Research Article / *Araştırma Makalesi*

Ege Journal of Medicine / *Ege Tıp Dergisi* 2026; 65 (3): 394-402

The influence of basilar artery morphology on the development of pontine infarctions

Baziler arter morfolojisinin pontin infarkt gelişimi üzerine etkisi

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ABSTRACT

Aim: Variations in the vertebrobasilar arterial system can influence cerebral hemodynamics and predispose to vascular disease. Because the inner ear is supplied by the vertebrobasilar circulation, patients with isolated vertigo may have increased posterior circulation stroke risk. This study compared basilar artery morphology between patients with isolated vertigo and those with pontine infarction.

Materials and Methods: We retrospectively analyzed 80 patients admitted with acute isolated PI and 59 controls presenting with isolated vertigo between September 2019 and August 2023. Demographics, vascular risk factors, neuroimaging features, and etiologies were reviewed. BA configuration, basilar artery length, basilar artery bending distance, vertebral artery dominance, and bulbar contact were assessed.

Results: Hypertension, diabetes mellitus, hyperlipidemia, prior posterior circulation stroke, and smoking were significantly more prevalent in the PI group ($p<0.05$). The C-shaped BA configuration was the most common in both groups and was not associated with PI. Neither BAL nor BABD correlated significantly with PI. In contrast, VA bulbar contact was markedly more frequent in the PI group ($p<0.001$). The dominant VA tended to displace the BA laterally toward the contralateral side.

Conclusions: Most PIs appear related to small vessel disease. Although BA morphological alterations are detectable in PI, similar changes are also common in isolated vertigo, indicating that BA variants are not specific to infarction. Larger, population-based studies are needed to clarify the contributions of genetic, racial, and other factors to BA morphology and its clinical relevance.

Keywords: Stroke, pontine infarction, artery morphology, basilar artery

ÖZ

Amaç: *Vertebrobaziler arteriyel sistemdeki varyasyonlar serebral hemodinamiği etkileyerek vasküler hastalıklara neden olabilir. İç kulak kanlanması da vertebrobaziler sistemden kaynaklandığı için izole vertigosu olan hastalar arka sistem infarktı geçirme riski taşımaktadır. Çalışmamız, izole vertigo şikayeti olan hastalar ile izole pontin infarkt geçiren hastalar arasında baziler arter morfolojisini karşılaştırmayı amaçlamaktadır.*

Gereç ve Yöntem: *Eylül 2019 ile Ağustos 2023 tarihleri arasında akut izole pontin infarkt tanısı alan 80 hastanın ve izole vertigo nedeni ile tetkik edilen 59 hastanın verileri retrospektif olarak analiz edildi. Demografik özellikler, vasküler risk faktörleri, nörogörüntüleme bulguları ve etiyolojiler kaydedildi. Baziler arter konfigürasyonu, baziler arter uzunluğu, baziler arter bükülme mesafesi, vertebral arter dominansı ve bulber temas değerlendirildi.*

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Application date: 21.01.2026 Accepted: 08.04.2026

Bulgular: *Hipertansiyon, diyabetes mellitus, hiperlipidemi, geçirilmiş arka sistem infarktı ve sigara kullanımı infarkt grubunda anlamlı derecede daha sıktı (p<0,05). Baziler arterde C-şeklinde konfigürasyon her iki grupta da en yaygın tipti ve iskemi ile ilişkili değildi. Baziler arter uzunluğu ve bükülme mesafesi infarkt gelişimi ile anlamlı bir korelasyon göstermedi. Buna karşılık, vertebral arterin bulber teması infarkt grubunda belirgin ölçüde sıktı (p<0,001). Dominant vertebral arterin baziler arteri karşı tarafa doğru ittiği gözlendi.*

Sonuç: *Pontin infarktların çoğu küçük damar hastalığıyla ilişkili görünmektedir. Bu hastalarda baziler artere ait morfolojik değişiklikler saptanabilse de benzer değişiklikler izole vertigo olgularında da yaygındır; bu durum baziler arter varyasyonlarının pontin infarktlara spesifik olmadığını göstermektedir. Baziler arter morfolojisine genetik, ırksal ve diğer etkenlerin katkılarını ve bunun klinik önemini netleştirmek için daha büyük, toplum temelli çalışmalara ihtiyaç vardır.*

Anahtar Sözcükler: *İnme, pontin infarkt, arteriyel morfoloji, baziler arter*

INTRODUCTION

Pontine infarctions (PI) represent approximately 7% of all ischemic strokes and account for 10–15% of strokes occurring within the posterior circulation (1). Clinically, PI can manifest across a broad spectrum, ranging from mild symptoms such as vertigo to severe neurological impairments. The most common etiological factor implicated in PI is small vessel disease (2). Well-established vascular risk factors such as hypertension (HT), diabetes mellitus (DM), hyperlipidemia (HL), coronary artery disease (CAD), and smoking significantly contribute to the development of ischemic stroke (3-5). Flow asymmetry and diameter discrepancies between the vertebral arteries (VAs) are frequently observed, with left-sided dominance being the most common pattern. Such asymmetries can result in uneven hemodynamic forces within the basilar artery (BA), often leading to lateral displacement or bending of the artery over time. Notably, increased discrepancies in VA caliber, along with heightened tortuosity and curvature of the BA, may promote turbulent flow dynamics. This hemodynamic disturbance has been implicated as a significant contributor to the development of atherosclerosis (6,7). Additionally, the posterior circulation is thought to be more vulnerable to atherosclerotic changes compared to the anterior circulation (8). These vascular morphological variations have been recognized as risk factors for stroke but have also been shown to correlate with the topographical distribution of infarcts (6,9-11).

Unexplained vertigo was defined as vertiginous symptoms occurring in the absence of identifiable causes. Previous studies have highlighted the potential role of dolichoectasia and arterial tortuosity in contributing to unexplained vertigo or dizziness (12,13). Notably, several reports have documented a correlation between aging, increased basilar artery tortuosity, and the occurrence of isolated vertigo, suggesting a possible mechanistic link (9,13).

The present study aims to examine the extent to which morphological variations of the BA and comorbid conditions contribute to the development of unexplained vertigo or PI and whether the anatomical features, combined with etiological risk factors, can be used to predict the topographical distribution of PI.

MATERIALS and METHODS

Study design and patient selection

This retrospective study included 80 patients admitted to the stroke unit with acute isolated pontine infarction and 59 control patients evaluated for unexplained vertigo in the neurology outpatient clinic between September 2019 and August 2023. Demographic characteristics, vascular risk factors, and computed tomography (CT) angiography findings were reviewed for all participants. BA morphology was assessed and classified in both groups using CT angiography. In the PI group, additional evaluations included infarct localization on cranial magnetic resonance imaging (MRI) and etiological classification of the stroke. Exclusion criteria were as follows: patients under 18 years of age, pregnant individuals, those with incomplete clinical or imaging data, inability to undergo CT angiography, presence of BA occlusion, pronounced tortuosity or dolichoectasia of the BA on imaging, or infarctions located outside the pons.

Diagnosis of ischemic stroke

The diagnosis of ischemic stroke was established based on clinical presentation and radiological

evaluations, including cranial CT/ MRI, and CT angiography. The classification of ischemic stroke subtypes was performed according to the Trial of Org 10172 in Acute Stroke Treatment (TOAST) criteria (14). Stroke severity was assessed using the National Institutes of Health Stroke Scale (NIHSS) at the time of admission and again within 24 hours (15). Stroke progression was defined as an increase of more than 4 points on the NIHSS. Functional outcomes were evaluated using the modified Rankin Scale (mRS) (16).

Diagnosis of unexplained vertigo

Vertigo is broadly categorized into central and peripheral etiologies. Central vertigo is attributed to disorders of the central nervous system, such as stroke, demyelinating diseases, or space-occupying lesions. The most common causes of peripheral vertigo include benign paroxysmal positional vertigo (BPPV), Ménière's disease, vestibular neuritis, and labyrinthitis. In this study, unexplained vertigo was defined as vertiginous symptoms in the absence of both identifiable central and peripheral causes. Neurological examinatıon and brain MRI were normal for all unexplained vertigo patıents.

Radiological assessment

All patients underwent brain CT, diffusion-weighted MRI, and CT angiography. These imaging studies were independently reviewed by two board-certified neurologists and one specialist radiologist. MRI scans were performed at the time of admission using either a 1.5 Tesla or 3.0 Tesla scanner. Specifically, MRI imaging was conducted with a 1.5 T system (MAGNETOM, Siemens Healthcare, Erlangen, Germany) and a 3.0 T system (MAGNETOM Lumina, Siemens Healthcare, Erlangen, Germany). Diffusion-weighted imaging parameters were as follows: repetition time (TR)/echo time (TE) = 6600/89 ms; b-value = 1000 s/mm²; field of view (FOV) = 230 × 230 mm; matrix size = 192 × 192; slice thickness = 5 mm; number of excitations (NEX) = 3. CT and CT angiography scans were obtained using a 128-slice CT scanner (GE Lightspeed, GE Medical Systems). CT angiographic source images were reconstructed with a slice thickness of 1 mm in axial, sagittal, coronal, and oblique planes to facilitate comprehensive evaluation of vascular morphology Arterial Morphology A comprehensive morphological analysis of the BA was conducted using several key parameters. These included measurements of the artery's length and diameter, which are essential for characterizing its overall structure. Based on CT angiography findings, BA morphology was classified into four categories: C-type (curving to the left), reverse C-type (curving to the right), S-type (with multiple bends), and I-type (straight, without significant curvature) (As shown in Figure-1) (9).

The basilar artery length (BAL) was defined as the linear distance from the origin of the BA at the vertebrobasilar junction to its bifurcation. The basilar artery bending distance (BABD) was measured as the perpendicular distance between the midpoint of the BAL and the furthest point of curvature, reflecting the extent of vascular bending (As shown in Figure-2) (9,32).

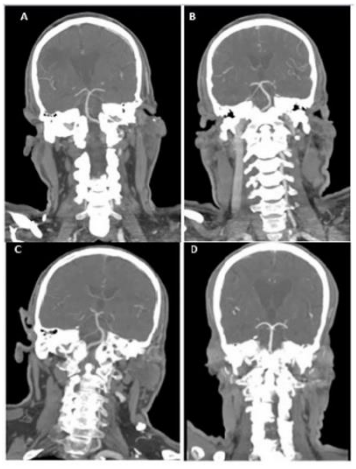

Figure-1. Basilar artery morphology according to CT angiography images, A: "C" type morphology, B: "Reverse C" type morphology, C: "S" type morphology, D: "I" type morphology

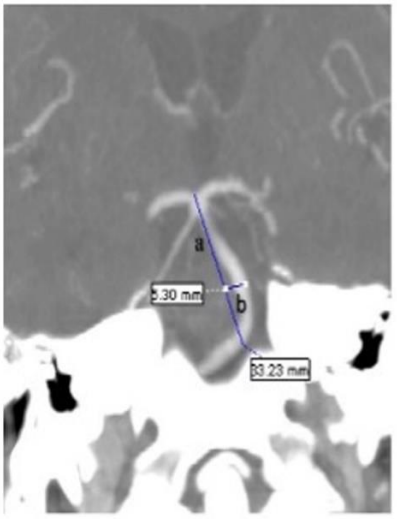

Figure-2. Measurement of basilar artery bending distance (BABD) and Length of the basilar artery (BAL) parameters on CT angiography, a: BAL b: BABD

Vertebral artery tortuosity was also assessed. Tortuosity refers to the degree of arterial twisting or coiling as the VA ascends through the cervical spine toward the brain. Due to the absence of a universally accepted quantitative method for tortuosity measurement, we adopted a commonly used qualitative approach—based on visual inspection and the number of vascular loops—consistent with prior literature (17,18).

Vertebral artery diameters were measured at 3 mm intervals starting from the vertebrobasilar junction, and the mean of these values was recorded as the representative VA diameter. Basilar artery diameter was measured at the mid-pons level, which is considered a reliable and reproducible anatomical landmark (19). Vertebral artery dominance was defined by a side-to-side diameter difference exceeding 0.3 mm (9). Ectasia of the vertebrobasilar system was defined as a BA diameter greater than 4.5 mm at its widest point, in line with established criteria (20-22). Additionally, the study investigated whether the VA exerted compressive effects on the medulla oblongata, potentially resulting in structural deformation. These parameters were analyzed collectively to construct a detailed morphological profile of the vertebrobasilar system.

This study was approved by the Ethics Committee of İzmir Katip Çelebi University, Atatürk Training and Research Hospital (Approval Number: 0048, Date: 23/02/2023).

Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics Standard Concurrent User Version 26 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as frequency (n), percentage (%), mean ± standard deviation ($\overline{x}$ ± SD), median (M), minimum, and maximum values. The distribution of numerical variables was assessed using the Shapiro-Wilk test for normality. Homogeneity of variances was tested using Levene's test. For comparisons between two independent groups, the Independent Samples t-test was used when assumptions of normality were met; otherwise, the Mann-Whitney U test was applied. In comparisons involving three or more groups, the Kruskal-Wallis H test was employed, as the data did not satisfy the assumptions of normality. Categorical variables were compared using the Pearson chi-square test or Fisher's exact test, depending on expected cell frequencies. The relationship between various parameters and the risk of pontine infarction was evaluated using logistic regression analysis. Correlations between continuous variables were analyzed using Spearman's rho correlation coefficient. A p-value of less than 0.05 was considered indicative of statistical significance.

RESULTS

Our study included 80 patients diagnosed with acute isolated PI and 59 control patients with unexplained vertigo. The age range of the PI group was 24–89 years (mean age 65.56 ± 13.45), while the control group ranged from 36–79 years (mean age 62.41±10.79). No significant differences were observed in the age and gender distributions between the two groups.

The PI group exhibited a higher prevalence of HT, DM, HL, and smoking ($p<0.05$). In contrast, the occurrence of CAD was lower in the PI group ($p<0.05$). Specifically, the risk of developing PI was increased by 7.191-fold in individuals with DM, 2.944-fold in those with HT, 3.528-fold in those with HL, and 6.572-fold in smokers ($p<0.001$; $p=0.039$; $p=0.012$; $p=0.003$, respectively). A negative correlation was observed between CAD and the risk of PI ($p<0.001$). Additionally, a higher incidence of prior posterior circulation infarction was noted in the PI group ($p=0.015$). No significant association was found between atrial fibrillation (AF) and the risk of developing PI (As shown in Table-1).

The morphological characteristics of the VB system were compared between the PI and control groups. C-type BA morphology was more frequently observed in both groups. Right vertebral artery dominance was noted in 71.4% of patients with BA deviation to the left, whereas left VA dominance was detected in 53.3% of patients with BA deviation to the right. However, BA morphology, BAL, BABD, VA dominance, and tortuosity were not significantly associated with stroke occurrence. VBE was detected in 6 patients (10.2%) in the control group (n:59) and in 27 patients (33.8%) in the PI group (n:80). Although the incidence of vertebrobasilar ectasia (VBE) was low in both groups, its presence was significantly correlated with the development of PI ($p=0.001$).

Furthermore, the incidence of bulbar contact of the VA was significantly higher in the PI group ($p<0.001$). The relationship of BA morphology with vertebral artery is summarized in Table-2.

Table-1. Logistic Regression Analysis for Pontine Infarction

	β	**se**	**Wald**	**df**	***p***	**Exp (*β*)**
	-2.145	0.525	16.680	1	**<0,001**	0.117
Diabetes mellitus	1.973	0.522	14.262	1	**<0,001**	7.191
Hypertension	1.080	0.524	4.241	1	**0,039**	2.944
Hyperlipidemia	1.261	0.501	6.343	1	**0,012**	3.528
CAD	-2.924	0.826	12.530	1	**<0,001**	0.054
Smoking	1.883	0.643	8.562	1	**0,003**	6.572
Atrial fibrillation	0.323	0.856	0.142	1	0,706	1.381

Table-2. The releationhip of BA morphology with vertebral artery

	Basilar Artery Morphology				**Test Statistics**	
	C	Reverse C	S	I	χ^2	p
Vertebral Artery Dominance						
No	38 (59,4)	12 (50,0)	5 (38,5)	24 (63,2)	9,607	0,131
Right	7 (10,9)	8 (33,3)	4 (30,8)	4 (10,5)		
Left	19 (29,7)	4 (16,7)	4 (30,8)	10 (26,3)		
Vertebral Artery Tortuosity						
No	15 (23,4)[a]		2 (15,4)[a]	23 (60,5)[b]	27,004	**<0,001**
Right	30 (46,9)[a]	3 (12,5)[a]	7 (53,8)[a]	7 (23,7)[a]		
Left	19 (29,7)[ab]	8 (33,3)[a]	4 (30,8)[ab]	6 (15,8)[a]		
		13 (54,2)[b]				
Vertebral Artery Contact						
No	40 (62,5)[a]	13 (54,2)[a]	5 (38,5)[a]	20 (54,1)[a]	11,839	**0,049**
Yes	20 (31,3)[a]	7 (29,2)[a]	5 (38,5)[a]	17 (45,9)[a]		
Deformation	4 (6,3)[ab]	4 (16,7)[ab]	3 (23,1)[b]	0 (0,0)[a]		

DISCUSSION

Pontine infarctions account for approximately 10-15% of strokes in the posterior circulation. Understanding the underlying etiological contributors is crucial for effective treatment planning and prognostic assessment. Patients diagnosed with unexplained isolated vertigo are at increased risk of stroke. It has been shown that approximately 35% experience a stroke within the first year following vertigo onset, and about 62% do so within two years (23). Therefore, the control group comprised patients who had not yet experienced a stroke but were considered to be at risk.

Basilar artery demonstrate varying degrees of curvature in both healthy individuals and those with cerebrovascular disease (9). In cases of recurrent and unexplained isolated vertigo episodes, aberrant VB arterial morphology has been implicated as a contributing factor (24).

Previous studies have identified DM, HT, HL, and smoking as key risk factors for the development of PI, which can also lead to morphological alterations in the posterior circulation (25-27). Research has shown that DM, in particular, more frequently affects the posterior circulation arteries, contributing to increased risk of infarction in this area (25,28). Wu et al. (2022) demonstrated that DM is an independent risk factor for the development of PI (27). Another study has reported that DM selectively impacts the pons, a phenomenon attributed to various vascular plasticity mechanisms, cyclic sympathetic innervation, and autonomic dysfunction associated with DM (25,26).

Our study corroborates these findings by showing an increased incidence of PIs in the presence of vascular risk factors such as DM, HT, HL, and smoking. Specifically, we found that the risk of developing PI was significantly elevated in individuals with these factors. However, we also found that CAD was not a significant risk factor for the development of PI in our cohort. This result may be attributable to the non-homogeneity of the patient group in terms of CAD. Furthermore,

individuals with CAD may be undergoing specific treatments or lifestyle modifications that mitigate their risk of experiencing PI.

In a study by Zheng et al., it was suggested that parameters such as BA morphological types and VA diameter differences contribute to plaque formation in the BA (29). BA morphology has been identified as a critical determinant of stroke in research focusing on posterior circulation strokes (30). BA is classified into several morphological types, including C, reverse C, S, and I types (11). The most commonly observed morphological variation across studies is the C-type, which was also the most prevalent in our study (9,10,31).

In the study by Zhang et al., it was demonstrated that a BABD greater than 3.77 mm is a significant risk factor for PI (9). However, in our study, no significant difference was found in BABD between the two groups. The average BABD was 4.44 mm in the control group, compared to 4.31 mm in the PI group. This discrepancy may be due to the presence of patients with similar age and vascular risk factors in both groups, potentially blurring the relationship between BABD and PI. Literature suggests that elongation of the BA is influenced by aging, whereas its curvature may be influenced by various other factors. Furthermore, differences in blood flow from the vertebral arteries are thought to contribute to the elongation of the BA, independent of age-related factors (32).

Additionally, a relationship has been identified between BA curvature and migraine with aura, potentially linked to endothelial dysfunction and microembolism formation (33). It is also postulated that the morphological and morphometric characteristics of the VB system vary across different ethnic groups. A study conducted on Caucasian twins indicated that the diameter and length of the VB arteries may be influenced by both genetic and environmental factors (34). In our study, no significant relationship was observed between BABD and age, which aligns with the findings of Nishikata et al. (32).

In our study, unlike previous studies, no significant impact of BA morphological features, BABD, or BAL on the development of PI was identified. This discrepancy may be attributed to the complex interplay of factors influencing the posterior circulation, such as genetic predispositions, individual anatomical variations, and susceptibility to various vascular diseases.

Intracranial dolichoectasia, characterized by the dilatation (ectasia) and increased length or tortuosity (dolichosis) of intracranial arteries, particularly affects the BA, which is the most commonly affected intracranial artery (35,36). The prevalence of dolichoectasia in VB arteries varies between 7.6% and 18.8% in stroke patients (37,38). In cohort studies, it has been shown that VBE is an independent risk factor for stroke, increasing the risk of posterior system pathologies (39). Hypotheses regarding the role of VBE in stroke development include slowed blood flow, mural thrombus or atherosclerotic plaque formation, and arterial deformation (31,40). Kumral et al. found that infarcts were predominantly located in the pons in the presence of VBE (41). Additionally, a prospective study by Passero et al. found that 37.8% of patients with VBE developed ischemic stroke during the follow-up period (20). In our study, we also found a significant association between VBE and the occurrence of PI, which is consistent with previous findings.

In line with the literature, left VA dominance was observed in our study (30,42). Several studies have suggested that VA dominance leads to a shift in the direction of the BA to the contralateral side (9,30,43,44). VA dominance is thought to create asymmetry in blood flow, which can result in mechanical changes that influence BA morphology, including increased BABD (9). Nishikata et al. proposed that BA flexion might be caused by the contralateral dominant flow from the VA (32). Consistent with the literature, we found that VA dominance influenced the direction of BA deviation in both groups. Specifically, right VA dominance led to a leftward deviation of the BA, while left VA dominance caused the BA to deviate to the right. Interestingly, the number of patients without VA dominance was higher in both the PI and control groups, suggesting that VA dominance alone may not be the sole factor driving BA curvature. This observation highlights the potential influence of other factors, such as the degree of tortuosity or the presence of other vascular abnormalities, on the morphology of the BA. In our study, although VA tortuosity was not found to be directly associated with the development of PI, it emerged as an important indicator for disease progression in cases where PI had already developed. VA tortuosity can result in compression and deformation of the medulla oblongata, potentially influencing neurological

outcomes. The literature offers differing viewpoints on the clinical impact of this condition. One study suggests that VA contact with the medulla oblongata may lead to PI, while another claims that such contact does not affect the patient's neurological status (45,46). Our findings indicate that while VA contact with the medulla oblongata was more commonly observed in patients with PI, it did not have a significant impact on clinical progression. This suggests that while the anatomical interaction between the VA and medulla may be present, other factors, such as vascular risk factors or underlying small vessel disease, may play more substantial roles in determining the progression of infarction.

Our study supports the established understanding that small vessel disease is a frequent contributor to the etiology of PIs. This reinforces the critical importance of controlling vascular risk factors, particularly in patients who may be at higher risk for developing small vessel disease. Although arterial morphological changes, such as those observed in the BA, may significantly contribute to stroke pathophysiology, there is a clear need for further studies to develop standardized, clinically applicable criteria for morphological assessment.

Our study has some limitations. First, it has a retrospective, single-center design with a moderate sample size. Second, there is no universally accepted quantitative method for evaluating vertebral artery tortuosity, therefore this may involve some subjectivity. Furthermore, it is not possible to measure hemodynamic changes.

CONCLUSION

Our study found that atherosclerotic risk factors — specifically DM, HT, HL, and smoking— were significantly more prevalent in the PI group, indicating their role in the pathogenesis of stroke. However, the morphology of the basilar artery did not show a clear correlation with the development of stroke, suggesting that BA morphology may not directly influence stroke risk. These findings underscore the need for stringent control of vascular risk factors in stroke prevention, as they may be more influential than morphological changes in the basilar artery. Furthermore, tortuosity was not observed as a feature of small vessel disease in our study. The presence of tortuosity in individuals without traditional atherosclerotic risk factors may serve as an early warning sign to explore alternative etiologies beyond small vessel disease.

For patients with unexplained isolated vertigo, the symptoms may indeed be related to perfusion changes caused by morphological alterations in the BA. This highlights the potential role of vascular morphology in understanding the pathophysiology of vertigo, particularly when no clear peripheral or central cause can be identified.

Funding: This research received no external funding.

Conflicts of interest: Authors declared no conflict of interest.

The Ethics Committee of İzmir Katip Çelebi University, Atatürk Training and Research Hospital approved the study (Ethics Approval Number: 0048, Date: 23/02/2023).

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