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ORIGINAL COMMUNICATION

Performance and clinical outcomes in telestroke remain robust during the COVID-pandemic: insight into the NEVAS network

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Abstract

Background The COVID-19 pandemic had significant impact on global healthcare, including stroke management. Telemedical stroke networks have emerged with positive results for patient outcome in rural areas without stroke expertise. However, telestroke faced enormous on-site challenges during the pandemic. So far, data on performance and clinical outcomes in telestroke settings during the COVID-pandemic are scarce.

Methods We retrospectively analyzed data from stroke patients treated in four spoke hospitals of the Bavarian telestroke network NEVAS in 2020–2021 and 2019 as reference year and compared the 3 years for various parameters. Primary outcome was functional outcome according to the modified Rankin scale (mRS). Secondary outcome parameters included time intervals, periprocedural intracranial hemorrhage rates, and mortality.

Results In 2019–2021, 2820 patients were treated for acute ischemic stroke with an admission decrease of 10% during the pandemic. Of those, 241 received only IVT and 204 were transferred to our center for MT. Door-to-imaging, door-to-needle, and symptom-onset-to-groin times remained comparable in the 3 years. Complication rates remained at a low level. Good clinical outcome rates (mRS 0–2) at discharge remained stable for all stroke patients (82–84%) and for those treated with IVT (64–77%). Good clinical outcome rates at 3 month follow-up for MT patients declined in 2020 (23% vs. 35% in 2019) but recovered again in 2021 (42%). Mortality rates did not increase for all patient groups analyzed.

Conclusions Stroke care remained robust during the COVID-pandemic within our network, indicating that well-established telestroke networks can overcome unexpected critical challenges such as a pandemic, guaranteeing best practice stroke care in rural areas.

Keywords Telemedicine network · Stroke · COVID-pandemic · Intravenous thrombolysis · Thrombectomy

Introduction

The COVID-19 pandemic in 2020–2021 had a significant impact on several aspects in global healthcare, presenting many challenges particularly to acute care. From prehospital emergency rescue and hyperacute care in the emergency department to the inpatient intensive or intermediate care units and later posthospitalization rehabilitation, medical staff was faced with many challenges including delays in diagnostics, higher influx of patients, shortage of normal ward, and monitored hospital care capacity and staff shortage due to COVID infection. As one of the leading diseases globally, stroke care was also heavily impacted by the pandemic [1, 2]. Together with reduced hospital admissions for stroke symptoms, delays in and reduced rates of intravenous thrombolysis (IVT) administration and mechanical thrombectomy (MT) were reported [3–5]. Telemedical stroke networks have emerged in the last years, offering a regionwide stroke care coverage with positive results in patient outcome also in rural areas without local stroke expertise [6, 7]. Due to the remote evaluation of stroke patients, minimizing direct contact and potentially compensating staff shortage in hospitals, telemedicine experienced a surge in several healthcare areas during the pandemic, including stroke [8]. On the other hand, telestroke faced

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similar on-site challenges in stroke care during the pandemic. While there are several reports regarding telestroke performance during the pandemic, they usually focused on the full lockdown period in March–April 2020 or only certain stroke care aspects [9–11]. So far, data on performance and clinical outcomes in telestroke settings comprising the total pandemic period of 2020–2021 are lacking.

The Neurovascular Network of Southwest Bavaria (NEVAS) is a telemedical stroke network operating since 2014, offering 24/7 teleconsultation for acute stroke care particularly including IVT and MT indication [12, 13]. In the previous studies, we have shown that essential workflow times and clinical outcomes were non-inferior to direct-to-center transfer of stroke patients to our comprehensive stroke center (CSC) and improved over time both for drip-and-ship patients eligible for MT and for those who received inpatient stroke care until discharge in the spoke partner hospitals [12–15].

In this study, we retrospectively analyzed data from all stroke patients treated in four partner spoke hospitals in 2020 and 2021 during the pandemic as well as 2019 as a reference year before the pandemic and compared the 3 years with each other for various clinical outcome and procedural parameters. A particular focus was given to patients treated with IVT that stayed in the spoke hospitals and those that were secondarily transported to our CSC for MT via "drip-and-ship". Functional clinical outcome and mortality rates as well as key time intervals and performance in stroke management were compared between the years to determine if the COVID-pandemic had an impact on stroke care.

Methods

Study design

We performed a retrospective multicenter cross-sectional study at the Department of Neurology of the University Hospital, Ludwig-Maximilians-University Munich for all stroke patients that were treated via the telemedicine stroke network NEVAS between 2019 and 2021.

Patient data

We included all consecutive patients (age > 18 years) with acute stroke that were treated between 2019 and 2021 in four regional spoke hospitals within the NEVAS network, that are assigned for telemedical consultation to the University Hospital, Ludwig-Maximilians-University Munich. We directly compared the three years 2019 (reference year before COVID-pandemic), 2020 and 2021 (during COVID-pandemic) for various parameters. Clinical data included biometrical data (age, sex), cardiovascular risk factors, diagnosis, neurological examination, and brain imaging, including vessel imaging and essential time intervals. Stroke severity was assessed by the National Institutes of Health Stroke Scale (NIHSS) and functional outcome by the modified Rankin Scale (mRS). Recanalization success was rated by experienced neurointerventionalists based on final angiograms according to the modified thrombolysis in cerebral infarction (mTICI) score. Successful recanalization was defined as TICI 2b-3. mRS at discharge or after 3 months and mortality rate served as primary outcome parameters. Regarding functional outcome, the overall mRS shift over the years was analyzed; further, excellent outcome was defined as mRS 0–1 and good outcome as mRS 0–2. Door-to-imaging, door-to-needle, and symptom onset to flow restoration times as well as periprocedural intracranial hemorrhage rates were secondary outcome parameters. The outcome parameters were compared over time for all stroke patients and as a focused subgroup for those undergone IVT and/or MT.

Supraregional telemedicine stroke network NEVAS

The NEVAS stroke telemedicine network consists of three CSCs (University Hospital, Ludwig-Maximilians-University Munich and the non-universitary maximum care hospitals, Klinikum Ingolstadt and district hospital Guenzburg). Each CSC provides telemedical stroke support to 4–6 non-CSC hospitals in local proximity on a 24 h basis. Patients with suspected stroke are presented immediately via videostream—together with their stroke CT-imaging—and clinical advice is given including eligibility for IVT administration and secondary transport to the CSC for MT [13].

Imaging

Standard imaging of patients with acute stroke consisted of an initial CT-imaging including non-contrast CT and CT angiography. CT-perfusion was not performed in any of the included cases, as it was not provided routinely in our spoke hospitals in the analyzed time period. Within 24 h after IVT/MT, each patient underwent CT or MRI to rate the extent of an ischemic lesion and to detect intracranial hemorrhage.

Indications for IVT and MT treatment

IVT eligibility was assessed during the telemedical consultation according to the national and international IVT guidelines with regard to time of onset, CT scan, and contraindications in medical history and medication. For MT, eligibility was assessed according to the current national and international guidelines. Those patients not fulfilling the guidelines' criteria were individually assessed by an interdisciplinary team of neurologists and neurointerventionalists

based on the severity of clinical symptoms, medical history, premorbid mRS score (pmRS), early ischemic damage on non-contrast CT and perfusion CT, as well as on stroke severity on presentation, according to in-house standard operating procedures.

Statistics

Statistical tests were performed using the Prism Software (GraphPad) and SPSS (IBM Corp, Armonk, NY). p values < 0.05 were considered significant. Each variable is displayed with median and interquartile range (IQR). Univariate analysis was conducted for comparison between three groups, using the Kruskal–Wallis and subsequently Dunn's multiple comparison test as well as the Chi^2-test, where appropriate. To determine association with outcome and safety parameters, ordinal (shift analysis) and binary logistic regression models were used. All regression analysis models were adjusted for age, sex, NIHSS, symptom onset to admission time, and door-to-needle time as well as all variables that were significantly different between groups in univariate analysis. Effect estimates are displayed as adjusted odds ratios (OR) with 95% confidence intervals (CI).

Results

Total stroke patients

Altogether 2820 patients were treated for acute ischemic stroke or transient ischemic attack in the four regional hospitals between 2019 and 2021 (Table 1). In comparison to 2019, the total number of stroke patients decreased by ca. 10%/year (n = ca. 100) during the pandemic years. Most baseline parameters were similar in all time periods. The percentage of stroke patients with unknown symptom onset fell from 10.4% in 2019 to 5.5% in 2021. IVT was administered in 11.4–13.8% of the patients. Hypertension rates were lower in 2020 compared to the other time periods ($p = 0.0005$), while the number of days in hospital was slightly lower in 2021 ($p = 0.0001$).

Table 1 Baseline patient characteristics for all stroke patients that were treated in rural hospitals until discharge within the telemedicine network NEVAS over the years

Baseline characteristics	2019 $n = 1015$	2020 $n = 911$	2021 $n = 894$	p value
Stroke/TIA	665/350	607/304	584/310	
Age, years, median (IQR)	77 (66–83)	78 (67–84)	77 (66–83)	0.307
Sex, female, n (%)	480 (47.3%)	436 (47.9%)	426 (47.7%)	0.968
Premorbid condition[a], median (IQR)	1 (1–1)	1 (1–1)	1 (1–1)	0.052
NIHSS at onset, median (IQR)	2 (0–5)	2 (1–4)	2 (1–4)	0.291
CT (%)	100%	100%	100%	–
CT angiography (%)	100%	100%	100%	–
Risk factors (%)	1010	911	860	–
Arterial hypertension	747 (74%)	606 (66.5%)	629 (73.1%)	**0.0005**
Diabetes mellitus	205 (20.3%)	181 (19.9%)	198 (23%)	0.210
Atrial fibrillation	242 (24%)	203 (22.3%)	217 (25.2%)	0.343
Days in hospital, median (IQR)	6 (4–9)	6 (3–9)	5 (3–8)	**0.0001**
Symptom onset unknown, %	10.4%	9.2%	5.5%	–
Symptom onset to admission time[b]	5 (2–7)	5 (2–7)	5 (2–7)	0.862
IVT administration %	13.8%	11.7%	11.4%	–
MT performance %	9.2%	12.5%	11.4%	–
Door-to-imaging minutes, median (IQR)	33 (16–81)	32 (16–77)	36 (21–79)	**0.018**
Door to imaging for potential IVT candidates, minutes, median (IQR)	19 (12–33)	20 (14–35)	23 (16–35)	**0.015**

Biometrical and clinical data of the included stroke patients were compared between time periods. Univariate analysis was performed using the Kruskal–Wallis test and the Chi^2 test, where appropriate. Significant p values < 0.05 are in bold letters. TIA = transient ischemic attack; IQR = interquartile range; a = premorbid condition defined as (1) independent at home, (2) nursing at home, (3) living in nursing home; CT = computed tomography; b: symptom onset to admission time defined as 1 = ≤ 1 h, 2 = > 1–2 h, 3 = > 2–3 h, 4 = > 3–4 h, 5 = > 4–5 h, 6 = > 5–6 h, 7 = > 6–24 h, 8 = > 24–48 h, 9 = > 48 h; IVT = intravenous thrombolysis

Follow-up at discharge, clinical outcome, complications, and key workflow time intervals in acute stroke management

Clinical outcome at discharge was assessed for all patients by the mRS score (Table 2). The mRS was available for 1010 patients (99.5%) in 2019, 911 (100%) in 2020, and 850 (95.1%) in 2021. In the univariate analysis, the mRS 0–2 percentages remained stable over the years (84.7% vs. 84.6% and 82.4%, $p=0.318$). The mRS shift analysis demonstrated no shift comparing 2020 and 2021 with 2019 (OR 0.89 and 0.98, respectively; $p=0.239$; Fig. 1A). Dichotomized regression analysis for the years 2020 vs. 2019 and 2021 vs. 2019 also revealed no decline during the pandemic years for mRS 0–2 (OR 1.00 and 0.83, respectively; $p=0.435$) at discharge. Mortality at discharge also was similar for 2019, 2020, and 2021 (2019:

Table 2 Clinical follow-up according to the modified Rankin scale (mRS)

mRS at discharge, *n* (%)	All stroke patients					
Univariate analysis	2019 *n* = 1010	2020 *n* = 911	2021 *n* = 850	2020 vs. 2019 OR (95% CI)	2021 vs. 2019 OR (95% CI)	*p* value
mRS 0–1	738 (73.1%)	667 (73.2%)	604 (71.1%)			0.526
mRS 0–2	855 (84.7%)	771 (84.6%)	700 (82.4%)			0.318
Mortality (mRS 6)	37 (3.7%)	33 (3.6%)	25 (2.9%)			0.644
Regression analysis						
mRS 0–6 shift analysis				0.89 (0.74–1.08)	0.98 (0.82–1.17)	0.239
mRS 0–1				1.10 (0.86–1.41)	1.01 (0.78–1.31)	0.734
mRS 0–2				1.00 (0.74–1.37)	0.83 (0.60–1.15)	0.435
Mortality (mRS 6)				0.85 (0.48–1.50)	0.62 (0.33–1.18)	0.343
mRS at discharge, *n* (%)	IVT patients					
Univariate analysis	2019 *n* = 89	2020 *n* = 71	2021 *n* = 64	2020 vs. 2019 OR (95% CI)	2021 vs. 2019 OR (95% CI)	*p* value
mRS 0–1	55 (61.8%)	47 (66.2%)	29 (45.3%)			**0.035**
mRS 0–2	65 (73%)	55 (77.4%)	41 (64.1%)			0.213
Mortality (mRS 6)	7 (7.9%)	2 (2.8%)	4 (6.3%)			0.392
Regression analysis						
mRS 0–6 shift analysis				0.63 (0.34–1.18)	1.36 (0.71–2.59)	0.251
mRS 0–1				1.01 (0.45–2.27)	0.72 (0.0.31–1.65)	0.678
mRS 0–2				0.94 (0.36–2.43)	0.71 (0.28–1.77)	0.742
Mortality (mRS 6)				0.16 (0.01–2.05)	1.08 (0.12–10.09)	0.288
mRS at 3 month follow-up, *n* (%)	MT patients					
Univariate analysis	2019 *n* = 51	2020 *n* = 74	2021 *n* = 53	2020 vs. 2019 OR (95% CI)	2021 vs. 2019 OR (95% CI)	*p* value
mRS 0–1	11 (21.6%)	10 (13.5%)	15 (28.3%)			0.119
mRS 0–2	18 (35.3%)	17 (23%)	22 (41.5%)			0.073
Mortality (mRS 6)	16 (31.4%)	31 (41.9%)	16 (30.2%)			0.308
Regression analysis						
mRS 0–6 shift analysis				1.09 (0.43–2.70)	1.49 (0.58–3.85)	0.631
mRS 0–1				0.73 (0.14–3.88)	1.23 (0.31–4.89)	0.741
mRS 0–2				0.65 (0.15–2.75)	0.91 (0.25–3.32)	0.723
Mortality (mRS 6)				1.40 (0.52–3.78)	1.19 (0.39–3.70)	0.634

Stroke patient clinical outcome at discharge (for all stroke patients and IVT patients) or at 3 month follow-up (for MT patients) was assessed using the mRS score. The percentage of patients with mRS 0–1, 0–2, and mortality rates were compared between 2019, 2020, and 2021. Univariate analysis was performed using the Chi^2-test. Ordinal regression analysis and binary logistic regression analysis (dichotomized mRS) was adjusted for age, sex, NIHSS, arterial hypertension, symptom onset to admission time, days in hospital, arterial hypertension, door-to-imaging time, door-to-needle time, diabetes mellitus, symptom-onset-to-groin time, IVT, and/or successful reperfusion (TICI 2b-3), as indicated in the Results section. Significant *p* values < 0.05 are in bold letters

IVT intravenous thrombolysis, *MT* mechanical thrombectomy, *OR* Odd's ratio, *CI* Confidence interval

3.7%; 2020: 3.6%; 2021: 2.9%) ($p=0.644$), OR 0.85 and 0.62 ($p=0.343$). All regression analysis models were adjusted for age, sex, NIHSS, symptom onset to admission time, and door-to-imaging time as well as hypertension and days in hospital.

Regarding workflow, we compared the door-to-imaging times over the years for all acute stroke patients. The median door-to-imaging time was 3–4 min longer in 2021 (36 min) compared to 2019 (33 min) and 2020 (32 min) ($p=0.018$). We further analyzed only those stroke patients that were potentially eligible for IVT, i. e. symptom onset < 4.5 h and an NIHSS ≠ 0. Similarly, the median door-to-imaging time was slightly longer in 2021 (2019: 19 min; 2020: 20 min; 2021: 23 min) ($p=0.015$).

Stroke patients treated with IVT without MT

A total of 241 patients (12.3%) received IVT between 2019 and 2021 (Table 3). Most baseline characteristics were similar in all time periods. NIHSS at onset was slightly, albeit not significantly, higher in 2019 (median 8 vs. 6 in 2020 and 2021, $p=0.056$). Hypertension rates were higher in 2021 compared to the other time periods ($p=0.001$).

Outcome at discharge: clinical data, complications, and key workflow time intervals

The mRS was available for all 241 patients (Table 2). mRS 0–2 rates were comparable between the three years (64.1–77.4%, $p=0.213$). The mRS shift analysis demonstrated no shift comparing 2020 and 2021 with 2019 (OR 0.63 and 1.36, respectively, $p=0.251$; Fig. 1, B). Dichotomized regression analysis for the years 2020 vs. 2019 and 2021 vs. 2019 also revealed no significant decline during the pandemic years for mRS 0–2 (OR 0.94 and 0.71, respectively; $p=0.742$) at discharge. Mortality rate at discharge were not significantly different (2019: 7.9%; 2020: 2.8%; 2021: 6.3%), OR 0.16 ($p=0.288$). All regression analysis models were adjusted for age, sex, NIHSS, symptom onset to admission time, and door-to-needle time as well as hypertension and days in hospital.

Regarding workflow, we compared door-to-imaging and door-to-needle times over the years for those stroke patients that received IVT. The median door-to-imaging time was comparable (15–17 min; $p=0.104$). The median door-to-needle time did also not change significantly (49–53 min; $p=0.951$).

Stroke patients treated with mechanical thrombectomy ± IVT

Basic clinical characteristics

A total of 204 patients were treated with MT via drip-and-ship between 2019 and 2021, 7.2% of all stroke patients (Table 4). Most baseline characteristics were similar in all time periods. Diabetes rates were higher in 2020 compared to the other years ($p=0.028$). IVT was applied in 54.2% of the patients in 2019, 46.6% in 2020, and 42.4% in 2021. Symptom onset was unknown in 59.2% of the patients in 2020, compared to 31.1% in 2019 and 34.3% in 2021.

Key workflow time intervals in acute stroke management, treatment, and complications

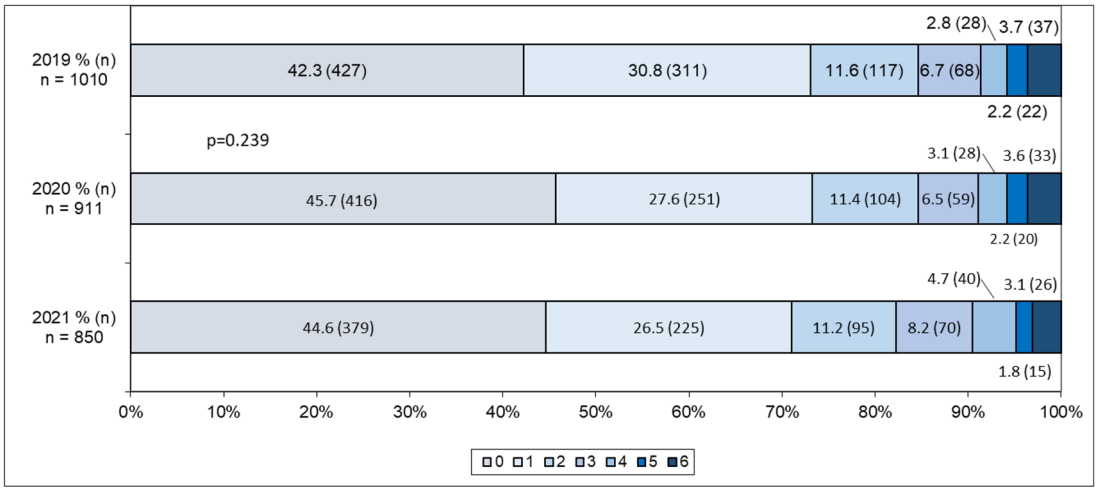
The thrombectomy patients were compared regarding key workflow time intervals in the management of acute stroke between 2019, 2020, and 2021 (Table 5). As expected, symptom onset to admission to our CSC was comparable over the years at ca. 200 min. Door-to-groin time after admission to our CSC was around 40–45 min for 2019, 2020, and 2021, respectively. Further, symptom onset to IVT (ca. 112 min) and symptom onset to flow restoration (300–310 min) times were comparable for each year.

With 60–70%, most patients underwent mechanical thrombectomy under conscious sedation in each year. Successful recanalization rates (i.e. TICI 2b-3) were not significantly different (79–88.5%; $p=0.309$). Rates of major periprocedural complications (ICH or subarachnoidal hemorrhage/SAH, vessel occlusion, vasospasm, and vessel dissection/perforation) were low and comparable between the three time periods (e.g., ICH/SAH 1.6% in 2019, 2.6% in 2020, and 0% in 2021; $p=0.423$).

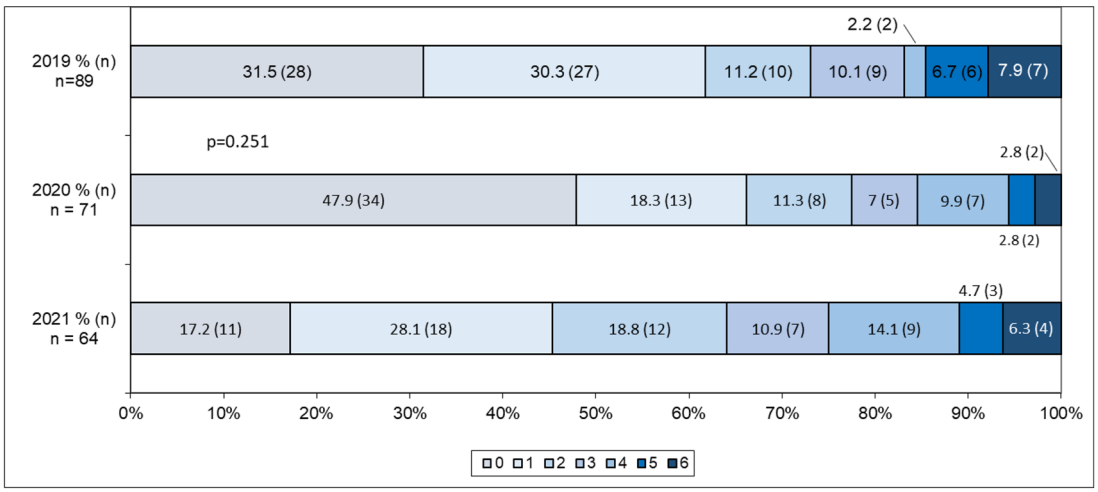
Clinical follow-up and outcome

Thrombectomy patients were clinically examined at 3 months after stroke and the mRS was assessed and compared (Table 2). The mRS at 3 months was available for 51 patients in 2019 (83.6%), 74 in 2020 (97.4%), and 53 in 2021 (79.1%) patients. In the univariate analysis, the mRS 0–2 percentages were lower in 2020, albeit marginally not significantly (23% vs. 35.3% and 41.5%, $p=0.073$). The mRS shift analysis demonstrated no significant shift comparing 2020 and 2021 with 2019 (OR 1.09 and 1.49, respectively; $p=0.639$; Fig. 1, C). Dichotomized adjusted regression analysis for the years 2020 vs. 2019 and 2021 vs. 2019 also revealed no significant decline during the pandemic years for mRS 0–2 (OR 0.65 and 0.91, respectively; $p=0.723$). Mortality rates did not differ significantly (2019: 30.2%; 2020: 41.9%; 2021: 31.4%) ($p=0.308$), the adjusted OR was 1.40 ($p=0.634$). All regression analysis models were adjusted for age, sex, premorbid mRS, NIHSS, diabetes mellitus, symptom-onset-to-groin time, IVT, and successful reperfusion (TICI 2b-3).

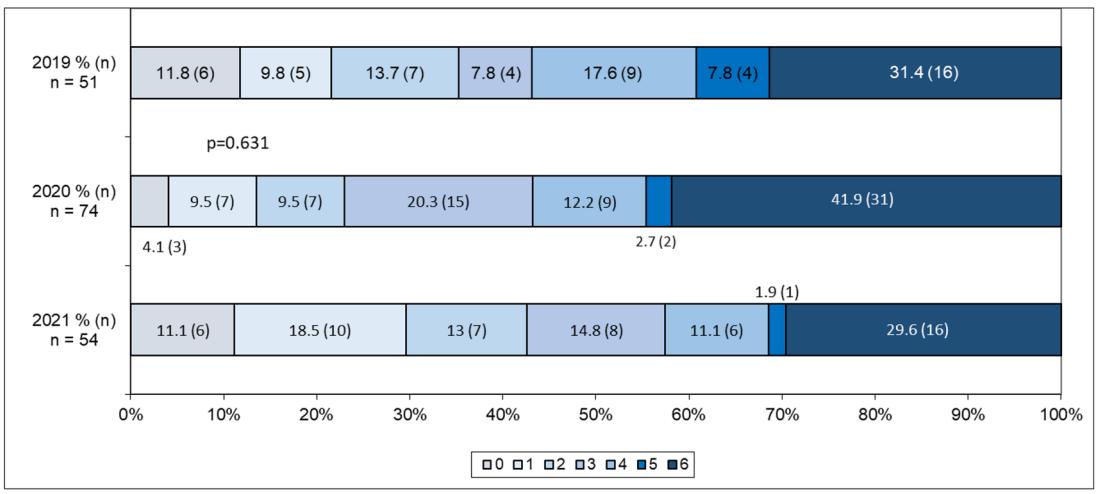
A


2019 % (n)
n = 1010
42.3 (427)
30.8 (311)
11.6 (117)
6.7 (68)
2.8 (28)
3.7 (37)
2.2 (22)
p=0.239
2020 % (n)
n = 911
45.7 (416)
27.6 (251)
11.4 (104)
6.5 (59)
3.1 (28)
3.6 (33)
2.2 (20)
2021 % (n)
n = 850
44.6 (379)
26.5 (225)
11.2 (95)
8.2 (70)
4.7 (40)
3.1 (26)
1.8 (15)
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
0 1 2 3 4 5 6

B


2019 % (n)
n=89
31.5 (28)
30.3 (27)
11.2 (10)
10.1 (9)
2.2 (2)
6.7 (6)
7.9 (7)
p=0.251
2020 % (n)
n = 71
47.9 (34)
18.3 (13)
11.3 (8)
7 (5)
9.9 (7)
2.8 (2)
2.8 (2)
2021 % (n)
n = 64
17.2 (11)
28.1 (18)
18.8 (12)
10.9 (7)
14.1 (9)
4.7 (3)
6.3 (4)
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
0 1 2 3 4 5 6

C


2019 % (n)
n = 51
11.8 (6)
9.8 (5)
13.7 (7)
7.8 (4)
17.6 (9)
7.8 (4)
31.4 (16)
p=0.631
2020 % (n)
n = 74
9.5 (7)
9.5 (7)
20.3 (15)
12.2 (9)
41.9 (31)
4.1 (3)
2.7 (2)
2021 % (n)
n = 54
11.1 (6)
18.5 (10)
13 (7)
14.8 (8)
11.1 (6)
1.9 (1)
29.6 (16)
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
0 1 2 3 4 5 6

◂**Fig. 1** **A**–**C** Modified Rankin Scale (mRS) for stroke patients within the NEVAS network in 2019–2021. Shift analysis of mRS score in stroke patients. For the total stroke population (**A**) and for those that received intravenous thrombolysis (IVT) (**B**), mRS at discharge is displayed. For the stroke patients that underwent mechanical thrombectomy (MT) (**C**), the mRS at 3 month follow-up is displayed. The absolute number and the percentage to the total number of each patient group are displayed for each mRS subscore

Discussion

In this study, we evaluated data from patients with acute stroke treated within the NEVAS telemedicine network from 2019 to 2021 to analyze if the COVID-pandemic had an impact on stroke management and clinical patient outcome. Our key findings were the following: (i) there was a decrease of 10% in the number of stroke patients treated within the network during the pandemic; (ii) good clinical outcome rates (mRS 0–2) at discharge remained stable for all stroke patients in the spoke hospitals, particularly also for those treated with IVT; (iii) good clinical outcome rates (mRS 0–2) at 3 month follow-up for patients treated with MT after admission to our CSC also stayed stable during the pandemic; (iv) door-to-imaging times, door-to-needle times, and symptom-onset-to-groin times remained similar in the three years; (v) mortality rates did not increase for all stroke patients and those treated with IVT and/or MT; (vi) intracranial hemorrhage rates remained stable and at a low level during the pandemic.

Admissions for acute stroke declined in 2020 and 2021 compared to 2019 by about 10%, in line with the previous reports [3, 5, 10]. Age and sex distribution as well as the premorbid condition did not differ between the years; interestingly, the percentage of patients with pmRS > 2 or a premorbid condition in need of nursing care was lower during the pandemic both for IVT and MT patients. One possible explanation for this could be the fear of a COVID infection upon hospital admission that could deteriorate the patients' multimorbid condition or an increased tendency for palliative home care. Clinical stroke severity was comparable before and during the pandemic for all stroke patients and for MT patients, while for IVT patients, it was slightly lower in 2020 and 2021 without reaching significance. Symptom onset to admission time was also similar between the years, suggesting a well-working prehospital acute management. The percentage of patients with unknown symptom onset did not increase during the pandemic despite a restriction in personal contacts. Hospital stay length was on average 2–3 days shorter for IVT patients during the pandemic, while for MT patients and the total stroke population, no differences were observed. Overall, the pre- and periclinical conditions were not substantially influenced by the pandemic.

Key workflow time intervals remained robust during the pandemic. For all stroke patients, door-to-imaging time was 32–36 min, for the IVT patients shorter with 15–17 min. Door and imaging times in the spoke hospitals were not available for MT patients. However, the time interval from symptom onset to admission at the CSC remained stable at about 200 min and thus was not different to previous years within our network [12, 15]. For the IVT patients, door-to-needle times were only marginally higher with 53 and 51 min during the pandemic compared to 49 min in 2019. For the MT patients, symptom onset to needle times did not differ between the years and were at 110–115 min. Beside the robust workflow in the spoke hospitals, time intervals in our CSC did also not substantially decline during the pandemic. The times for door-to-groin and groin-to-flow restoration at our CSC did not significantly change during the pandemic. In total, the overall time from symptom onset to flow restoration, encompassing all workflow procedures in acute stroke treatment, was also similar between 2019, 2020, and 2021. We also calculated the door-to-groin and groin-to-flow restoration times for directly admitted MT patients in our CSC and found somewhat longer door-to-groin times (68 min in 2019, 77 in 2020 and 76 in 2021) compared to ca. 40 min for drip-and-ship patients, as in the latter clinical examination, imaging and IVT administration already occurred in the spoke hospitals. Groin-to-flow restoration times were with 45 min in 2019, 40 min 2020, and 41 min in 2021 comparable to the drip-and-ship patients. Thus, key work time intervals remained overally robust for our CSC during the pandemic. Interestingly, the type of anesthesia during MT shifted non-significantly toward conscious sedation with local anesthesia by 10% (from 59 to 72% and 67%) during the pandemic, possibly for temporal reasons and reflecting a higher threshold for GA due to risk from airway access [20]. While there is a lack of studies concerning workflow times in telestroke setting during the pandemic, workflow time data for stroke patients varied in published studies, from a significant delay during the pandemic [16] to small or no differences [17–19]. However, most data were collected during the initial lockdown period between March and May 2020, with only a few studies examining the time period after end of lockdown in May 2020. Thus, within our telestroke network, the overall procedural performance in acute stroke care management was not negatively affected by the pandemic, displaying that well-established telestroke networks guarantee high-quality healthcare also in times of extraordinary situations such as pandemics or other comparable critical events in the healthcare system.

Good clinical outcome at discharge, defined as mRS 0–2, was also comparable among all stroke patients before and during the pandemic with an excellent overall outcome rate of 82–84%. For IVT patients, good clinical outcome rates remained also high and stable (64–77%). Outcome data at 3 month follow-up were not available for these patient cohorts. As expected, for MT patients,

Table 3 Baseline patient characteristics and key workflow time intervals for stroke patients that were administered intravenous thrombolysis (IVT) in the telemedicine network NEVAS over the years

Baseline characteristics for IVT patients	2019 $n=92$	2020 $n=71$	2021 $n=78$	p value
Age, years, median (IQR)	77 (68–83)	77 (63–82)	75 (64–83)	0.522
Sex, female, n (%)	37 (40.2%)	32 (45.1%)	40 (51.3%)	0.352
Premorbid condition[a], median (IQR)	1 (1–1)	1 (1–1)	1 (1–1)	0.578
NIHSS at onset, median (IQR)	8 (5–12)	6 (4–10)	6 (3–10)	0.056
Risk factors, *n* (%)			$n=177$	–
Arterial hypertension	45 (50.6%)	37 (52.1%)	51 (77.3%)	**0.001**
Diabetes mellitus	16 (18%)	12 (16.9%)	12 (18.2%)	0.977
Atrial fibrillation	26 (29.2%)	10 (14.1%)	16 (24.2%)	0.075
CT %	100%	100%	100%	–
CT angiography n (%)	100%	100%	100%	–
Days in hospital, median (IQR)	9 (4–12)	6 (4–10)	7 (3–12)	0.243
Symptom onset to admission time[b]	2 (2–3)	2 (1–2)	2 (2–3)	0.152
ICH, *n* (%)	5 (5.4%)	2 (2.8%)	3 (3.8%)	0.688
Key workflow time intervals (minutes), median (IQR)				
Door to imaging	15 (9–20)	16 (9–23)	17 (13–23)	0.104
Door to needle	49 (35–70)	53 (36–68)	51 (39–65)	0.951

Biometrical and clinical data of the included stroke patients were compared between time periods. Univariate analysis was performed using the Kruskal–Wallis test and the Chi^2-test, where appropriate. Significant p values < 0.05 are in bold letters. IQR = interquartile range; a = premorbid condition defined as (1) independent at home, (2) nursing at home, (3) living in nursing home; b: symptom onset to admission time defined as 1 = ≤ 1 h, 2 = > 1–2 h, 3 = > 2–3 h, 4 = > 3–4 h

CT computed tomography, *ICH* intracranial hemorrhage

Table 4 Baseline patient characteristics for stroke patients underwent mechanical thrombectomy via drip-and-ship

Baseline characteristics	2019 $n=61$	2020 $n=76$	2021 $n=67$	p value
Age, years, median (IQR)	76 (64–83)	80 (68–84)	76 (65–84)	0.351
Sex, female, *n* (%)	23 (37.7%)	39 (51.3%)	33 (49.3%)	0.246
pmRS score, median (IQR)	0 (0–1)	0 (0–1)	0 (0–1)	0.941
pmRS > 2, *n* (%)	8 (13.1%)	7 (9.2%)	6 (9%)	–
NIHSS at onset, median (IQR)	15 (9–21)	17 (10–22)	13 (8–19)	0.116
CT, n (%)	100%	100%	100%	
CT angiography, *n* (%)	100%	100%	100%	
IVT, %	54.2%	46.6%	42.4%	0.242
Days in hospital, median (IQR)	8 (4—11)	7 (4–10)	7 (4–10)	0.905
Onset unknown, %	31.1%	35.5%	34.3%	0.773
Risk factors, *n* (%)	$n=58$	$n=71$		
Arterial hypertension	42 (72.4%)	58 (81.7%)	52 (77.6%)	0.454
Diabetes mellitus	9 (15.5%)	23 (32.4%)	11 (16.4%)	**0.028**
Hypercholesterolemia	13 (22.4%)	13 (18.3%)	18 (26.9%)	0.484
Smoking	10 (17.2%)	16 (22.5%)	17 (25.4%)	0.542
Atrial fibrillation	16 (27.6%)	30 (42.3%)	22 (32.8%)	0.203

Biometrical and clinical data of the included patients are compared between time periods. Univariate analysis was performed using the Kruskal–Wallis test and the Chi^2-test, where appropriate. Significant p values < 0.05 are in bold letters

IQR interquartile range, *pmRS* premorbid modified Rankin Scale, *CT* computed tomography, *IVT* intravenous thrombolysis

Table 5 Key workflow time intervals, treatment efficacy, and complications

Key workflow time intervals (minutes), median (IQR)	2019 $n=61$	2020 $n=76$	2021 $n=67$	p value
Symptom onset to arrival in our center	209 (175–259)	199 (155–270)	213 (158–256)	0.922
Arrival in our center to groin	40 (25–53)	45 (31–62)	39 (29–55)	0.117
Arrival in our center to flow restoration	82 (64–114)	96 (64 -152)	94 (71–121)	0.418
Symptom onset to IVT	112 (72–152)	110 (95–146)	115 (85–180)	0.708
Symptom onset to groin	249 (201–300)	258 (202–308)	240 (205–299)	0.910
Groin-to-flow restoration	39 (25–65)	44 (30–63)	45 (30–73)	0.755
Symptom onset to flow restoration	306 (243–385)	302 (241–381)	315 (255–408)	0.697
Treatment and complications				
Type of anesthesia, *n* (%)				0.230
GA	20 (32.8)	16 (21.1%)	14 (20.9%)	
CS	36 (59%)	55 (72.4%)	45 (67.2%)	
Switch CS to GA	5 (8.2%)	5 (6.5%)	8 (11.9%)	
No. of passages, median (IQR)	2 (1–4)	2 (1–4)	2 (1–3)	0.609
Successful revascularization, TICI, *n* (%)				
TICI 0	4 (6.6%)	7 (9.2%)	7 (10.4%)	
TICI 1	1 (1.6%)	2 (2.6%)	3 (4.5%)	
TICI 2a	2 (3.3%)	7 (9.2%)	3 (4.5%)	
TICI 2b	38 (62.3%)	44 (57.9%)	40 (59.7%)	
TICI 3	16 (26.2%)	16 (21.1%)	14 (20.9%)	
TICI 2b-3	54 (88.5%)	60 (79%)	54 (80.6%)	0.309
Complications after MT, *n* (%)				
SAH or ICH 24 h after MT (ECASS-3)	1 (1.6%)	2 (2.6%)	0	0.423
Other vessel occlusion	1 (1.6%)	6 (7.9%)	6 (9%)	0.189
Vasospasm	6 (9.8%)	12 (15.8%)	4 (6%)	0.161
Technical problems with access	0	1 (1.3%)	0	0.429
Dissection/vessel perforation	3 (4.9%)	6 (7.9%)	6 (9%)	0.665

Key workflow time intervals in acute stroke management as well as treatment efficacy and periprocedural complications are compared between direct-to-center (DC) and drip-and-ship (DS) patients. Univariate analysis was performed using the Kruskal–Wallis test and the Chi^2-test, where appropriate. Significant p values < 0.05 are in bold letters

IQR interquartile range, *pmRS* premorbid modified Rankin Scale, *IVT* intravenous thrombolysis, *GA* general anesthesia, *CS* conscious sedation with local anesthesia, *TICI* Thrombolysis in Cerebral Infarction, *SAH* subarachnoidal hemorrhage, *ICH* intracranial hemorrhage

good outcome rates (mRS 0–2) at 3 month follow-up were overall lower with 35% in 2019 and 42% in 2021 and declined slightly further in 2020 to 23%. In general, the observed rates of a good outcome with a mRS of 0–2 after 3 months in those patients receiving MT after drip-and-ship transfer are comparable to the outcome rates from the large thrombectomy trials in a direct-to-center manner [21, 22]. The observed decrease of a good clinical outcome with only 23% in 2020 (as compared to 35% and 42%) could possibly be attributed to the observed slightly older median age, a smaller percentage of IVT administration, and a slightly higher percentage of unknown symptom onset as well as higher rates of hypertension, diabetes and atrial fibrillation. Further, there was a higher percentage of periprocedural complications. Another factor to be considered are possible differences in post-acute rehabilitation care, since important parameters for procedural workflow quality, such as door-to-needle, door-to-groin, and flow restoration times, did not worsen during the pandemic. Staff shortage, lower capacity, longer waiting times, restructuring of rehabilitation clinics to COVID-19 units, and restrictions due to quarantine obstructed post-stroke care might all have negatively impacted smooth and immediate transfer to appropriate neurological rehabilitation units after the acute care setting as well as the usually high quality in these units [23]. If a possible concomitant COVID infection affected the clinical outcome after stroke could not be assessed, as data on this issue were not available. One interesting issue would be to examine if the outcome remained stable also after the pandemic; however, data for the time after the pandemic (2022–2023) were not available. Yearly monitoring of key parameters is

important in telestroke networks to maintain high-performance quality. One important limitation of our study with regard to different outcomes is that the number of IVT and MT patients was relatively small (about 70–80 patients per subgroup), so that the power of the study could be reduced.

With a stable average IVT rate of ca. 12.3% among all stroke patients before and during the pandemic, our results are in line with IVT rates from other studies [24]. Interestingly, IVT rates for MT patients gradually and slightly declined during the pandemic from 54 to 47% and 42%. One factor for that observation could be the slightly higher percentage of patients with unknown symptom onset in 2020 and 2021. Furthermore, the number of patients with prior anticoagulation and already ischemic demarcation in CT as relevant contraindications for IVT was higher in 2020 and 2021 (data not shown); the former also plausibly reflected by a higher prevalence of atrial fibrillation. However, due to missing times of symptom onset to admission to the spoke clinics, we cannot exclude this as a relevant factor for the reduced IVT rates.

Regarding safety, ICH rates remained low during the pandemic both for IVT (2.8 and 3.8% in 2020 and 2021, respectively) and MT patients (2.6 and 0% in 2020 and 2021, respectively) and were lower compared to major IVT trials [21, 25–27], thus guaranteeing that IVT and MT remained safe. Furthermore, the mortality rate also remained stable for all stroke patients at about 3% and for those receiving IVT 7% and thus was somewhat lower than those reported in major IVT trials [25, 26]. For MT patients, mortality was overall higher than for non-MT patients with 31–42% without significant differences before and during the pandemic. Comorbidities in detail as well as status of complicating COVID-19 infection of these patients as additional potential factors for a worse outcome were not available. Nevertheless, acute stroke treatment including IVT and MT via our telemedical stroke network generally remained safe during the pandemic.

In conclusion, performance and clinical outcomes remained robust during the COVID-19 pandemic within our telemedicine stroke network, indicating that well-established telestroke networks can overcome unexpected challenges of nationwide and global reach such as a pandemic and provide ongoing excellent stroke care.

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Data availability The data that support the findings of this study are available upon reasonable request and in compliance with the local and international ethical guidelines.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

Ethical approval All data were collected according to the Declaration of Helsinki. The study was centrally approved by the Ethics Committee of the LMU Munich (protocol: 689-15).

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