norway between January 1, 2008, and December 31, 2021, were included and regional differences and time trends were explored.

RESULTS The national annual rate of shunt surgery in the study period was 6.0 per 100,000. A total of 4139 individuals (49.5% male) underwent primary shunt surgeries, and a total of 9262 operations including revision surgeries were performed. There were statistically significant regional differences between the 4 treating centers in Norway in terms of patients' age (median 61 years, range 53–65 years); mean annual rate of primary shunt surgery (5.1–7.6 per 100,000); annual rate of primary shunt surgery in patients of different age groups (0.9–1.2 in 0–17 years, 1.8–2.7 in 18–64 years, and 1.6–3.9 in ≥ 65 years); annual rate of revision surgeries (2.4–5.7 per 100,000); annual rate of primary surgery for communicating HC (0.7–2.0 per 100,000); annual rate of primary surgery for normal pressure HC (0.5–1.8 per 100,000); and annual rate of primary surgery for HC associated with cerebrovascular disease (0.5–2.0 per 100,000). There was significant variation in overall shunt surgeries during the study period ($p = 0.026$), and there was an overall decrease in revision surgeries over time ($p < 0.001$). There appears to be a homogenization of revision surgeries over time.

CONCLUSIONS There are significant and large practice variations in the surgical management of HC in Norway. There are significant differences between regions, particularly in terms of rates of shunt surgery for some diagnoses (communicating HC, normal pressure HC, and HC associated with cerebrovascular disease) as well as revision rates.

https://thejns.org/doi/abs/10.3171/2022.12.JNS222083

KEYWORDS practice variation of shunt surgery; hydrocephalus; registry

Shunt surgery remains the most common and important permanent CSF diversion surgery, but is associated with high failure rates and significant comorbidity.[1–5] Treatment choices and indications can be challenging, partly due to our incomplete understanding of the pathophysiology, the lack of comparative clinical studies, and the paucity of regional, national, and international consensus for diagnostic criteria and surgical treatment indications.

The incidence of congenital and adult hydrocephalus (HC) varies in reported studies, but in Europe and North America the annual crude incidence rates have been estimated to be 56–77 per 100,000, with a far greater incidence seen in low-income countries.[6–8] However, rates of surgically treated HC are usually reported to be much lower.[9–12] Previous epidemiological studies examining rates of surgical treatment for CSF disorders are limited by several factors,[9,10,12–14] such as only considering single etiological entities or patient groups, limited longitudinal analysis, and few having reviewed possible trends over time. For instance, CSF surgery for children in high-income countries is decreasing, probably due to improved pre- and postnatal care. However, with an aging population the surgical treatment for other CSF disorders, such as normal pressure hydrocephalus (NPH), may increase. Knowledge about potential changes in surgery rates and regional practice

ABBREVIATIONS HC = hydrocephalus; ICD-10 = *International Classification of Diseases, Tenth Revision*; LOS = length of stay; LP = lumboperitoneal; NCSP = Nomesco Classification of Surgical Procedures; NPH = normal pressure hydrocephalus; NPR = Norwegian Patient Registry; SAH = subarachnoid hemorrhage; VA = ventriculoatrial; VP = ventriculoperitoneal.

SUBMITTED September 18, 2022. **ACCEPTED** December 9, 2022.

INCLUDE WHEN CITING Published online February 3, 2023; DOI: 10.3171/2022.12.JNS222083.

variations is useful for understanding changes in epidemiology and addressing controversies in management.

In the current population-based study, we sought to examine the rates of shunt surgery in Norway for all etiologies and to examine possible regional differences in care.

Methods

Study Design and Overview

This nationwide registry–based study was approved by the Regional Committee for Medical and Health Research Ethics Central Norway.

In Norway, inpatient treatment by specialist healthcare services is free, and health resources are uniform. There are 4 administrative and geographic health regions, each served exclusively by 4 regional hospitals in 5 different locations that offer surgical treatment for HC. There is no private healthcare for HC in Norway, and CSF diversion procedures are only performed in these 4 regional hospitals.

Data were obtained from the Norwegian Patient Registry (NPR), a national health registry containing data from both inpatient and outpatient consultations from all 4 health regions in Norway. The registry receives data monthly, and since 2008, personal data have been individually identifiable. All Norwegians have a unique 11-digit ID number that enables follow-up and prevents duplicate recordings in the registry. The database contains a wide range of data including patient demographics, name of treating hospital/region, admission dates, length of stay (LOS), state of emergency, Nomesco Classification of Surgical Procedures (NCSP) codes, and *International Classification of Diseases, Tenth Revision* (ICD-10) codes. State of emergency refers to whether surgery is coded as planned (i.e., if initially referred to or from the outpatient clinic) or as urgent (if admitted directly to the hospital department without previous referral). ICD-10 codes are diagnostic codes used to classify patients according to diagnosis. Relevant ICD-10 diagnosis codes used in this study included G91, G93, C71–C79, D32–D33, I60–I69, Q01–Q87, and others specifying HC. NCSP codes are surgical codes used to classify the surgical procedures that a patient has undergone. The retrieved procedure codes for this study were AAF05 (ventriculoperitoneal [VP] shunt), AAF10 (lumboperitoneal [LP] shunt), AAF15 (ventriculoatrial [VA] shunt), AAF20 (revision of shunt of ventricle of brain), AAF25 (removal of shunt of ventricle of brain), AAF99 (other shunt operation on ventricle of brain or intracranial cyst), JAL50 (intraabdominal revision of shunt of ventricle of brain), and JAL51 (laparoscopic revision of shunt of ventricle of brain).

In Norway, a patient cannot be discharged without at least one registered ICD-10 code. The patient's ICD-10 code or codes are logged together with NCSP codes for those who undergo surgery. The main ICD-10 and NCSP codes further determine the diagnosis-related group codes, which determine the reimbursement the hospital receives from the government. All working doctors undergo training in how to code appropriately, and hospitals have personnel who regularly review coding for all admitted patients before these reports are sent to the NPR. Coding of neurological and neurosurgical discharge diagnoses in the NPR has previously been found to be of high quality.[15]

Patient Population

All patients who underwent shunt surgery in Norway between January 1, 2008, and December 31, 2021, and who had a diagnosis of HC and/or an HC-associated condition and at least one of the following surgical procedures were included: VP shunt, LP shunt, and VA shunt. There were no age restrictions. For included patients, the following data were extracted: main ICD-10 codes, relevant NCSP codes for all surgeries in this time span, year of surgery, LOS for primary surgery, category of urgency, region of care, and patient demographics (sex, age).

Statistical Analysis

Crude surgery rates were calculated from the population of the geographic health regions (retrieved from the Statistical Research of Statistics, Norway; public registry, www.ssb.no) served by the treating center, in cases per 100,000 person-years. When calculating the overall estimates for the entire period, the mean number of inhabitants over the 14 years was used.

Statistical analyses were performed using SPSS version 26 (IBM Corp.). For all categorical data, frequencies with number of cases and percentages were presented. For continuous data, normality was tested using the Shapiro-Wilk test and visualized using Q-Q plots. Normally distributed data were presented as the mean and standard deviation, whereas skewed data were presented as the median and range. The chi-square test was used to compare the different healthcare regions for categorical data. The Kruskal-Wallis test was used to compare groups for continuous data not normally distributed. A p value < 0.05 was considered significant. Possible variations or trends over time were explored using the chi-square test in R Statistical Software and were visualized graphically with line diagrams created in Microsoft Excel version 16.

Results

Primary Surgery

Patient characteristics, overview of surgeries, and corresponding diagnoses are presented in Table 1. A total of 4139 individual patients underwent primary shunt insertion in the study period. Of these, 49.5% were male, the median age was 61 years (range 0–95 years), and 83.7% were 18 years or older. The median LOS was 5 days (range 0–322 days). In 32.1% of cases, primary surgery was performed during the patient's first contact with the department. Elective surgery accounted for 54% of operations. Insertion of a VP shunt was the most common procedure, totaling 3949 of primary operations (95.4%), followed by VA and LP shunts with 2.3% and 2.2%, respectively. The most common diagnoses were communicating HC and NPH (1.5 per 100,000 per year for both diagnoses), followed by HC associated with cerebrovascular diseases (1.0 per 100,000 per year) and others (0.6 per 100,000). Rates of primary surgery were lowest in 2012 (5.1 per 100,000) and highest in 2020 (6.8 per 100,000), and there were significant variations in the overall rate of primary shunt surgery during the study period (p = 0.026). The rates of primary surgeries per year for all health regions are displayed in Fig. 1.

Regional Differences in Patient and Surgical Characteristics

An overview of regional patient characteristics and primary surgery rates is shown in Table 2. Rates of primary shunt surgeries varied from 5.1 to 7.6 in the 4 geographic health regions, reflecting a significant difference across regions (p < 0.001). The median ages were 61, 53, 65, and 65 years for the Southeastern, Central, Western, and Northern regions, respectively, with significant differences across regions (p < 0.001). Rates of shunt surgery for different ages are displayed in Fig. 2. Rates of primary shunt operations in pediatric patients (< 18 years) differed across regions, with treatment rates ranging from 0.9 to 1.2 per 100,000 (p = 0.02), and similarly for the other 2 age categories (18–64 years and ≥ 65 years), with rates of 1.8 to 2.7 and 1.6 to 3.9, respectively (both p < 0.001). During the study period, surgical treatment rates increased over time in the Western and Northern regions (both p < 0.001). There was significant treatment variation, with a decrease in surgical rates in the Southeastern region (p = 0.01). There was no obvious trend observed in the Central region (p = 0.38). Surgical treatment rates over time for the different health regions (i.e., centers) are displayed in Fig. 3.

The most commonly reported diagnoses in patients undergoing primary shunt surgery were communicating HC, NPH, and HC associated with cerebrovascular disease. The annual rates of primary surgery for communicating HC ranged from 0.7 to 2.0 per 100,000 in the 4 regions (p < 0.001), annual rates for NPH ranged from 0.5 to 1.8 per 100,000 in the 4 regions (p < 0.001), and annual rates for HC associated with cerebrovascular disease were 0.5 to 2.0 per 100,000 in the 4 regions (p < 0.001).

Overall Shunt and Revision Surgery

An overview of all shunt and revision surgeries is shown in Table 3. A total of 9262 surgeries were performed during the study period. The most frequent surgery was insertion of a VP shunt (46.2%, 6.2 per 100,000 per year), followed by shunt revision (35.0%, 4.7 per 100,000 per year).

The mean annual rate of revision surgeries (AAF20) ranged from 2.4 to 5.7 per 100,000 in the different regions (p < 0.001). There was a significant trend over time, with an overall decrease of revision surgeries in Norway during the study period (p < 0.001). Over time, rates of revision surgeries decreased in the Southeastern region (p < 0.001), as displayed in Fig. 4. There was an increase in the rate of revision surgery over time observed in the Western region (p = 0.003). There was no significant time trend observed for the rate of revision surgery in the Central (p = 0.576) or the Northern (p = 0.532) region. The differences in rates of revision surgeries among the 4 regions decreased over time, as displayed in Fig. 4. The annual rate of revision surgeries in pediatric patients (0–17 years) was 2.4 per 100,000 overall, and ranged from 1.1 to 3.0 per 100,000 in the 4 regions (p < 0.001); the annual revision rate in adults (18–64 years) was 1.7 per 100,000 overall, and ranged from 0.8 to 2.0 per 100,000 (p < 0.001); and the annual revision rate in elderly patients (≥ 65 years) was 0.6 overall, and ranged from 0.3 to 0.8 per 100,000 (p < 0.001). Revision surgeries in different age categories are displayed in Fig. 5, indicating the highest rate of revisions per 100,000 in the pediatric population, and decreasing rates for older age groups, and with considerable differences in the 4 geographic regions.

TABLE 1. Overview of overall shunt surgery in Norway

	No. of Pts	%	Rate of Surgery
All shunts in included pts	4139	100	6.0
Male sex	2047	49.5	
Median age in yrs (range)	61	0–95	
Age groups			
0–17 yrs	672	16.2	1.0
18–64 yrs	1620	39.1	2.3
≥65 yrs	1847	44.6	2.7
Median LOS in days (range)	5	0–322	
First contact	1329	32.1	1.9
Type of shunt			
VP	3949	95.4	5.7
VA	97	2.3	0.1
LP	93	2.2	0.1
Urgency			
Acute	1888	45.6	2.7
w/in 6 hrs	11	0.3	<0.1
Btwn 6 & 24 hrs	6	0.1	<0.1
Elective >24 hrs	2234	54.0	3.2
Diagnosis			
Communicating HC	1011	24.4	1.5
Obstructive HC	308	7.4	0.4
NPH	1003	24.2	1.5
Posttraumatic HC	45	1.1	0.1
HC, other	75	1.8	0.1
Unspecified HC	99	2.4	0.1
Cerebral cysts	20	0.5	<0.1
IIH	162	3.9	0.2
Malignant neoplasms	156	3.8	0.2
Benign neoplasms	54	1.3	0.1
HC associated w/ cerebrovascular diseases	666	16.1	1.0
Congenital malformations	153	3.7	0.2
Other	387	9.4	0.6
Median surgeries per yr (range)	288	246–364	

IIH = idiopathic intracranial hypertension; pts = patients.
Unless otherwise indicated, values are expressed as the number of patients (%) or the median (range).

Discussion

Primary shunt surgery was performed in 6.0 per 100,000 person-years during the study period. This is a higher rate of surgery compared to other epidemiological

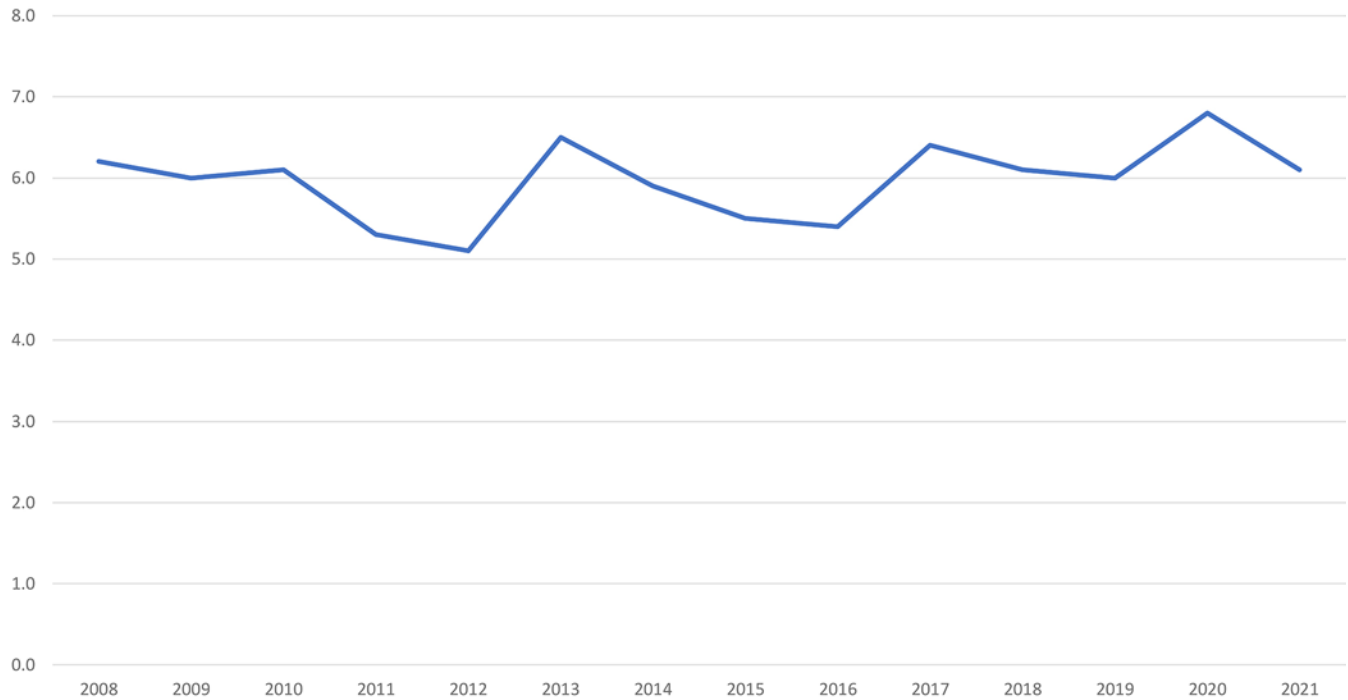

FIG. 1. Rate of shunt surgery per 100,000 (y-axis) in Norway from 2008 through 2021. Figure is available in color online only.

studies.[9–12] However, despite universal and free healthcare there were considerable regional differences in surgery rates per population served by the 4 centers. There were also large regional differences in revision surgery rates. The Norwegian population is homogeneous, and life expectancy as well as distribution of healthcare resources is similar across regions in Norway. Hence, we do not have reasons to believe that other confounding factors such as socioeconomic conditions or a patient's geographic location play a significant role in the observed differences. Assuming that clinical decisions leading to such large regional differences in care are of importance to the patients, there are potentially regional differences in quality of care, although these are not directly documented in this primary study.

We cannot judge if there is systematic overtreatment or undertreatment in the different regions. However, although the shunt literature focuses a lot on surgical techniques and types of implants that could reduce revision rates, agreeing on treatment indications for both primary and revision surgery should be a priority, and is presumably of more importance to our patients than choice of implants. Our data indicate that higher rates of primary shunt surgeries are not necessarily associated with higher rates of revisions, and vice versa. Interestingly, the highest-volume center in terms of number of primary surgeries also has the highest revision rates, despite the common perception that higher-volume centers may provide safer procedures with consequently lower revision rates or fewer complications compared to low-volume centers. Department attitude or treatment traditions could be a major and understudied factor that affects both treatment indications and treatment results in patients with HC.

The large regional differences in surgical treatment provided to patients with HC may reflect a lack of consensus regarding the diagnostic criteria and etiological factors contributing to the development of HC, and the lack of agreement about indications for surgical treatment or revisions. Attempting to classify HC presents a challenge, which is reflected in the current literature; a wide range of different classifications are interchangeably used to describe this condition,[6,7,16] and there might therefore be regional differences in classifying HC. For instance, posthemorrhagic HC might be classified as a communicating HC or an obstructive HC. This issue will always remain a point of uncertainty in the published literature. In the current study, communicating HC, NPH, and HC associated with cerebrovascular disease were the most common etiologies in all 4 regions, with similar proportions of obstructing HC. Regarding differences in reported HC associated with cerebrovascular disease, this can indicate that some centers more readily implant a shunt after subarachnoid hemorrhage (SAH), for instance (during primary admission), thus using the ICD-10 code I61 (SAH). Other centers are perhaps more prone to wait, implanting a shunt at a later date, and for that later admission they more readily use the ICD-10 code G91 (communicating HC). This can result in an underestimation of the group with communicating HC. However, because the proportion of obstructive HC is similar in all regions, we do not think that possible individual differences in classifying communicating and obstructive HC have affected the current results significantly.

Some previous studies have indicated the presence of regional differences in rates of surgery,[9,12] whereas others have not.[10] In the current study, the most notable regional

TABLE 2. Overview of shunt surgery in Norway for the 4 different health regions

	Southeastern			Central			Western			Northern		
	No. of Pts	%	Rate of Surgery	No. of Pts	%	Rate of Surgery	No. of Pts	%	Rate of Surgery	No. of Pts	%	Rate of Surgery
Total no. of ops	2336		6.2	501		5.1	796		5.3	506		7.6
Male sex	1136	48.6		233	46.5		414	52.0		264	52.2	
Median age in yrs (range)	61	0–89		53	0–90		65	0–95		65	0–89	
Age groups												
0–17 yrs	357	15.3	0.9	121	24.2	1.2	127	16.0	0.9	67	13.2	1.0
18–64 yrs	949	40.6	2.5	225	44.9	2.3	266	33.4	1.8	180	35.6	2.7
≥65 yrs	1030	44.1	2.7	155	30.9	1.6	403	50.6	2.7	259	51.2	3.9
Median LOS in days (range)	5	0–124		6	0–251		5	0–268		8	1–322	
First contact	648	27.7		214	42.7		236	29.6		231	45.7	
Type of shunt												
VP	2247	96.2	5.9	457	91.2	4.6	756	95.0	5.1	489	96.6	7.3
VA	64	2.7	0.2	20	4.0	0.2	12	1.5	0.1	2	0.4	<0.1
LP	25	1.1	0.1	24	4.8	0.2	28	3.5	0.2	15	3.0	0.2
Urgency												
Acute	1021	43.7	2.7	272	54.3	2.8	311	39.1	2.1	284	56.1	4.3
w/in 6 hrs	1	<0.1	<0.1	10	2.0	0.1	0	0.0	0.0	0	0.0	0.0
Btwn 6 & 24 hrs	1	<0.1	<0.1	4	0.8	<0.1	1	0.1	<0.1	0	0.0	0.0
Elective, >24 hrs	1313	56.2	3.5	215	42.9	2.2	484	60.8	3.2	222	43.9	3.3
Diagnosis												
Communicating HC	578	24.7	1.5	67	13.4	0.7	292	36.7	2.0	74	14.6	1.1
Obstructive HC	179	7.7	0.5	44	8.8	0.4	57	7.2	0.4	28	5.5	0.4
NPH	674	28.9	1.8	50	10.0	0.5	158	19.9	1.1	121	23.9	1.8
Posttraumatic HC	29	1.2	0.1	6	1.2	0.1	10	1.3	0.1	0	0.0	0.0
HC, other	32	1.4	0.1	15	3.0	0.2	20	2.5	0.1	8	1.6	0.1
Unspecified HC	40	1.7	0.1	35	7.0	0.4	18	2.3	0.1	6	1.2	0.1
Cerebral cysts	13	0.6	<0.1	4	0.8	<0.1	3	0.4	<0.1	0	0.0	0.0
IIH	100	4.3	0.3	18	3.6	0.2	32	4.0	0.2	12	2.4	0.2
Malignant neoplasms	83	3.6	0.2	28	5.6	0.3	14	1.8	0.1	31	6.1	0.5
Benign neoplasms	26	1.1	0.1	4	0.8	0.0	13	1.6	0.1	11	2.2	0.2
HC associated w/ cerebrovascular diseases	339	14.5	0.9	111	22.2	1.1	82	10.3	0.5	134	26.5	2.0
Congenital malformations	94	4.0	0.2	31	6.2	0.3	16	2.0	0.1	12	2.4	0.2
Other	149	6.4	0.4	88	17.6	0.9	81	10.2	0.5	69	13.6	1.0
Median surgeries per yr (range)	166	98–133		37	24–47		46	26–83		46	17–65	

Unless otherwise indicated, values are expressed as the number of patients (%) or the median (range).

discrepancies were observed for overall rates of shunt surgeries; surgical rates for different diagnoses (communicating HC, NPH, and HC associated with cerebrovascular disease); rates of revision surgeries; and age groups for both primary and revision surgeries. The large practice variations most likely indicate that quality of care is not uniform. The study further found that 83.7% of shunt surgeries are performed in patients 18 years or older. Compared to age distributions in the past, when HC was mainly considered to be a congenital or pediatric condition, the current study highlights that in industrialized countries, HC is largely a condition of adults. We further found that rates of primary and revision surgeries have changed over time. The rates of revision surgeries varied greatly between regions, but in later years became more uniform. These variations can perhaps reflect change in local management culture or perhaps even change of influential personnel.

The rate of NPH surgery in the current study was 1.5 per 100,000 person-years, but with significant regional differences, contrary to a previous study.[10] The national incidence of idiopathic NPH has previously been estimated to be 5.5 per 100,000;[17] this suggests that only approximately 1 in 3 patients with NPH are surgically treated in

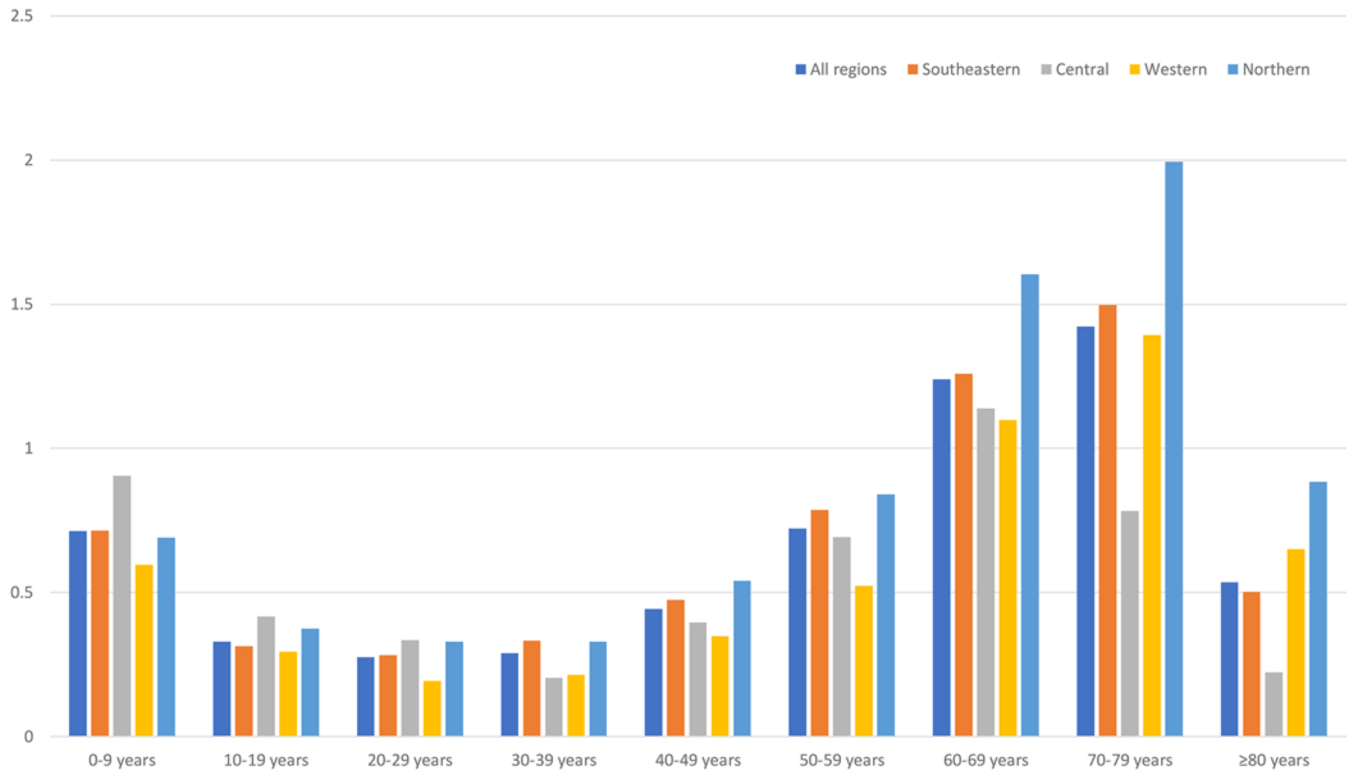

FIG. 2. Rate of shunt surgery per 100,000 (y-axis) in Norway for different age categories in the different health regions from 2008 through 2021. Figure is available in color online only.

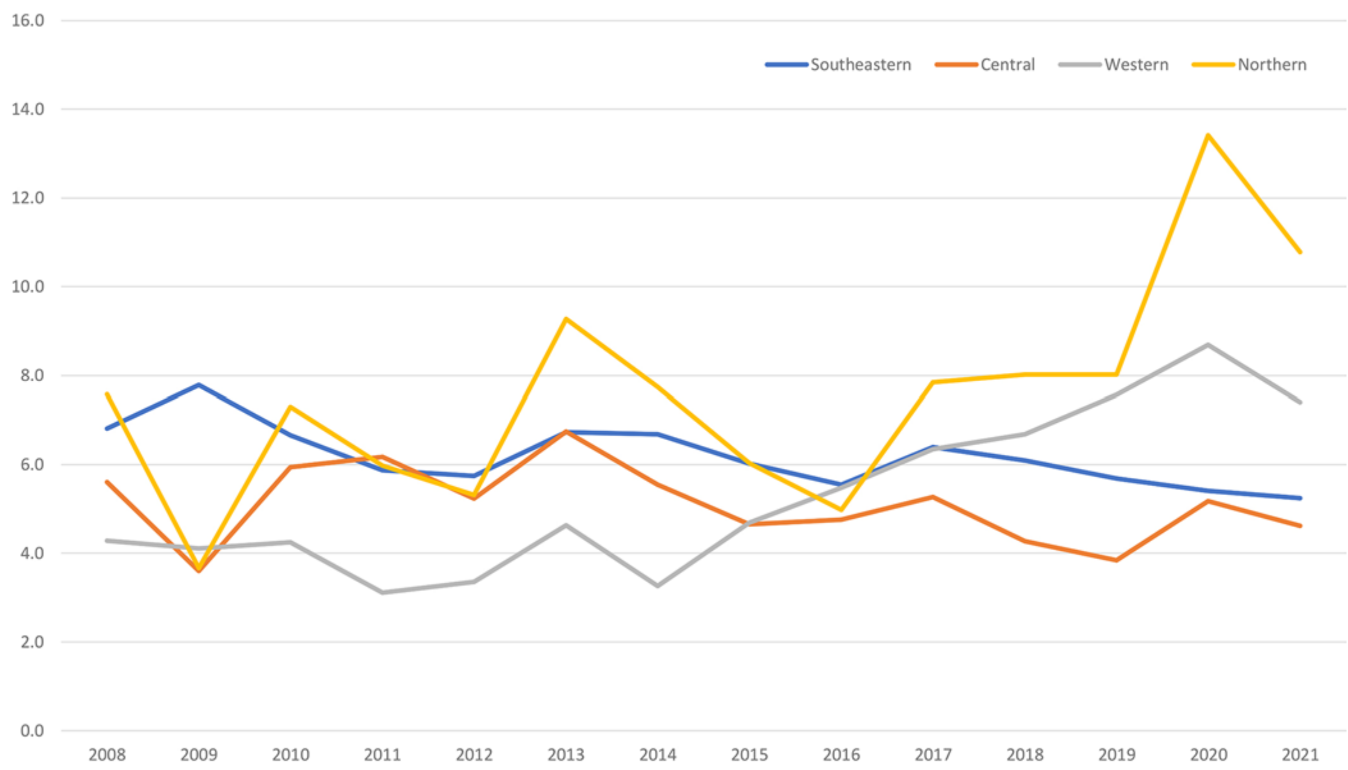

FIG. 3. Rate of shunt surgery per 100,000 (y-axis) in Norway in the different health regions from 2008 through 2021. Figure is available in color online only.

TABLE 3. Overview of all shunt and revision surgeries for the 4 different health regions

Surgical Procedure	All Regions			Southeastern			Central			Western			Northern		
	No. of Ops	%	Rate of Surgery	No. of Ops	%	Rate of Surgery	No. of Ops	%	Rate of Surgery	No. of Ops	%	Rate of Surgery	No. of Ops	%	Rate of Surgery
VP shunt	4281	46.2	6.2	2458	44.3	6.5	504	38.8	5.1	803	50.4	5.4	516	62.6	7.7
LP shunt	139	1.5	0.2	40	0.7	0.1	37	2.9	0.4	38	2.4	0.3	24	2.9	0.4
VA shunt	204	2.2	0.3	125	2.3	0.3	52	4.0	0.5	20	1.3	0.1	7	0.9	0.1
Revision of shunt	3245	35.0	4.7	2150	38.8	5.7	426	32.8	4.3	506	31.8	3.4	163	19.8	2.4
Removal of shunt	898	9.7	1.3	571	10.3	1.5	126	9.7	1.3	140	8.8	0.9	61	7.4	0.9
Other shunt surgery	428	4.6	0.6	193	3.5	0.5	120	9.2	1.2	65	4.1	0.4	50	6.1	0.7
Intraabdominal revision	59	0.6	0.1	6	0.1	<0.1	33	2.5	0.3	17	1.1	0.1	3	0.4	<0.1
Laparoscopic revision	8	0.1	<0.1	5	0.1	<0.1	0	0.0	0.0	3	0.2	<0.1	0	0.0	0.0
Total	9262			5548			1298			1592			824		

Full surgical procedure terms and their respective NCSP codes: ventriculoperitoneal shunt, AAF05; lumboperitoneal shunt, AAF10; ventriculoatrial shunt, AAF15; revision of shunt of ventricle of brain, AAF20; removal of shunt of ventricle of brain, AAF25; other shunt operation on ventricle of brain or intracranial cyst, AAF99; intraabdominal revision of shunt of ventricle of brain, JAL50; laparoscopic revision of shunt of ventricle of brain, JAL51.

Norway. The discrepancy between incidence of NPH and surgery for NPH has previously been described, suggesting also that NPH is grossly underdiagnosed.[18] The discrepancy between diagnosis and surgery for this condition may be due to differences in assessment of potential for shunt responsiveness in these patients, who exhibit significant comorbidity. However, referral policies among local hospitals or general practitioners and/or diverse standards for diagnostic workups, including potential regional differences in radiological reports, may also play a role.

A previous Norwegian population-based study showed that the most common indication for shunt treatment in adults in the Central region was posthemorrhagic HC after SAH.[2] Reasons behind regional differences in surgery for communicating HC and HC associated with cerebrovascular disease can be the variations in HC treatment in patients with SAH (for instance, in duration of temporary CSF diversion). Furthermore, criteria may vary for what is considered symptomatic HC in a patient group that may already be severely affected by their primary condition, so that distinguishing a symptomatic HC can be challenging. It might also be due to differences in follow-up routines, and to the fact that assessments in terms of indication for shunt surgery are not uniform across different departments based on the clinical and/or radiological findings.

There were also large regional differences in shunt revision rates. Revisions accounted for 35% of all shunt surgeries nationwide, indicating a lower proportion of surgeries than reported in a similar study.[12] Shunt revisions made up 19.8%–38.8% of all shunt surgeries in the different

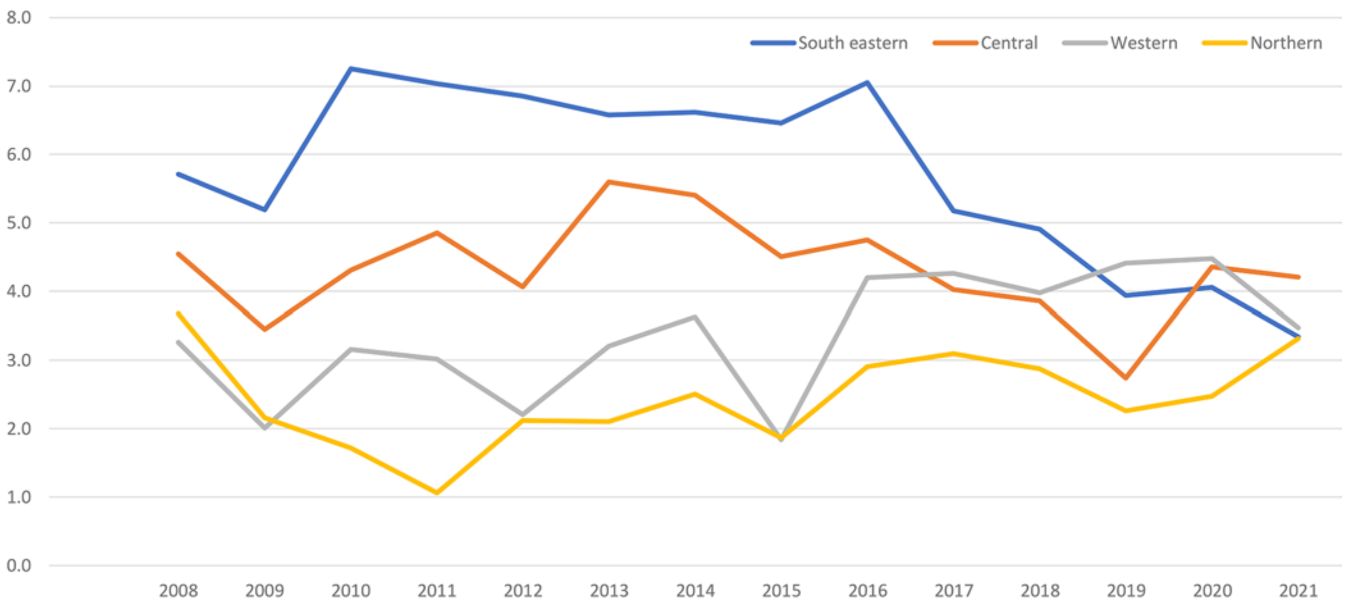

FIG. 4. Rate of revision surgery (AAF20) per 100,000 (y-axis) for all health regions from 2008 through 2021. Figure is available in color online only.

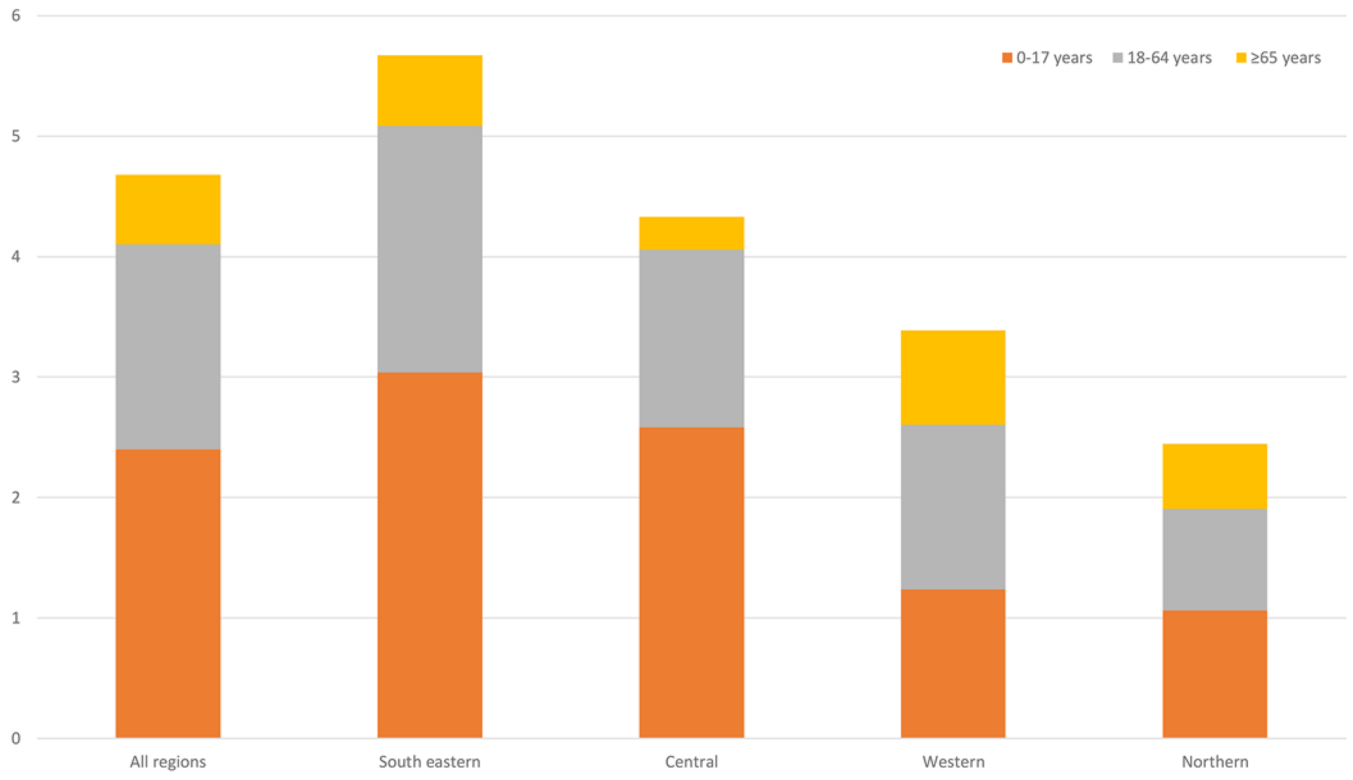

FIG. 5. Rate of revision surgery (AAF20) per 100,000 (y-axis) for each age category from 2008 through 2021. Figure is available in color online only.

regions, and the high-volume centers had higher revision rates. In terms of age groups, the literature is adamant that younger patients (children) have greater risks of shunt failure and thus shunt revisions.[19] The difference in proportion of shunt revisions, particularly in the youngest age group, could be affected by the usage of different implants in the different departments, differences in surgical technique or in evaluations or indications for revision surgery, and/or combinations of the aforementioned. However, surgical techniques and implants are rather similar from center to center in Norway, and observed regional differences are therefore believed to reflect mostly differences in decision-making and indications—for instance, differences potentially reflect variances in the way in which the extent of observation or noninvasive workup is used compared to surgical exploration in shunt-treated patients presenting with symptoms.

Because this study does not evaluate the quality of the current treatment, it remains difficult to pinpoint how current practice should be altered, but the large diversity in management of this patient group is thought provoking. In lieu of a national consensus to guide treatment for this patient group, establishment of national shunt registries could prove useful to synchronize the management of HC. The UK and Sweden have already established such registries, and consequently several publications regarding the epidemiology of HC, as well as surgical complications.[11,12,20–22] This may contribute to our overall understanding of this heterogeneous and complex patient group and may guide clinicians in approaching a more standardized care, as well as highlighting current care that should be further evaluated for areas of improvement. Patient-centered outcomes such as patient-reported outcome measures and employment rates should be encouraged; an ideal end result would be data that serve as a source for solid evidence-based national consensus, guidelines, and surgical strategies to which the departments could adjust their practice. Furthermore, this would lay the foundation of uniform, evidence-based care across different regions and departments.

Strengths and Limitations

Strengths of this study include a large nationwide sample size, completeness of the registry data, and a long inclusion period. Furthermore, it is the most recent epidemiological study on shunt surgery rates. Other studies have similarly reviewed epidemiological nationwide shunt surgery rates, but either reviewed a shorter time interval,[11,12] are already relatively long-standing,[4,9] or only examined one particular etiological entity.[9,10,13] Our study is an important addition to the current literature highlighting several aspects of shunt surgery not commonly reviewed in depth, namely regional variations in terms of treatment rates for both primary and revision surgery.

The limitations of this study include limited detailed data of current practice in the different departments in terms of information on the type of implant (i.e., different valves [adjustable, nonadjustable], tubing system [antibiotic impregnated, nonantibiotic impregnated]), as well as information from preoperative evaluations, radiological findings, and other diagnostic tools. Furthermore, this study does not consider the clinical outcome of the patients who have undergone shunt surgery in this period. Due to Norwegian social security codes, individual patients are differentiated in the registry and we were able to calculate the rate of primary surgeries on an individual level. However, revisions were calculated as total number of revisions in the study period, not accounting for individual patients. Classification of HC is based on reported ICD-10 codes, and we cannot exclude the fact that variations in the classification of HC can occur. For example, the distinction between noncommunicating and obstructive HC can be debatable in some cases. Still, the completeness and quality of reporting to the NPR has been found to be of high quality.[15] We also did not explore potential differences in endoscopic third ventriculostomies in this study.

Conclusions

There are large regional differences in rates of primary shunt surgery and shunt revision surgeries in Norway, reflecting differences in standards of care. This could indicate both under- and overtreatment in the different regions (i.e., centers), and might indicate variations in quality of care.

References

1. Mansoor N, Solheim O, Fredriksli OA, Gulati S. Shunt complications and revisions in children: a retrospective single institution study. *Brain Behav*. 2021;11(11):e2390.
2. Mansoor N, Solheim O, Fredriksli OA, Gulati S. Revision and complication rates in adult shunt surgery: a single-institution study. *Acta Neurochir (Wien)*. 2021;163(2):447-454.
3. Kofoed Månsson P, Johansson S, Ziebell M, Juhler M. Forty years of shunt surgery at Rigshospitalet, Denmark: a retrospective study comparing past and present rates and causes of revision and infection. *BMJ Open*. 2017;7(1):e013389.
4. Wu Y, Green NL, Wrensch MR, Zhao S, Gupta N. Ventriculoperitoneal shunt complications in California: 1990 to 2000. *Neurosurgery*. 2007;61(3):557-563.
5. Stein SC, Guo W. Have we made progress in preventing shunt failure? A critical analysis. *J Neurosurg Pediatr*. 2008;1(1):40-47.
6. Dewan MC, Rattani A, Mekary R, et al. Global hydrocephalus epidemiology and incidence: systematic review and meta-analysis. *J Neurosurg*. 2018;130(4):1065-1079.
7. Isaacs AM, Riva-Cambrin J, Yavin D, et al. Age-specific global epidemiology of hydrocephalus: Systematic review, metanalysis and global birth surveillance. *PLoS One*. 2018;13(10):e0204926.
8. Bir SC, Patra DP, Maiti TK, et al. Epidemiology of adult-onset hydrocephalus: institutional experience with 2001 patients. *Neurosurg Focus*. 2016;41(3):E5.
9. Tisell M, Höglund M, Wikkelsø C. National and regional incidence of surgery for adult hydrocephalus in Sweden. *Acta Neurol Scand*. 2005;112(2):72-75.
10. Brean A, Fredø HL, Sollid S, Müller T, Sundstrøm T, Eide PK. Five-year incidence of surgery for idiopathic normal pressure hydrocephalus in Norway. *Acta Neurol Scand*. 2009;120(5):314-316.
11. Sundström N, Malm J, Laurell K, et al. Incidence and outcome of surgery for adult hydrocephalus patients in Sweden. *Br J Neurosurg*. 2017;31(1):21-27.
12. Fernández-Méndez R, Richards HK, Seeley HM, Pickard JD, Joannides AJ. Current epidemiology of cerebrospinal fluid shunt surgery in the UK and Ireland (2004-2013). *J Neurol Neurosurg Psychiatry*. 2019;90(7):747-754.
13. Lemcke J, Stengel D, Stockhammer F, Güthoff C, Rohde V, Meier U. Nationwide incidence of normal pressure hydrocephalus (NPH) assessed by insurance claim data in Germany. *Open Neurol J*. 2016;10(1):15-24.
14. Krauss JK, Halve B, Sahuquillo J, Thomeer RTWM. Normal pressure hydrocephalus: survey on contemporary diagnostic algorithms and therapeutic decision-making in clinical practice. *Acta Neurochir (Wien)*. 2004;146(4):379-388.
15. Øie LR, Madsbu MA, Giannadakis C, et al. Validation of intracranial hemorrhage in the Norwegian Patient Registry. *Brain Behav*. 2018;8(2):e00900.
16. Rekate HL. A contemporary definition and classification of hydrocephalus. *Semin Pediatr Neurol*. 2009;16(1):9-15.
17. Brean A, Eide PK. Prevalence of probable idiopathic normal pressure hydrocephalus in a Norwegian population. *Acta Neurol Scand*. 2008;118(1):48-53.
18. Martín-Láez R, Caballero-Arzapalo H, López-Menéndez LÁ, Arango-Lasprilla JC, Vázquez-Barquero A. Epidemiology of idiopathic normal pressure hydrocephalus: a systematic review of the literature. *World Neurosurg*. 2015;84(6):2002-2009.
19. Paff M, Alexandru-Abrams D, Muhonen M, Loudon W. Ventriculoperitoneal shunt complications: a review. *Interdiscip Neurosurg*. 2018;13:66-70.
20. Andrén K, Wikkelsö C, Sundström N, et al. Long-term effects of complications and vascular comorbidity in idiopathic normal pressure hydrocephalus: a quality registry study. *J Neurol*. 2018;265(1):178-186.
21. Richards HK, Seeley HM, Pickard JD. Efficacy of antibiotic-impregnated shunt catheters in reducing shunt infection: data from the United Kingdom Shunt Registry. *J Neurosurg Pediatr*. 2009;4(4):389-393.
22. Gasslander J, Sundström N, Eklund A, Koskinen LD, Malm J. Risk factors for developing subdural hematoma: a registry-based study in 1457 patients with shunted idiopathic normal pressure hydrocephalus. *J Neurosurg*. 2021;134(2):668-677.

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Mansoor, Solheim. Acquisition of data: Mansoor. Analysis and interpretation of data: Mansoor, Salvesen. Drafting the article: Mansoor, Solheim. Critically revising the article: Gulati, Fredriksli, Solheim. Reviewed submitted version of manuscript: all authors. Study supervision: Solheim.

Correspondence

Nadia Mansoor: St. Olavs University Hospital, Trondheim, Norway. nadia.mauland.mansoor@stolav.no.