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INFLUENCE OF COVID-19 ON LONG-TERM CONSEQUENCES OF PRE-PANDEMIC-PERFORMED EXTRA AND INTRACRANIAL ATHEROSCLEROTIC STENTING: TERTIARY INSTITUTIONAL EXPERIENCE

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Abstract

Introduction. Endovascular stenting for atherosclerotic stenosis in the intra- and extracranial arteries is a minimally invasive procedure, but comprehensive studies on long-term complications following COVID-19 infection are lacking. Given the potential for increased rates of stent thrombosis, stroke, myocardial infarction, and mortality among COVID-19 patients, understanding the long-term outcomes of stenting for extra- and intracranial atherosclerotic stenosis is crucial for public health. This study addresses the dearth of extensive research on the long-term adverse outcomes associated with endovascular stenting procedures in patients who have experienced atherosclerotic stenosis in intracranial and extracranial arteries following COVID-19 infection.

Materials and methods. This retrospective study analyzed data from a tertiary hospital database, focusing on individuals who underwent extracranial or intracranial atherosclerotic stenting procedures at the Central Clinical Hospital JSC, Department of Neurosurgery, between 2016 and 2017, before the COVID-19 pandemic. The primary outcome measures evaluated were the incidence of stent thrombosis, ischemic stroke, myocardial infarction, and all-cause mortality.

Results. This study consisted of 81 participants, of whom 32 had a prior COVID-19 infection confirmed by PCR, antigen, and antibody testing, forming the COVID-19 group, while the remaining 49 comprised the control group. The analysis revealed no statistically significant differences in mortality, stroke, and myocardial infarction rates between the COVID-19 and control groups. However, high blood pressure was found to be a significant predictor of mortality and stroke. The binary logistic regression analysis indicated a trend toward increased cardiovascular risk with smoking, but the association did not reach statistical significance. While smoking remains a major modifiable risk factor for vascular disease, further studies with larger sample sizes are needed to confirm its specific impact in post-stenting patients.

Conclusion. While COVID-19 infection did not significantly influence long-term mortality, stroke, or myocardial infarction rates, elevated blood pressure, smoking, and high

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stress levels were associated with worse outcomes. These findings highlight the importance of managing cardiovascular risk factors in patients undergoing endovascular stenting

Keywords: atherosclerosis; stroke; risk factors; intracranial stenosis; extracranial stenosis; COVID-19; public health; in-stent thrombosis; myocardial infarction

Introduction. Atherosclerotic disease is a chronic condition characterized by the accumulation of lipids, inflammatory cells, and fibrous tissue within the arterial walls, leading to plaque formation [1]. This process can result in stenosis, or the narrowing of the arterial lumen, which impedes blood flow and increases the risk of ischemic events, such as stroke and myocardial infarction [1,2]. Intracranial and extracranial stenosis, particularly in the carotid and vertebral arteries, is a major cause of cerebrovascular events, contributing significantly to morbidity and mortality worldwide [3].

The clinical management of atherosclerotic stenosis has evolved over recent decades, with endovascular stenting emerging as a minimally invasive and effective treatment modality [4]. Stenting restores vascular patency and stabilizes plaques, reducing the risk of embolic events [5]. However, patients undergoing stenting remain at risk for complications such as in-stent thrombosis, restenosis, and vascular inflammation, especially when compounded by systemic factors, like smoking, hypertension, or diabetes [5,6].

The COVID-19 pandemic introduced an additional layer of complexity to managing atherosclerotic disease. COVID-19 is associated with heightened pro-inflammatory and pro-thrombotic states, which may exacerbate vascular complications in patients with pre-existing conditions [7]. Understanding the interplay between COVID-19 infection and the long-term outcomes of intracranial and extracranial stenting is critical for optimizing patient care and improving prognoses [8].

This study aims to address the gap in research by examining the long-term outcomes of endovascular stenting in patients with atherosclerotic stenosis who were affected by COVID-19. By comparing these outcomes with those of a control group, this study provides insights into the potential impact of COVID-19 on vascular interventions, contributing to the broader understanding of how systemic diseases influence cerebrovascular health.

Materials and methods

Study Design and Patient Population

This study retrospectively analyzed data from a tertiary hospital database. The patient population consisted of individuals who underwent extracranial or intracranial atherosclerotic stenting at the Central Clinical Hospital JSC, Department of Neurosurgery, between 2016 and 2017, before the COVID-19 pandemic. The primary outcome measures evaluated were the incidence of stent thrombosis, ischemic stroke, myocardial infarction, and all-cause mortality. This study included patients who underwent extracranial or intracranial atherosclerotic stenting procedures. The control group consisted of patients who tested negative for COVID-19.

This retrospective study analyzed data from a tertiary hospital database. The patient population consisted of individuals who underwent extracranial or intracranial atherosclerotic stenting at the Central Clinical Hospital JSC, Department of Neurosurgery, between 2016 and 2017, before the COVID-19 pandemic. Patients were followed up until December 2023, with a mean follow-up duration of six years.

Patients from 2018 and 2019 were not included in this study to ensure a clear distinction between pre-pandemic stenting cases and those potentially impacted by pandemic-related healthcare system changes. Additionally, many patients who underwent stenting in 2018 and 2019 had incomplete follow-up data due to the disruptions caused by the COVID-19 pandemic, limiting the reliability of long-term outcome assessments.

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The primary outcome measures evaluated were the incidence of stent-related complications (such as in-stent thrombosis and restenosis), ischemic stroke, myocardial infarction, and all-cause mortality. Given that this study focused on patients with intracranial and extracranial stenting, complications related to stents were considered a primary endpoint to capture clinically relevant vascular outcomes.

Patients were stratified into two groups based on COVID-19 status during the follow-up period. The COVID-19 group included individuals with a history of COVID-19 infection confirmed by PCR, antigen, and antibody testing. The control group comprised patients confirmed as COVID-19 negative using the same diagnostic tests.

Due to the retrospective nature of this study, the precise timing of COVID-19 infection for each participant was not always available. However, based on hospital records and follow-up questionnaires, infection dates generally ranged from 2020 to 2022. Follow-up evaluations were conducted at regular intervals (3 months or 1-year post-stenting), and any major adverse events (stroke, myocardial infarction, mortality) occurring post-COVID-19 were documented.

Sample Size Determination

Although this study was retrospective in design, a post hoc power analysis was conducted to ensure that the sample size was adequate for detecting meaningful differences between the COVID-19 and control groups. Based on preliminary data and effect size estimations, the study was powered to detect differences in mortality, stroke, and myocardial infarction outcomes at an alpha level of 0.05 and a power of 80%. The final sample size of 81 participants met these criteria and was deemed sufficient for the planned statistical analyses.

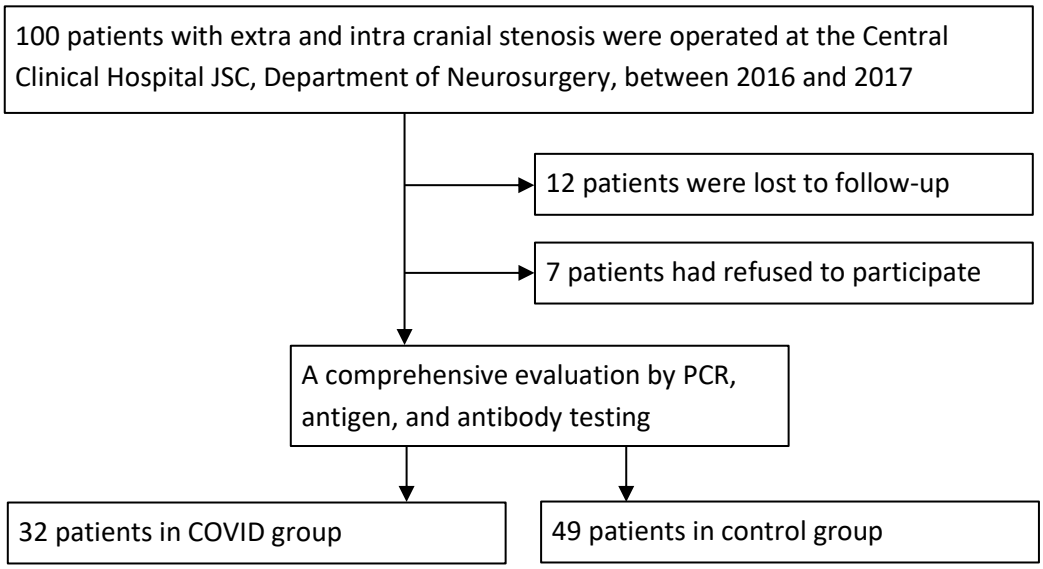

Figure 1. Inclusion and exclusion flowchart.

Survey Questionnaire

All the participants or their representatives provided voluntary informed consent and were sent the questionnaire “Assessment of the Risk of Complications Following Cerebrovascular Atherosclerotic Stenting” (copyright certificate No. 30993, issued on 9 December 2022). Our center specifically developed the questionnaire in collaboration with the Public Health Department to address this study’s objectives. It was used to collect data on (1) treatment outcomes, including stroke, myocardial infarction, and mortality; (2) the number of months post-procedure that the outcome occurred, and (3) risk factors, such as lifestyle, nutrition,

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medication adherence, and management of concurrent conditions. The questionnaire was presented in Kazakh and Russian and consisted of 33 questions. The questionnaire can be found in Supplementary Material S1.

This study complied with the ethical principles outlined in the Declaration of Helsinki and received approval from the local bioethics committee of the Kazakhstan School of Public Health, a medical university in Kazakhstan (№IRB-A333, date 05.01.2023).

Predictive Model

A predictive model was developed using binary logistic regression [9] to estimate the probability of mortality, stroke, and myocardial infarction based on various risk factors. The model incorporated factors such as the severity and treatment setting of the COVID-19 infection, location of atherosclerotic plaques, smoking status, body mass index, changes in body weight, sex, age, stress levels, sleep duration, physical activity patterns, adherence to medication regimens, and type of stent used during the surgical procedure.

Stress levels were assessed using a standardized patient questionnaire, which included self-reported measures of perceived stress, sleep disturbances, and anxiety symptoms. Responses were scored using a Likert scale, with higher scores indicating greater stress levels. Additionally, medical records were reviewed for documented stress-related symptoms such as hypertension spikes and physician-reported psychological distress.

Statistical Analysis

The Shapiro–Wilk test was used to assess the normality of the distribution of the measured variables. Non-parametric quantitative data were analyzed using the Mann–Whitney U-test, while parametric data were analyzed using Student's *t*-test. Fisher's exact test was applied to examine the nominal data. Pearson's chi-square test was leveraged to evaluate the strength of associations, and the effect size was quantified using Cramer's V metric.

Binary logistic regression modeling was employed to evaluate the impact of various factors on the likelihood of developing complications. The coefficient of determination was calculated using the Nagelkerke method. Sensitivity and specificity were determined through the formulas Se = TP/100% and Sp = TN/100%, as well as by constructing an ROC curve.

Statistical significance was set at a *p*-value of less than 0.05. All the analyses were conducted using the SPSS statistical software, version 26.

Results

Patient Characteristics

The final study cohort consisted of 81 participants, with 32 individuals in the COVID-19 group and 49 in the control group. The average follow-up duration was six years (mean: 6.2 ± 1.1 years, range: 5.5–7 years), with the last recorded follow-up in December 2023. For the COVID-19 group, the mean time from stenting to COVID-19 infection was 4.3 ± 1.5 years. Among them, nine patients experienced COVID-19 in 2020, 16 in 2021, and 7 in 2022. The mean time from COVID-19 diagnosis to the occurrence of vascular events (stroke, myocardial infarction, or death) was 15.8 ± 4.2 months.

The two cohorts did not exhibit statistically significant differences in terms of sex or age, as seen in Table 1.

Table 1. Patient characteristics

	COVID-19	**Control**	***p*-Value**	**Effect Size**
Gender				
Male	81.3% (26/32)	65.3% (32/49)	0.095	0.173 (0.138)
Female	18.8% (6/32)	34.7% (17/49)		
Age	65.3 ± 7.1	66.6 ± 6.9	0.947	

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Data are % (n/N) or Mean ± SD. SD: standard deviation.

In the COVID-19 group, the severity of illness varied, with 9 patients experiencing mild, 16 moderate, and 7 severe COVID-19 cases. Regarding the treatment setting, 16 patients were managed at home, 4 received day-patient care, and 12 required full hospitalization, as seen in Table 2.

Table 2. Characteristics of COVID-19

COVID-19 Characteristic	**% (n/N)**
Severity of symptoms	
Mild	28.1% (9/32)
Average	50.0% (16/32)
Severe	21.9% (7/32)
Location of symptoms	
At home	50.0% (16/32)
Day-patient facility	12.5% (4/32)
Hospital	37.5% (12/32)

The most common endovascular stent used by the study participants was the Protégé stent. Medication adherence, including antiplatelet therapy, was assessed in both the COVID-19 and control groups. All the patients were required to take antiplatelet agents for 6 months following their endovascular procedure. In the COVID-19 group, 10 patients fully adhered to the antiplatelet regimen, 13 adhered intermittently or in cycling patterns, and 9 did not take the medication as prescribed. Similarly, in the control group, 21 patients adhered to the antiplatelet therapy, 15 adhered partially or cyclically, and 13 did not take the medication. The differences in medication adherence between the two groups were not statistically significant, as seen in Table 3.

Table 3. Medications and adherence to prescribed dosage.

Medication Type	**Adherence**	**COVID-19**	**Control**	***p*-Value**	**Effect Size**
Anti-hypertensives	Yes	50.0% (16/32)	63.3% (31/49)	0.421	0.183 (0.421)
	Only when hypertension was elevated	28.1% (9/32)	12.2% (6/49)		
	Irregular usage	9.4% (3/32)	8.2% (4/49)		
	No	12.5% (4/32)	16.3% (8/49)		
Lipid-lowerings	Yes	31.3% (10/32)	42.9% (21/49)	0.699	0.092 (0.699)
	Sometimes or in dosing cycles	40.6% (13/32)	30.6% (15/49)		
	No	28.1% (9/32)	26.5% (13/49)		
Antiplatelets	Yes	31.3% (10/32)	42.9% (21/49)	0.699	0.092 (0.699)

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	Sometimes or in dosing cycles	40.6% (13/32)	30.6% (15/32)		
	No	28.1% (9/32)	26.5% (13/49)		
Mandatory course of antiplatelets regimen after the surgery	Yes	15.6% (5/32)	24.5% (12/49)	0.299	0.294 (0.299)
	Stopped after 1 month	12.5% (4/32)	20.4% (10/49)		
	Stopped after 3 months	28.1% (9/32)	12.2% (6/49)		
	Stopped after 6 months	37.6% (12/32)	24.5% (12/49)		
	Stopped after 12 months	0% (0/32)	8.2% (4/49)		
	No	6.2% (2/32)	6.1% (3/49)		
	Unknown	0% (0/32)	4.1% (2/49)		
Blood-sugar lowerings	Yes	31.3% (10/32)	38.8% (19/49)	0.399	0.092 (0.399)
	No	68.6% (22/32)	61.2% (30/49)		

Data are % (n/N)

Long-Term Outcomes

To assess whether COVID-19 severity influenced long-term outcomes, we stratified patients into three subgroups: mild (n = 9), moderate (n = 16), and severe (n = 7) COVID-19 cases. The key outcome measures (mortality, stroke, and myocardial infarction) were compared across these subgroups.

The overall mortality rate was 21.9% in the COVID-19 group and 34.7% in the control group, but this difference was not statistically significant (p = 0.271). However, patients with severe COVID-19 infections had the highest mortality rate (42.9%) compared to those with mild (11.1%) or moderate (18.8%) COVID-19 cases (p = 0.041). The causes of mortality in the COVID-19 group included stroke, COVID-19, other causes, and unknown causes. Similarly, in the control group, the causes of mortality were stroke, myocardial infarction, other causes, and unknown causes. These differences in mortality causes between the two groups were not statistically significant, as seen in Table 4.

Regarding stroke, the overall incidence was 56.3% in the COVID-19 group and 44.9% in the control group. Although this difference did not reach statistical significance (p = 0.052), the observed odds ratio of 1.4 (95% CI: 0.55–3.25) suggests a meaningful clinical trend toward increased cerebrovascular events among post-COVID patients. Stratified analysis revealed increasing stroke rates by severity: 3 of 9 patients (33.3%) in the mild group, 7 of 16 (43.8%) in the moderate group, and 5 of 7 (71.4%) in the severe group. Although these differences did not reach statistical significance (p = 0.19, Fisher's exact test), the data suggest a dose-dependent trend between COVID-19 severity and cerebrovascular risk.

The myocardial infarction rate was 3.1% in the COVID-19 group, while in the control group, it was 4.1%. The odds ratios for mortality and myocardial infarction in the COVID-19

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group compared to the control group were both 0.5. However, these differences were not found to be statistically significant, as seen in Table 4.

The data analysis revealed that individuals with severe COVID-19 infections experienced significantly higher mortality rates compared to those with mild COVID-19 cases. Furthermore, the severe COVID-19 cohort exhibited the highest incidence of myocardial infarction. While a trend toward increased stroke risk was observed in the severe COVID-19 group, this association did not reach statistical significance.

Timing of Events Relative to COVID-19 Infection

To evaluate the temporal relationship between COVID-19 infection and vascular events, we assessed the incidence of major adverse outcomes within 3, 6, and 12 months following COVID-19 diagnosis. Within 3 months post-infection, 2 strokes, 1 myocardial infarction, and 2 deaths were observed. Over the subsequent 6-month period, 5 strokes, 1 myocardial infarction, and 4 deaths occurred. Finally, within 12 months post-infection, 10 strokes, 3 myocardial infarctions, and 5 deaths were documented. While there was an apparent increase in cerebrovascular events during the first year after COVID-19, the difference in event rates between the COVID-19 and control groups did not reach statistical significance.

Table 4. Long-term outcomes.

Outcome	**COVID-19**	**Control**	**OR (95% CI)**	***p*-Value**	**Effect Size**
Mortality	21.9% (7/32)	34.7% (17/49)	0.5 (0.212, 1.551)	0.271	0.114 (90.271)
Before the pandemic	0% (0/7)	29.4% (5/17)			
Missed	0	3			
Causes of mortality			0	0.651	0.329 (0.651)
Stroke	14.3% (1/7)	17.6% (3/17)			
Myocardial infarction	0% (0/7)	11.8% (2/17)			
COVID-19	57.1% (4/7)	0% (0/17)			
Other	14.3% (1/7)	52.9% (9/17)			
Unknown	14.3% (1/7)	17.6% (3/17)			
Myocardial infarction	3.1% (1/32)	4.1% (2/49)	0.5 (0.053, 5.366)	0.588	0.092 (0.588)
Before the pandemic	0% (0/1)	0% (0/2)			
Missed	100% (1/1)	50.0% (1/2)			
Stroke	56.3% (18/32)	44.9% (22/49)	1.4 (0.550, 3.251)	0.521	0.070 (0.531)
Before the pandemic					
Missed	0	4.5% (1/22)			

CI: confidence interval; OR: odds ratio.

Predictors of Outcomes

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The binary logistic regression analyses revealed that overall, maximum systolic blood pressure, stress levels, and the type of stent used were statistically significant predictors of mortality. Collectively, these factors accounted for 41.2% of the observed mortality. Specifically, higher maximum systolic blood pressure and greater stress levels demonstrated a significant positive association with the likelihood of death. The type of stent utilized showed a varying association with clinical outcomes, with some types demonstrating a lower probability of a lethal outcome, as shown in Table 5. The authors should specify how the stress level was calculated.

Table 5. Predictors of mortality

Risk Factor	**Unadjusted OR (95% CI)**	***p*-Value**	**Adjusted OR (95% CI)**	***p*-Value**
Max systolic blood pressure	1.005 (0.992–1.018)	0.466	1.042 (1.000, 1.085)	0.049 *
Stress	1.586 (1.069–2.354)	0.022 *	3.612 (1.192, 10.943)	0.023 *
Stent	0.942 (0.775–1.145)	0.548	0.660 (0.404, 1.088)	0.098
Sensitivity	0			
Specificity	100%			
Total percentage	74.3%			
Nagelkerke R2	0.412			
p-value	0.021 *			

CI: confidence interval, OR: odds ratio. * $p < 0.05$.

The binary logistic regression analysis revealed statistically significant associations between stroke and elevated maximum systolic blood pressure as well as the number of cigarettes smoked per day. These two risk factors collectively accounted for 53.4% of the observed strokes. Specifically, higher maximum systolic blood pressure demonstrated a significant positive relationship with the likelihood of experiencing a stroke, as seen in Table 6.

Table 6. Predictors of stroke

Risk Factor	**Unadjusted OR (95% CI)**	***p*-Value**	**Adjusted OR (95% CI)**	***p*-Value**
Max systolic blood pressure	1.015 (1.001, 1.028)	0.035 *	1.046 (1.007, 1.086)	0.019 *
Number of cigarettes per day	1.025 (0.976, 1.077)	0.320	1.077 (0.966, 1.2)	0.182
Sensitivity	0			
Specificity	100%			
Total percentage	53.8%			
Nagelkerke R2	0.534			
p-value	0.017 *			

CI: confidence interval; OR: odds ratio. * $p < 0.05$. Overall model fit: Nagelkerke $R^2 = 0.534$, $p = 0.017$ (significant), indicating that overall model variables contributed to stroke risk.

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The binary logistic regression analysis showed a trend toward increased myocardial infarction risk with smoking, but this association did not reach statistical significance (adjusted p = 0.100). However, the overall model was significant (Nagelkerke R^2 = 0.236, p = 0.03), indicating that other risk factors in the model contributed to the prediction of myocardial infarction, as seen in Table 7. This suggests that while smoking remains an important cardiovascular risk factor, our sample size may have been insufficient to detect a significant association in this cohort.

Table 7. Predictors of myocardial infarction.

Risk Factor	**Unadjusted OR (95% CI)**	***p*-Value**	**Adjusted OR (95% CI)**	***p*-Value**
Number of cigarettes per day	1.035 (0.993, 1.080)	0.107	1.037 (0.993, 1.083)	0.1
Sensitivity	0			
Specificity	100%			
Total percentage	74.3%			
R-Nigel Kirk square	0.236			
p-value	0.03 *			

CI: confidence interval; OR: odds ratio. * $p < 0.05$. Overall model fit: Nagelkerke R^2 = 0.236, p = 0.03 (significant), indicating that overall model variables contributed to myocardial infarction risk.

Discussion. This study examines the impact of the COVID-19 pandemic on the long-term outcomes of patients who underwent endovascular stenting procedures before the pandemic. It is one of the first investigations of this nature conducted in Kazakhstan, exploring the association between COVID-19 infection, various risk factors, and the development of long-term complications following neuroendovascular interventions. Our findings underscore the significant association between severe COVID-19 and poorer long-term outcomes in stented patients. We observed that those with severe COVID-19 had the highest mortality rate and a markedly increased risk of myocardial infarction. These results align with existing evidence that severe COVID-19 can induce a hyperinflammatory and hypercoagulable state, exacerbating cardiovascular complications in vulnerable individuals. While stroke incidence was highest in the severe COVID-19 group, the association did not reach statistical significance, likely due to the limited sample size. Nevertheless, the observed trend suggests that severe group COVID-19 statistically significantly (p = 0.048) increased stroke incidence, suggesting that greater systemic inflammation and endothelial dysfunction in severe COVID-19 may contribute to increased cerebrovascular risk.

During the COVID-19 pandemic, primary stroke centers and healthcare facilities witnessed a significant decline in the number of stroke-related hospitalizations. This reduction was associated with a global decrease in various medical interventions, such as intravenous thrombolysis treatments and endovascular procedures. These procedures, including cerebral angiograms, carotid artery stent placements for both symptomatic and asymptomatic stenoses, as well as intracranial angioplasty and/or stent placements for stenosis, experienced notable decreases of 55.4% and 45%, respectively [10,11].

Despite the lack of confirmed COVID-19 infection, patients undergoing endovascular procedures during the pandemic experienced serious complications. For instance, the VERN and COVER international multicenter observational study conducted during the COVID-19 pandemic revealed a significant increase in mortality rates across all types of endovascular

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interventions, even though most participants did not exhibit SARS-CoV-2 infection [12]. Before the pandemic, the reported in-hospital mortality rate following carotid stenting was 1%, while during the pandemic, the in-hospital mortality rate in the COVER study was 10.7%. Additionally, some researchers have identified an elevated susceptibility to both arterial and venous thrombosis [7,13], as well as a higher risk of thromboembolism [14], cerebral venous thrombosis [15], and thrombotic microangiopathy [16] involving multiple organs in COVID-19 patients, including an increased likelihood of stent thrombosis. While some reports have suggested an association between certain COVID-19 vaccines and thrombotic complications, particularly thrombosis with thrombocytopenia syndrome following viral vector vaccines [17], large-scale studies have indicated that the absolute risk remains low and is outweighed by the protective effects of vaccination against severe COVID-19 complications [18]. These factors synergistically contributed to a disproportionately high intraluminal thrombus burden relative to mild underlying atherosclerotic plaque [19]. As a result, the authors recommended considering the possibility of deferring endovascular procedures [20].

The analysis of our results revealed that despite patients undergoing endovascular stenting before the pandemic, the long-term complications did not show statistically significant differences between the COVID-19 and control groups. While the rates of mortality, stroke, and myocardial infarction were similar across the two groups, we identified the impact of other risk factors. Specifically, we found that elevated blood pressure in the long term was significantly correlated with an increased probability of death and stroke. Furthermore, the number of cigarettes smoked per day exhibited a significant association with the likelihood of myocardial infarction, and higher stress levels demonstrated a significant relationship with the probability of mortality. The authors should specify how the stress level was calculated.

The results indicate that higher stress levels were associated with an increased risk of mortality, stroke, and myocardial infarction. Stress was evaluated using a standardized questionnaire that incorporated measures of perceived stress, sleep disturbances, and anxiety symptoms, in addition to hypertension spikes documented in medical records. Given that chronic stress is known to exacerbate endothelial dysfunction and systemic inflammation, these findings align with previous research linking stress to atherosclerotic disease progression [21].

The complications observed during a COVID-19 infection can be attributed to a cascade of pathological processes, including systemic inflammation throughout the body, impaired blood clotting, and local inflammation of the blood vessel lining. To mitigate the complications associated with systemic inflammation and coagulation disorders, some researchers have advocated for the surgical removal of atherosclerotic plaques in extracranial atherosclerotic lesions [16]. Nevertheless, the impact of COVID-19 on intracranial artery stenting continues to be an unexamined area of research.

Conversely, some researchers advocate for a “carotid artery stenting-first” approach during the COVID-19 pandemic, arguing that it is a safe and justified strategy. This perspective suggests that prioritizing CAS as the initial treatment may help mitigate the burden on healthcare facilities and ensure the timely and sufficient provision of care to patients, particularly when healthcare resources are constrained [22]. Existing research suggests that prioritizing carotid artery stenting as the initial treatment approach may be a safe and justified strategy, even during the COVID-19 pandemic. This perspective contends that a CAS-first approach for managing symptomatic carotid artery stenosis can remain a safe and effective intervention, particularly for patients concurrently affected by COVID-19 infection [14].

While this study aimed to evaluate the impact of COVID-19 on long-term outcomes after endovascular stenting, the actual results appear to reflect more the natural evolution of atherosclerosis rather than a direct consequence of COVID-19 infection. Similar findings have been extensively discussed in multiple other studies [23]. Given that the COVID-19 pandemic

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occurred more than three years after the initial procedures, its influence on vascular complications might be less significant than expected [24]. This suggests that the progression of atherosclerosis itself remains the dominant factor influencing long-term outcomes, rather than the added impact of COVID-19.

Emerging evidence suggests that hybrid immunity—resulting from both vaccination and natural infection—can lead to heightened immune responses, potentially contributing to inflammatory and thrombotic complications [25]. While our study did not collect data on vaccination or hybrid immunity status, this remains an important area for future investigation. Prospective studies incorporating immune response profiling could provide deeper insights into the role of hybrid immunity in patients with intracranial and extracranial atherosclerotic disease undergoing endovascular interventions [26].

Unfortunately, the existing literature lacks comprehensive, rigorous data examining the long-term outcomes and associated risk factors following stenting procedures for both intra- and extracranial arteries and how these factors may impact subsequent prognoses. This significant knowledge gap has been recognized by numerous researchers during the COVID-19 pandemic era. Factors such as resource limitations, service closures to curb virus transmission, and guidance to postpone surgeries until more urgent clinical presentations have likely hindered surgeons' ability to optimize patient care before interventions.

Study Limitations

This study has several limitations. First, its retrospective design restricts the ability to establish causal relationships. Second, the single-center design in Kazakhstan may limit external validity and generalizability to populations with different healthcare systems, demographics, or treatment protocols. Third, the relatively small sample size, while adequate based on power analysis, limits detailed subgroup analyses, such as distinguishing between intracranial and extracranial stenting outcomes. Expanding the cohort by including patients treated in 2018 and 2019 and reducing follow-up intervals to 3 months, 1 year, and 3 years may improve statistical power and provide more structured insights into vascular complications.

Fourth, while the patient questionnaire was specifically developed for this study, it has not been externally validated, which may impact broader applicability. Fifth, the lack of vaccination data prevents analysis of vaccine-related vascular outcomes, such as thrombotic complications or hybrid immunity effects. Sixth, the study may have been underpowered to detect smaller but clinically meaningful associations between smoking and cardiovascular events, warranting further investigation with larger cohorts.

Another key consideration is the potential impact of post-COVID syndromes, which can emerge 3 weeks to 1 year after acute SARS-CoV-2 infection. Since these conditions may contribute to vascular complications, future research should systematically track post-COVID symptoms to assess their influence on long-term cerebrovascular health. Lastly, the timing of COVID-19 infection relative to major adverse events was not consistently available, limiting the ability to analyze event clustering around the infection period.

Implications for Future Research

Future studies should incorporate detailed vaccination data to assess the impact of vaccination on thrombotic risks in patients undergoing neurovascular stenting. A direct comparison of outcomes between vaccinated and unvaccinated individuals could help elucidate this relationship. Additionally, the role of hybrid immunity as a potential modifier of long-term cerebrovascular risk warrants further investigation.

Conclusion. The analysis revealed that the rates of mortality, stroke, and myocardial infarction did not differ significantly between the COVID-19 group and the control group. However, elevated blood pressure, increased cigarette consumption, and higher stress levels were identified as significant predictors of long-term adverse outcomes. To better comprehend

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the impact of COVID-19 on extra- and intracranial atherosclerotic stenting, more rigorous and prospective data are required. The authors should specify how the stress level was calculated.

No conflicts of interest have been declared
Authors' contributions
Concept development - MA, BS, MM
Execution - SM, AM, MB
Processing of results - AZ, SM, DS
Scientific interpretation of the results - AM, RB, MM
Article writing - SM, AM
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COVID-19-ДЫҢ ПАНДЕМИЯҒА ДЕЙІН ЖАСАЛҒАН ЭКСТРА- ЖӘНЕ ИНТРАКРАНИАЛДЫҚ АТЕРОСКЛЕРОЗДЫ СТЕНТТЕУДІҢ ҰЗАҚ МЕРЗІМДІ САЛДАРЛАРЫНА ӘСЕРІ: ҮШІНШІ ДЕҢГЕЙЛІ МЕКЕМЕНІҢ ТӘЖІРИБЕСІ

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Түйіндеме

Кіріспе. Интра- және экстракраниалдық атеросклероздық стеноз кезінде эндоваскулярлық стенттеу — минималды инвазивті процедура болғанымен, COVID-19 инфекциясынан кейінгі ұзақ мерзімді асқынулар бойынша жан-жақты зерттеулер жеткіліксіз. COVID-19-бен ауырған науқастарда стент тромбозы, инсульт, миокард инфарктісі және өлім-жітімнің артуы мүмкін болғандықтан, бұл науқастарда стенттеуден кейінгі ұзақ мерзімді нәтижелерді зерттеу қоғамдық денсаулық сақтау үшін маңызды. Бұл зерттеу COVID-19 инфекциясынан кейін интра- және экстракраниалдық артерияларда атеросклероздық стенозбен эндоваскулярлық стенттеуден кейінгі жағымсыз ұзақ мерзімді нәтижелерді зерттеудің жеткіліксіздігін шешуге бағытталған.

Материалдар мен әдістер. Бұл ретроспективті зерттеу 2016–2017 жылдары пандемияға дейін Қазақстан Республикасы Президенті Іс Басқармасының Орталық клиникалық ауруханасының Нейрохирургия бөлімінде интра- немесе экстракраниалдық атеросклероздық стенттеу жүргізілген науқастар деректерін талдады. Негізгі нәтижелер — стент тромбозы, ишемиялық инсульт, миокард инфарктісі және жалпы өлім-жітім жиілігі.

Нәтижелер. Зерттеуге барлығы 81 қатысушы кірді, олардың 32-сінде COVID-19 расталған (ПТР, антиген және антидене сынамалары арқылы) және олар COVID-19 тобына енді, қалған 49 қатысушы бақылау тобын құрады. Талдау COVID-19 және бақылау топтары арасында өлім-жітім, инсульт және инфаркт жиілігі бойынша статистикалық маңызды айырмашылықтарды анықтамады. Дегенмен, артериялық гипертензия өлім мен инсульттің елеулі болжаушысы ретінде анықталды. Бинарлық логистикалық регрессиялық талдау темекі шегудің жүрек-қантамырлық қауіптерін арттыруға бейімділік бар екенін көрсетті, бірақ статистикалық маңыздылыққа жеткен жоқ. Темекі шегу модификацияланатын негізгі қауіп факторы болғанымен, оның

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стенттеуден кейінгі нақты әсерін анықтау үшін үлкен көлемді зерттеулер қажет.

Қорытынды. COVID-19 инфекциясы ұзақ мерзімді өлім-жітім, инсульт немесе миокард инфарктісі деңгейіне айтарлықтай әсер етпегенімен, артериялық гипертензия, темекі шегу және созылмалы стресс нашар нәтижелермен байланысты болды. Бұл нәтижелер эндоваскулярлық стенттеуден өткен науқастарда жүрек-қантамырлық қауіп факторларын басқарудың маңыздылығын көрсетеді.

Түйінді сөздер: атеросклероз; инсульт; қауіп факторлары; интракраниалдық стеноз; экстракраниалдық стеноз; COVID-19; қоғамдық денсаулық; стент ішілік тромбоз

ВЛИЯНИЕ COVID-19 НА ОТДАЛЁННЫЕ ПОСЛЕДСТВИЯ ЭКСТРА- И ИНТРАКРАНИАЛЬНОГО АТЕРОСКЛЕРОТИЧЕСКОГО СТЕНТИРОВАНИЯ, ВЫПОЛНЕННОГО ДО ПАНДЕМИИ: ОПЫТ ТРЕТИЧНОГО УЧРЕЖДЕНИЯ

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Аннотация

Введение. Эндоваскулярное стентирование при атеросклеротическом стенозе интра- и экстракраниальных артерий является малоинвазивной процедурой, однако комплексные исследования отдалённых осложнений после перенесённой COVID-19-инфекции в настоящее время отсутствуют. С учётом потенциального увеличения частоты тромбоза стента, инсульта, инфаркта миокарда и смертности у пациентов, перенёсших COVID-19, изучение долгосрочных исходов стентирования при атеросклеротическом стенозе представляет важность для системы общественного здравоохранения. Настоящее исследование восполняет нехватку данных о неблагоприятных отдалённых последствиях эндоваскулярных вмешательств у таких пациентов.

Материалы и методы. Ретроспективный анализ выполнен на базе данных третичного медицинского учреждения — Ортопедического клинического госпиталя АО «Центральная клиническая больница» (отделение нейрохирургии), где в 2016–2017 гг. до пандемии COVID-19 проводилось экстра- или интракраниальное стентирование по поводу атеросклероза. Основными исходами были тромбоз стента, ишемический инсульт, инфаркт миокарда и общая смертность.

Результаты. В исследование включено 81 пациент: 32 пациента с подтверждённым COVID-19 (ПЦР, антиген, антитела) — COVID-группа; 49 пациентов — контрольная группа. Анализ не выявил статистически значимых различий в уровне смертности, инсульта и инфаркта миокарда между группами. Однако артериальная гипертензия

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оказалась значимым предиктором летальности и инсульта. Бинарная логистическая регрессия показала тенденцию к повышенному риску при курении, но статистической значимости достигнуто не было. Несмотря на это, курение остаётся модифицируемым фактором риска, требующим дальнейшего изучения.

Заключение. Перенесённая COVID-19 инфекция не показала достоверного влияния на отдалённые исходы, такие как смертность, инсульт и инфаркт, повышенное артериальное давление, курение и стресс ассоциировались с ухудшением прогноза. Полученные данные подчёркивают необходимость эффективного контроля факторов сердечно-сосудистого риска у пациентов, перенёсших стентирование.

Ключевые слова: атеросклероз; инсульт; факторы риска; интракраниальный стеноз; экстракраниальный стеноз; COVID-19; общественное здравоохранение; тромбоз стента