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RESEARCH

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The Relationship between Vascular Elasticity and Cognitive Function in Medical Students

Mochammad Nafi Al Munthoharri^{1a}, Nurfitri Bustamam^{2b*}, Maulidya Ayudika Dandanah^{3c}, Marlina Dewiastuti^{4d}

¹ Undergraduate Medical Program, Universitas Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia

² Department of Physiology, Faculty of Medicine Universitas Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia

³ Department of Thoracic Cardiovascular Surgery, Faculty of Medicine Universitas Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia

⁴ Department of Internal Medicine, Faculty of Medicine Universitas Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia

^a Email address: 2110211087@mahasiswa.upnvj.ac.id

^b Email address: nurfitri.bustamam@upnvj.ac.id

^c Email address: ayudika84@gmail.com

^d Email address: marlina_malik@upnvj.ac.id

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Abstract

Vascular stiffness is a known risk factor for cognitive impairment, particularly in the elderly. However, its impact on younger populations, such as medical students, remains less explored. Early subtle changes in vascular health may affect cognitive domains necessary for academic performance. This study aimed to examine the relationship between vascular elasticity and cognitive function in medical students. A cross-sectional study design was conducted using simple random sampling. Cognitive function was assessed using the Mini-Mental State Examination (MMSE), Digit Symbol Substitution Test (DSST), and Digit Span Test (DST). Vascular elasticity was measured using the SA-3000P accelerated photoplethysmography analyzer and categorized as suboptimal, normal, or optimal. The sample size was 51 subjects who met the following criteria: non-smokers with low to moderate stress levels, and no history of head trauma, brain haemorrhage, narcotics use, diabetes mellitus, or hypertension. The Mann-Whitney test revealed a significant difference in MMSE scores between groups with different levels of vascular elasticity ($p = 0.042$). The Chi-square test also revealed a significant difference in DSST between groups with different levels of vascular elasticity ($p = 0.023$; $PR = 6.667$; $CI = 0.969 - 45.857$). However, no significant difference was found in DST scores ($p = 0.072$). In conclusion, this study found a significant relationship between vascular elasticity and cognitive function in medical students, suggesting that early vascular changes may influence cognitive function even in young, healthy individuals.

Keywords: Cognitive Function, Medical Students, Vascular Elasticity.

Corresponding Author:

Nurfitri Bustamam

Department of Physiology, Faculty of Medicine Universitas Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia

Email: nurfitri.bustamam@upnvj.ac.id



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1. INTRODUCTION

Cognitive function comprises a range of mental processes that allow individuals to acquire, process, store, and apply information for reasoning, problem-solving, and decision-making. In academic and professional settings, cognitive performance is largely driven by memory, executive function, and processing speed, which are essential for learning, adapting to complex tasks, and responding efficiently to environmental demands (Cristofori et al., 2019). These cognitive domains are key determinants of educational attainment, occupational performance, and long-term health outcomes (Djajasaputra & Halim, 2019; Fu et al., 2018).

Although cognitive impairment has traditionally been studied in older populations, there is growing recognition of the need to examine early vascular cognitive interactions in younger adults, as vascular alterations may occur long before overt cognitive decline becomes clinically apparent. This issue is especially relevant for medical students, a population characterized by high cognitive demands. Medical training requires sustained attention, rapid information processing, complex decision making, and robust working memory functions that are highly dependent on optimal vascular and cognitive health (Djajasaputra & Halim, 2019; Fu et al., 2018). Moreover, medical students are frequently exposed to lifestyle-related risk factors at a young age, including prolonged sedentary behavior, high academic stress, irregular dietary patterns, insufficient physical activity, and inadequate sleep (Ayudia et al., 2025). These factors are known to adversely affect vascular elasticity and may contribute to changes in cognitive performance. Therefore, investigating this population provides a valuable opportunity to identify early, subclinical associations between vascular health and cognition, before irreversible impairment develops. Recent studies among Indonesian medical students have reported suboptimal vascular elasticity associated with low muscle-to-visceral fat ratios (Ayudia et al., 2025). Other investigations have demonstrated poorer cognitive performance among students with prehypertension, obesity, and increased visceral fat, conditions linked to systemic inflammation and impaired cerebral perfusion (Budiman et al., 2024; Widyaningrum et al., 2024). Beyond individual academic outcomes, medical students represent the future healthcare workforce. Thus, preserving their vascular and cognitive health is essential not only for personal academic performance but also for ensuring the long-term quality of healthcare delivery. This focus is consistent with national priorities, including Indonesia's Golden Indonesia 2045 vision, which emphasizes the development of a healthy and productive young population.

Despite increasing interest in the relationship between vascular elasticity and cognition, most existing studies, both nationally and internationally, have focused on middle-aged or older adults and have relied predominantly on the Mini-Mental State Examination (MMSE) to assess cognitive function (Iulita et al., 2018). While MMSE is useful for detecting global cognitive impairment, it may lack sensitivity in younger, high-functioning populations and may not adequately capture domain-specific changes, particularly in processing speed and working memory. Consequently, the relationship between vascular elasticity and multidimensional cognitive function in young adults remains insufficiently explored. To address this gap, the present study aimed to examine the relationship between vascular elasticity and cognitive function in medical students at Universitas Pembangunan Nasional Veteran Jakarta. Cognitive function was assessed using a comprehensive battery combining the MMSE, the Digit Symbol Substitution Test (DSST), and the Digit Span Test (DST), enabling a more sensitive and multidimensional evaluation of global cognition, processing speed, and working memory in this population.

2. RESEARCH METHOD

The study employed a cross-sectional design, and subjects were selected using a simple random sampling technique. Random sampling was performed by listing all eligible medical students in Microsoft Excel and using the RAND() function to generate random numbers.

Participants were then selected after sorting the list by these random values, ensuring that each student had an equal chance of being included.

The study population consisted of approximately 533 active undergraduate medical students enrolled at the FM UPNVJ in the 2024 academic year. This group was chosen as the target population because they are relatively homogeneous in terms of age and educational background, which helps minimize potential confounding variables. Medical students are also a particularly relevant population, as both cognitive performance and vascular health are critical for their academic success and future roles as healthcare professionals. To reduce bias, specific inclusion and exclusion criteria were applied to eliminate conditions that could independently influence vascular function or cognitive performance, thereby ensuring that the selected sample reflected healthy young adults within this population.

The sample size was calculated using the hypothesis testing formula for the difference between two proportions, where $\alpha = 5\%$, $\beta = 90\%$, $P1 = 0.58$ (Astutik et al., 2020), and $P2 = 0.19$ (Pais et al., 2020). The minimum sample size required was calculated to be 46 subjects. To accommodate potential dropouts, the sample size was increased by 10%, resulting in a total of 51 subjects. The criteria for the research subject were nonsmoking medical students with low to moderate stress levels and no history of head trauma, brain haemorrhage, narcotics use, diabetes mellitus, or hypertension. Additionally, subjects had to eat breakfast and obtain at least six hours of sleep before cognitive function testing to minimize the effects of transient hypoglycemia and sleep deprivation, which may independently influence cognitive performance and confound the assessment of vascular cognitive associations.

Subject characteristics were collected using a structured questionnaire, which included questions on demographic information (e.g., name, education level, address, contact details), stress levels measured using the Perceived Stress Scale (PSS-10) (Gärtner et al., 2019), and physical activity levels measured using the Global Physical Activity Questionnaire (GPAQ) (Nainggolan et al., 2019).

Cognitive function was assessed using the following instruments: 1) Mini-Mental State Examination (MMSE), a structured questionnaire consisting of 30 items divided into seven categories. It provides a general evaluation of basic cognitive functions, including orientation, attention, short-term memory, language, and object recognition. This instrument is also useful even for young populations for assessing their basic cognitive functions. The MMSE is both valid and reliable, demonstrating a Cronbach's alpha of 0.78 (Arevalo-Rodriguez et al., 2015); 2) Digit Symbol Substitution Test (DSST), a paper-and-pencil test used to assess executive functions. Subjects match symbols to corresponding numbers based on a reference key. The DSST demonstrated high validity in assessing executive functions, with correlation values ranging from 0.70 to 0.87. Scores are quantified by the number of correct symbols completed within a set time, typically 90 to 120 seconds (Jaeger, 2018); and 3) Digit Span Test (DST), which consists of two main parts: Forward and Backward. In the Digit Span Forward (DSF) test, the subjects are required to recall sequences of numbers in the same order as presented by the examiner. In the Digit Span Backward (DSB) test, subjects must recall the sequences in reverse order. In both components, the length of sequences increases progressively with each correct response. The maximum score for DSF is 16, and for DSB is 14, resulting in a maximum total DST score of 30. DST is widely used and validated as a screening instrument for cognitive impairment and dementia, with reported validity coefficients ranging from 0.80 to 0.85 (Lamar et al., 2018).

The SA-3000P Accelerated Photoplethysmography (APG) Analyzer was used to measure vascular elasticity (Elgendi et al., 2024). Vascular elasticity values were classified into sub-optimal (<30), normal (30–70), and optimal (>70) (Murakami et al., 2019). The procedure was conducted as follows: 1) The testing environment was controlled to ensure quietness, low lighting, and a cool, comfortable room temperature, 2) Subjects were instructed to abstain from

consuming caffeine, smoking, or eating for at least two hours before the test, 3) During the procedure, the subjects were seated comfortably, remained still, refrained from speaking, closed their eyes or rested, and breath normally, 4) The APG sensor was attached to the subject's left index finger, and measurements were recorded over approximately three minutes. The sensitivity and specificity of the APG for evaluating vascular elasticity are reported as 71.4% and 90.1%, respectively.

Ethical approval for this study was obtained from the Research Ethics Committee of Universitas Pembangunan Nasional Veteran Jakarta (approval number: 424/XI/2024/KEP). This study was conducted at the Faculty of Medicine Universitas Pembangunan Nasional Veteran Jakarta (FM UPNVJ) and the Medical Education and Research Center (MERCE) UPNVJ from February to November 2024.

3. RESULTS AND DISCUSSION

In this study, 141 students met the research criteria. From this population, 51 subjects were selected using the simple random sampling technique. Table 1 presents the characteristics of the research subjects. The majority of the subjects were male, 21 years old, exhibited low levels of stress, had a normal body mass index (BMI), and reported high levels of physical activity.

Table 1. Characteristics of Research Subjects.

Characteristic	Category	Frequency (n)	Percentage (%)
Age (years)	18	2	3.9
	19	11	21.6
	20	15	29.4
	21	20	39.2
	22	2	3.9
	23	1	2
Gender	Male	37	72.5
	Female	14	27.5
Stress Level	Low	46	90.2
	Moderate	5	9.8
Body Mass Index	Underweight	2	3.9
	Normal	30	58.8
	Overweight	14	27.5
	Obese	5	9.8
Physical Activity	Low	4	7.8
	Moderate	23	45.1
	High	24	47.1

Arterial elasticity generally declines with age as a result of vascular stiffening, increased arterial wall thickness, and endothelial dysfunction. Intima-media thickness also tends to increase in older adults. While endothelial aging typically becomes evident after the age of 60, it may occur earlier in certain individuals. Previous studies in young adults with type 1 diabetes mellitus, with a mean age of 19 years, have demonstrated a tendency toward arterial stiffness. Contributing risk factors include hyperglycemia, the accumulation of advanced glycation end-products (AGEs), insulin resistance, autonomic dysfunction, and elevated pulse pressure (Lu et al., 2023). Despite the relatively narrow and young age range in the present study, variations in vascular elasticity were observed, suggesting early subclinical vascular changes even among young adults.

Gender differences were also taken into account. The predominance of male subjects (72.5%), who tend to have thicker arterial walls and higher blood pressure, may contribute to the relatively lower vascular elasticity observed in this group compared to females. Female

subjects may have greater vascular elasticity because oestrogen has endothelial-protective and vasodilatory effects (DuPont et al., 2019).

Most subjects had a normal BMI (58.8%), reflecting national health survey data in 2018 for individuals aged 19–24 years (Kementerian Kesehatan Republik Indonesia, 2018). However, overweight and obese subjects were also present in this study. Evidence indicates that healthy people with normal BMI have less arterial stiffness than those who are overweight or obese (Piko et al., 2023; Tang et al., 2020).

Chronic stress has a well-established negative impact on cognitive function. Repeated activation of the hypothalamic–pituitary–adrenal (HPA) axis can result in increased cortisol levels, which may damage the hippocampus, a region essential for memory and learning, thereby impairing executive function and reducing memory capacity. Furthermore, psychosocial stress has been shown to negatively affect executive function and memory, particularly in conditions of high emotional load (Scott et al., 2015). In the present study, the majority of the subjects (n = 46) reported low levels of stress, which may mitigate these adverse effects.

Physical activity enhances cerebral blood flow, thereby supporting cognitive function and brain health as a whole. It promotes synaptogenesis and brain plasticity by facilitating the delivery of nutrients and oxygen to neural tissue and inducing the release of neurotrophic factors (Szaló et al., 2021). Physical activity has a major impact on cognitive functioning, according to a study conducted among young adults (Shah et al., 2020). Nearly half of the subjects in this study reported high levels of physical activity, which probably acts as a protective factor by improving neuroplasticity and cerebral perfusion. Additionally, it has been demonstrated that physical fitness can mitigate the cognitive effects of arterial stiffness (Nascimento et al., 2019).

Further evidence is provided by a study that examined the relationship between arterial elasticity and working memory capacity (WMC) in healthy older adults. The findings revealed that arterial elasticity, rather than physical fitness alone, was a direct predictor of WMC performance in complex span tasks (Qin & Basak, 2022). Importantly, the study discovered that the positive effect of physical fitness on cognition was fully mediated by arterial elasticity. This suggests that preserving vascular health may be a more fundamental factor in maintaining cognitive function than fitness alone. Although our study sample consisted of younger adults, the implications remain consistent: vascular elasticity seems to have an independent effect on cognitive function, particularly in tasks that depend on prefrontal and hippocampal function.

Table 2. Comparison of Cognitive Function Score (MMSE) between Vascular Elasticity Groups.

Group	MMSE Score	p-value
Suboptimal	30 (28-30)	0.042
Normal+Optimal	30 (29-30)	

The Mann–Whitney test revealed slightly lower MMSE scores in the suboptimal group compared to the normal+optimal group (p = 0.042). Although MMSE scores remained within the normal range for all subjects, these subtle differences may indicate early cognitive impairment. Reduced vascular elasticity, which is commonly assessed via pulse wave velocity (PWV), has been associated with impaired cerebral perfusion, particularly in the prefrontal cortex and hippocampus (Vikner et al., 2021). The findings of this study are consistent with previous research demonstrating a correlation between MMSE scores and vascular elasticity (Muela et al., 2017).

Table 3. Comparison of Cognitive Function Results of DSST Between Vascular Elasticity Groups.

Groups:								
Group	Cognitive Function						PR (95 % CI)	p- value
	Low		Normal		Total			
	N	%	N	%	N	%		
Suboptimal	16	44.4	20	55.6	36	100	6.667	0.023
Normal+Optimal	1	6.66	14	93.3	15	100	0.969 – 45.857	

Table 3 presents the result of the Chi-square test, indicating a significant difference in DSST scores between groups ($p = 0.023$). Suboptimal vascular elasticity was associated with a 6.7-fold higher risk of low cognitive function. Previous studies have reported that individuals with higher arterial stiffness tend to perform worse on the DSST. The DSST assesses cognitive processing speed and executive functions, both of which are negatively influenced by vascular elasticity. Reduced vascular elasticity weakens the brain's ability to process information quickly. Increased vascular stiffness often results in microangiopathy or white matter damage in the brain, which is essential for efficient information processing. Damage to small brain vessels (microangiopathy) impairs both global and specific cognitive functions, such as memory and attention (Jaeger, 2018).

The findings of the present study are consistent with the results of the Maastricht Study, which demonstrated a relationship between carotid stiffness and poorer cognitive performance, particularly in the domains of processing speed and executive function. In the Maastricht Study, a one standard deviation increase in carotid stiffness corresponded to a cognitive aging effect of approximately 1–2 years for processing speed and 2–4 years for executive function (Geijselaers et al., 2016). Similarly, another study observed that increased carotid stiffness is related to cognitive function and brain connectivity (Nieboer et al., 2016).

A systematic review summarizing evidence from 30 observational studies concluded that arterial stiffness (as measured by cfPWV and baPWV) is associated with poorer cognitive performance, particularly in domains of memory, executive function, and processing speed (Li et al., 2017). The review emphasized that arterial stiffness may play a role in the development of cerebral small vessel disease and impair cerebral autoregulation, ultimately reducing brain perfusion and contributing to neuronal damage. These mechanisms align closely with the findings of the present study, particularly the poorer DSST performance in subjects with suboptimal vascular elasticity. The significant difference in DSST scores between vascular elasticity groups in this study underscores the importance of information processing speed as a sensitive cognitive domain influenced by vascular health.

This finding is supported by a tablet-based version of the Symbol Digit Modalities Test (T-SDMT) to assess processing speed in stroke patients (Tung et al., 2016). Both the SDMT and the DSST used in the present study have the essential cognitive demands of attention, visual scan, and motor speed, all of which are vulnerable to vascular-related cerebral microstructural changes. The observed association between DSST impairment and suboptimal vascular elasticity in this present study is consistent with the results study of Tung et al., thereby further supporting the use of such tests in identifying early cognitive vulnerability related to vascular factors.

The Chi-square test results indicated no difference in cognitive function, as measured by the DST, between vascular elasticity groups ($p = 0.072$) (Table 4). Two main components of DST are Digit Span Forward (DSF) and Digit Span Backward (DSB). The Digit Span Test, particularly DSF, examines short-term working memory, specifically the storage capacity of information, reflecting a less complex cognitive function. Conversely, DSB requires subjects to recall sequences in a reversed order, thereby recruiting more complex cognitive processes such as mental manipulation, cognitive flexibility, and executive control. Due to these increased cognitive demands, DSB is considered more sensitive at detecting subtle vascular or neurological changes than DSF (Cai et al., 2024).

Table 4. Comparison of Cognitive Function Results of DST Between Vascular Elasticity Groups.

Group	Cognitive Function						PR (95 % CI)	p-value
	Normal		High		Total			
	N	%	N	%	N	%		
Suboptimal	16	44.4	20	55.6	36	100	3.333	0.072
Normal+Optimal	2	13.3	13	86.7	15	100	0.872 -12.742	

In the studies related to vascular elasticity, DSF often shows no significant association ($p > 0.05$), likely due to its limited sensitivity to vascular-related changes. This observation supports that vascular stiffness may have more influence on the more complex cognitive domains that are tested using DSB rather than the basic working memory functions that are tested using DSF (Cai et al., 2024). However, in the present study, the total DST score (ranging from 0 to 30) was used for analysis rather than analyzing DSF and DSB scores separately. As a result, subtle differences in DSB performance due to reduced vascular elasticity may have been obscured within the DST aggregate score, resulting in a statistically non-significant group difference.

Additionally, the findings of the present study align with those of a previous study, which demonstrated that older adults with increased arterial stiffness and greater pulsatile cerebral arteries exhibited poorer episodic memory and hippocampal microvascular function (Vikner et al., 2021). While the present study involved young adults without any obvious signs of cognitive decline, the significant differences in cognitive test scores between vascular elasticity groups may indicate early functional impairment. Increased systolic flow pulsatility may damage the hippocampal neurovascular unit, even before detectable volumetric changes or white matter lesions. This supports the present study findings that MMSE and DSST, but not DST, differed between groups, as these tests are more sensitive to perfusion-dependent brain regions like the hippocampus and prefrontal cortex.

A previous study demonstrated that increased aortic stiffness, measured using cfPWV, was significantly associated with lower cognitive function, with 16.2% of this relationship mediated by microvascular dysfunction, including cerebral small vessel disease and endothelial dysfunction markers (Rensma et al., 2020). These findings indicate that vascular stiffness may impair cognition not only through macrovascular hemodynamics but also via subtle alterations in microcirculation and blood-brain barrier integrity. Consistent with this evidence, our study found that even within a relatively young and homogeneous population of medical students, variations in vascular elasticity were linked to differences in cognitive performance, particularly in processing speed and executive function. This indicates that mechanisms typically observed in older or high-risk populations may already be present at earlier ages, with subclinical vascular changes influencing cognitive domains essential for academic performance. By demonstrating these associations in young adults, our findings extend previous evidence and highlight the importance of early detection and preventive strategies to preserve both vascular and cognitive health.

A recent large-scale study confirmed that arterial stiffness measured by cfPWV is significantly associated with poorer cognitive performance across multiple domains, including long- and short-term memory, executive function, and manual dexterity, even after adjusting for age, BMI, and cardiovascular risk factors (Bareiro et al., 2024). Similarly, a study in young adults demonstrated that primary arterial hypertension is linked to cognitive dysfunction, highlighting that vascular factors may affect cognition early in life (Puteikis et al., 2024). A comprehensive review further emphasized that increased arterial stiffness impairs cerebrovascular function, such as cerebral blood flow, microvascular integrity, and endothelial health, all of which are closely tied to cognitive decline (Reeve et al., 2024). Consistent with these findings, our study found that reduced vascular elasticity was significantly associated

with poorer performance in processing speed and executive function among medical students. Together, this evidence suggests that mechanisms commonly seen in older or high-risk populations may already operate in younger individuals, reinforcing the need for early vascular health monitoring and preventive strategies to safeguard cognitive function.

The present study contributes to the evidence of the important role of vascular health in cognitive function, even among young adults. This study found that reduced vascular elasticity was significantly associated with lower cognitive function in tests measuring executive function and processing speed. This study underscores the public health significance of vascular stiffness as a potential early biomarker for cognitive decline, even among young adults. The findings support the implementation of routine vascular and cognitive health screenings in younger populations.

This study has several limitations. It utilized only three cognitive tests (MMSE, DSST, and DST), which may not capture all cognitive domains comprehensively. The relatively small size, drawn from one center, restricts the generalizability of the findings. Additionally, unmeasured confounding factors, such as diet and sleep quality, may affect the relationships between vascular stiffness and cognitive function.

Future research should involve larger, multi-center samples to increase the generalizability of findings. The use of advanced neuroimaging techniques, such as MRI, may provide greater insight into cerebral alteration with vascular stiffness. Future studies also need to examine the effects of specific interventions, such as aerobic exercise, diet, and stress management, to explore their potential in preserving vascular and cognitive health.

4. CONCLUSION

Although all subjects demonstrated MMSE scores within the normal range, there were significant differences in MMSE and DSST scores between the vascular elasticity groups, indicating that suboptimal vascular elasticity might be linked to early deficits in processing speed and executive function. Basic working memory may be less susceptible to vascular changes, as evidenced by the lack of significant differences in DST performance. These findings emphasize the importance of maintaining vascular health to support optimal cognitive function, even in young, healthy people. Early identification of vascular stiffness and timely lifestyle interventions may serve as effective strategies to preserve cognitive health throughout life.

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