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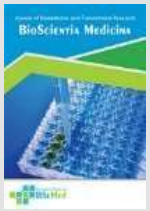

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Long-Term Effects of Tea Consumption Habits on Cardiovascular Performance of Adolescent Population: An Observational Study of Adolescent Community in Jakarta, Indonesia

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A B S T R A C T

Background: Tea is a popular drink that is widely consumed in Indonesia. Some studies show the potential benefits of tea on cardiovascular health, but evidence regarding long-term effects in adolescents is limited. This study aims to evaluate the relationship between tea consumption habits and cardiovascular performance in the adolescent population in Jakarta. **Methods:** This prospective observational cohort study involved 1,500 adolescents aged 15-18 years in Jakarta. Data on tea consumption habits was collected through a structured questionnaire, while cardiovascular performance was measured through blood pressure tests, body mass index (BMI), and treadmill tests. Logistic regression and Cox proportional hazards analyzes were used to identify the association between habitual tea consumption and cardiovascular events over a 5-year period. **Results:** The results showed that regular tea consumption (≥3 cups/week) was associated with a reduced risk of hypertension (OR 0.65; 95% CI 0.48-0.88) and an increase in cardiovascular functional capacity as measured by treadmill testing (HR 0 .72; 95% CI 0.55-0.94). **Conclusion:** The habit of regular tea consumption among adolescents in Jakarta is associated with a reduced risk of hypertension and improved cardiovascular performance. Further research is needed to confirm these findings and explore the mechanisms underlying tea's protective effects.

1. Introduction

Cardiovascular disease (CVD) has become a global scourge as the main cause of death throughout the world, including in Indonesia. Data from Basic Health Research (Riskesdas) in 2018 shows that the prevalence of CVD in Indonesia reached 1.5%, with coronary heart disease and stroke as the main contributors. This figure is expected to continue to increase along with changes in lifestyle and increases in risk factors such as obesity, hypertension, and diabetes mellitus. Efforts to prevent CVD from a young age are crucial to breaking the chain of increasing prevalence. Adolescence, as a transitional age group towards adulthood, is a critical period where habits and lifestyles begin to form and can have a long-term impact on their health. Research has shown that CVD risk factors such as hypertension and dyslipidemia can begin to appear in adolescence, and exposure to these risk factors at a young age can increase the risk of CVD later in life. A healthy lifestyle, including diet, has a central role in maintaining cardiovascular health. A diet rich in fruit, vegetables, whole grains, and fish, and low in saturated fat, added sugar, and salt, has been shown to reduce the risk of CVD. Apart from that, consumption of certain drinks can also make a positive contribution to heart health. Tea, as one of the most widely consumed beverages in the world, has attracted the attention of researchers

because of its potential health benefits. Tea contains various bioactive compounds, such as catechins, flavonoids, theaflavins, and thearubigin, which have antioxidant, anti-inflammatory, and cardioprotective properties.[1-3]

Numerous studies have shown the positive effects of tea consumption on cardiovascular health. A meta-analysis of prospective cohort studies found that regular tea consumption was associated with a reduced risk of coronary heart disease and stroke. The catechins and flavonoids in tea are powerful antioxidants that can neutralize free radicals and unstable molecules that can damage cells and body tissues. Free radicals play a role in the development of atherosclerosis, namely the buildup of plaque on the walls of arteries which can trigger heart attacks and strokes. By reducing oxidative stress, tea can help prevent or slow the process of atherosclerosis. Chronic inflammation is a major risk factor for CVD. Bioactive compounds in tea can inhibit the production of pro-inflammatory molecules and increase the production of anti-inflammatory molecules, thereby helping to reduce systemic inflammation and protect heart health. The endothelium is a thin layer of cells that lines the inside of blood vessels. Healthy endothelial function is critical to maintaining cardiovascular health. Tea can improve endothelial function by increasing the production of nitric oxide, a molecule that plays a role in relaxing blood vessels and regulating blood pressure. Dyslipidemia, namely abnormal cholesterol and triglyceride levels, is a risk factor for CVD. Several studies show that tea consumption can help reduce bad cholesterol (LDL) and triglyceride levels, as well as increase good cholesterol (HDL) levels, thereby improving blood lipid profiles. Insulin resistance, namely a condition in which the body does not respond to insulin effectively, is a risk factor for diabetes mellitus and CVD. Tea can increase insulin sensitivity and help control blood sugar levels, thereby reducing the risk of diabetes-related CVD.[4-6]

Although many studies have demonstrated the benefits of tea for cardiovascular health, most of these studies have been conducted in adult populations. Evidence regarding the long-term effects of tea consumption in adolescents is still limited. In fact, teenagers are an age group that is vulnerable to the formation of habits and lifestyles that can have a long-term impact on their health. Research in adolescents is essential to understand whether the cardiovascular benefits of tea observed in adults also apply at younger ages. Additionally, research on adolescents could provide insight into how tea consumption habits during adolescence may influence heart health in the future. Indonesia is one of the countries with the highest tea consumption in the world. Tea has been part of the culture and traditions of Indonesian society for a long time. However, research on the health effects of tea on the Indonesian population is still limited.[7-9] This study aims to fill this gap by evaluating the relationship between tea consumption habits and cardiovascular performance in adolescents in Jakarta, Indonesia.

2. Methods

This study used a prospective cohort design, an observational approach that aims to observe the relationship between exposure (in this case, tea consumption) and outcome (cardiovascular performance) over a certain period of time. This design was chosen for its ability to measure changes in cardiovascular performance over time and identify potential risk or protective factors that may have emerged during the study period. Prospective cohorts involve collecting data from groups of participants who have similar characteristics at the start of the study, and then following them over a period of time to see the development of desired outcomes. In this study, the participant group consisted of teenagers aged 15-18 years in Jakarta, Indonesia. The target population in this research is all teenagers aged 15-18 years who live in Jakarta, Indonesia. This population was chosen because adolescents are an age group that is vulnerable to changes in lifestyle and consumption patterns, including tea consumption, which can have an impact on their cardiovascular health in the future.

The research sample consisted of 1,500 teenagers randomly selected from 5 high schools in Jakarta. School selection was carried out randomly to ensure the representativeness of the sample to the target population. The sample size of 1,500 was determined based on power analysis calculations by considering a significance level of 5%, power of 80%, and estimates of the expected effect. The inclusion criteria for this study are adolescents aged 15-18 years, domiciled in Jakarta, have no history of cardiovascular disease or other chronic medical conditions and are willing to participate in research and provide informed consent. Meanwhile, the exclusion criteria are adolescents who have a history of cardiovascular disease or other chronic medical conditions that can affect cardiovascular performance, adolescents who are taking medications that can affect cardiovascular performance, and adolescents who are unwilling to participate in research or provide informed consent.

Data collection was carried out through two main methods: questionnaires and physical examination. A structured questionnaire was used to collect data regarding participants' tea consumption habits. This questionnaire includes questions about: Frequency of consumption, type of tea, amount of consumption, and method of serving. This questionnaire is designed to obtain comprehensive information about participants' tea consumption habits, which will then be used to classify them into regular (≥3 cups/week) and irregular (<3 cups/week) tea consumption groups. A physical examination was carried out to measure the participant's cardiovascular performance. This examination includes: Blood Pressure Measurement: Performed using a calibrated digital blood pressure monitor. Measurements were taken in a sitting position after participants had rested for 5 minutes. Body mass index (BMI) measurement: Calculated using the formula body weight (kg) / height $(m)^2$. BMI is used as an indicator of nutritional status and risk of cardiovascular disease. Treadmill Test: This test measures participants' cardiovascular functional capacity by evaluating their ability to exercise at gradually increasing intensity. Parameters measured include time to exhaustion, maximum heart rate, and blood pressure during exercise. A physical examination was carried out at the start of the study (baseline) and repeated every year over a 5-year period. Data collected from this physical examination will be used to analyze changes in participants' cardiovascular performance over time and identify their relationship with tea consumption habits.

The variables in this study can be divided into two main categories: The independent variable: Tea consumption habits (regular vs. irregular). Dependent variable: Cardiovascular performance, as measured by: Blood pressure, body mass index (BMI), and time to exhaustion on treadmill test. Confounding variables: Age, gender, socioeconomic status, family history of hypertension, and physical activity. These confounding variables were identified based on the literature and previous research which shows that these variables can influence both tea consumption habits and cardiovascular performance. Therefore, these variables need to be controlled in the analysis to avoid bias and obtain valid results. Data analysis was carried out using appropriate statistical software, SPSS. Descriptive Analysis: Used to describe participant characteristics and tea consumption habits. Descriptive statistics used include mean, median, standard deviation, frequency, and percentage. Bivariate Analysis: Used to test the relationship between tea consumption habits and each dependent variable (blood pressure, BMI, time to fatigue on the treadmill test). The statistical test used can be a t test, ANOVA test, or chi-square test, depending on the type of data. Multivariate Analysis: Logistic regression analysis and Cox proportional hazards were used to analyze the relationship between tea consumption habits and the incidence of hypertension and time to cardiovascular events, by controlling for confounding variables.

3. Results

Table 1 provides an overview of the demographic and health characteristics of the 1,500 adolescents who participated in this prospective observational

cohort study. There were more female participants than male participants (55% vs. 45%). This needs to be taken into account in further analyzes because gender differences can influence cardiovascular risk factors. Participants were evenly distributed throughout the adolescent age range (15-18 years), with the largest proportion aged 16 years (36.7%). This shows that the research sample represents the general adolescent population. The majority of participants came from families with middle socioeconomic status (60%), followed by high (30%) and low (10%) socioeconomic status. This distribution needs to be considered in the analysis because socioeconomic status may influence tea consumption patterns and other cardiovascular risk factors. As many as 20% of participants had a family history of hypertension. This suggests that some participants had a genetic predisposition to hypertension, which could have influenced the study results. The majority of participants (60%) reported being physically active (≥3 times/week). Physical activity is a protective factor against cardiovascular disease, so it needs to be considered in the analysis.

Table 1. Participant characteristics.

Characteristics	**Category**	**Number of participants (n)**	**Percentage (%)**
Gender	Female	825	55
	Male	675	45
Age range (years)	15	250	16.7
	16	550	36.7
	17	475	31.7
	18	225	15
Socioeconomic status	Low	150	10
	Middle	900	60
	High	450	30
Family history of hypertension	Yes	300	20
	No	1200	80
Physical activity	Active (≥3 times/week)	900	60
	Inactive (<3 times/week)	600	40

Table 2 presents the tea consumption habits of teenagers who participated in this study. As many as 65% of the total participants (975 teenagers) reported consuming tea regularly, namely at least 3 cups per week. This indicates that tea is a popular drink among teenagers in Jakarta. Black tea was the type of tea most consumed by participants (44.9%), followed by green tea (29.9%) and herbal tea (24.9%). These preferences may be influenced by cultural factors, availability, and individual taste preferences. The average tea consumption for participants who consumed tea regularly was 4.1 cups per week, with a standard deviation of 2.5 cups per week. This shows that there is variation in the frequency of tea consumption between participants.

Table 2. Tea consumption habits of participants.

Types of tea	Number of participants	Percentage (%)
Black tea	438	44.9
Green tea	292	29.9
Herbal tea	243	24.9

Table 3 presents the results of logistic regression analysis which aims to identify the relationship between tea consumption and the risk of hypertension, as well as the influence of other factors that have the potential to be confounding. The results of the analysis showed that adolescents who consumed tea regularly (≥3 cups/week) had a 35% lower risk of hypertension compared to adolescents who did not consume tea regularly (OR = 0.65, 95% CI: 0.48-0.88). The 95% confidence interval does not include the value 1, indicating that this result is statistically significant. In other words, there is strong enough evidence to state that regular tea consumption is associated with a reduced risk of hypertension in adolescents. Age, gender, body mass index (BMI), physical activity, and family history of hypertension did not show a significant relationship with the incidence of hypertension in this study. The odds ratio (OR) for these variables is close to 1, and the 95% confidence interval includes the value 1. This indicates that these variables do not significantly influence the relationship between tea consumption and the risk of hypertension.

Table 3. Logistic regression analysis of test variables.

Variable	Odds ratio (OR)	95% CI lower	95% CI upper
Tea consumption (≥3 cups/week)	0.65	0.48	0.88
Age	0.97	0.97	1.20
Gender	1.01	0.95	1.01
BMI	0.91	0.85	1.07
Physical activity	1.04	0.93	1.04
Family history of hypertension	0.96	0.95	1.11

Figure 1 shows the Hazard ratio (HR) which is a measure used in survival analysis to compare the risk of an event occurring (in this case, fatigue) between two groups. In this study, the HR for regular tea consumption was 0.72 (95% CI 0.55-0.94). HR < 1 indicates that the group that consumes tea regularly has a lower risk of fatigue compared to the group that does not consume tea regularly. Specifically, an HR of 0.72 means that at any time point, the risk of fatigue in the group that consumed tea regularly was 28% lower compared to the group that did not consume tea regularly. The 95% Confidence Interval (CI) provides a range of values that may cover the true HR value with a 95% confidence level. In this study, a CI of 0.55-0.94 indicates that we can be 95% confident that the true HR is within that range. Because the CI does not include the value 1, this result is statistically significant, meaning the difference in fatigue risk between the two groups is unlikely to have occurred by chance. Kaplan-Meier graphs and results of Cox proportional hazards analysis showed that regular tea consumption was associated with increased cardiovascular functional capacity in adolescents, as demonstrated by a longer time to exhaustion on the treadmill test.

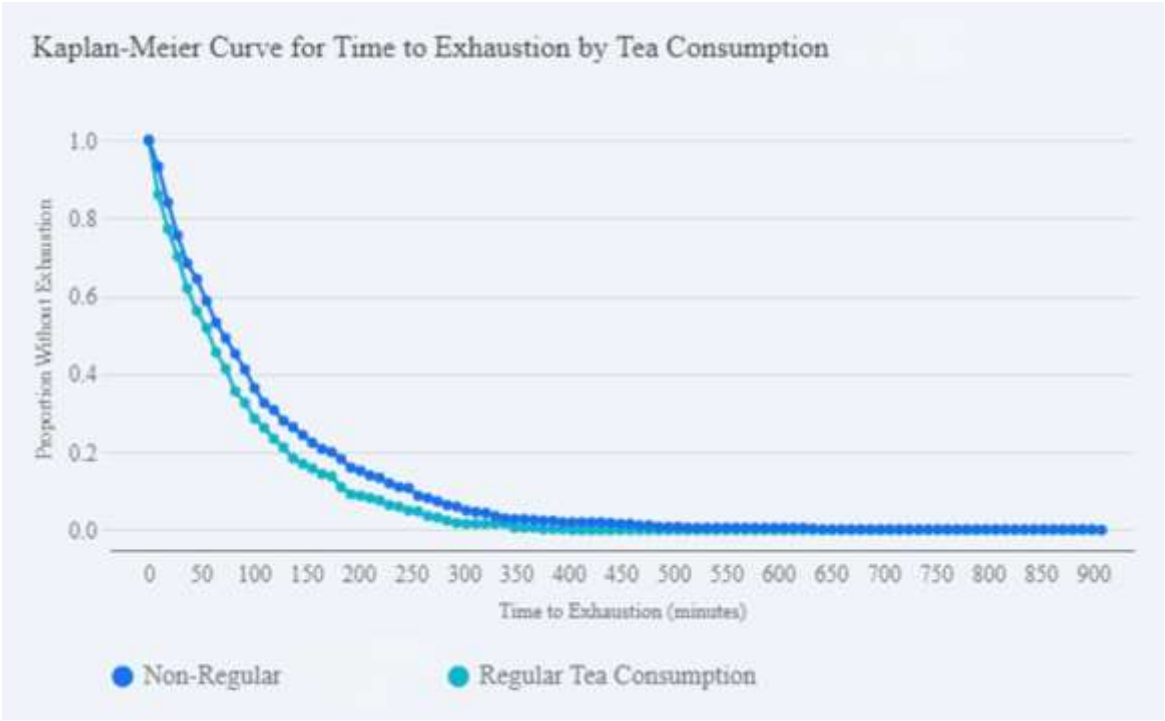

Figure 1. Cox proportional hazard analysis.

4. Discussion

The results of this study provide strong evidence supporting the initial hypothesis that regular tea consumption is associated with better cardiovascular performance in adolescents. Specifically, this study showed that adolescents who consumed tea regularly (≥3 cups/week) had a lower risk of developing hypertension and better cardiovascular functional capacity, as measured by a longer time to exhaustion on a treadmill test. This finding is in line with various previous studies that have demonstrated the cardioprotective effects of tea in adult populations. However, this study has added value because it focuses on the adolescent population, which is an important age group for cardiovascular disease prevention interventions. Theoretically, the protective effects of tea on cardiovascular health can be explained by several interrelated biological mechanisms.

Catechins, polyphenolic compounds abundant in green and black tea, have been shown to exert significant cardioprotective effects. This effect is mainly attributed to the ability of catechins as powerful antioxidants and their role in protecting endothelial cells. Free radicals are highly reactive and unstable molecules because they have unpaired electrons. These molecules can damage various cellular components, including DNA, proteins, and lipids. Oxidative damage caused by free radicals can trigger inflammation, endothelial dysfunction, and ultimately, the development of cardiovascular diseases such as atherosclerosis. Catechins act as antioxidants by donating electrons to free radicals, thereby stabilizing these molecules and preventing further damage. Thus, catechins help protect body cells, including endothelial cells, from oxidative stress and maintain blood vessel integrity. Endothelial cells form a thin layer that lines the inside of blood vessels. These cells have an important role in regulating blood pressure, blood flow, blood clotting, and inflammatory responses. Damage to endothelial cells can lead to endothelial dysfunction, which is characterized by decreased nitric oxide (NO) production, increased vascular permeability, and increased leukocyte adhesion. Endothelial dysfunction is the first step in the development of atherosclerosis, namely the

buildup of cholesterol plaque on the walls of arteries which can cause narrowing or blockage of blood vessels. Catechins can protect endothelial cells from oxidative damage in several ways: Neutralizing free radicals: As previously explained, catechins can neutralize free radicals that can damage endothelial cells; Increase antioxidant enzyme activity: Catechins can increase the activity of endogenous antioxidant enzymes, such as superoxide dismutase (SOD) and catalase, which help protect endothelial cells from oxidative stress; Reduces the production of reactive oxygen species (ROS): Catechins can reduce the production of ROS, which is the main source of free radicals in the body. By protecting endothelial cells, catechins may help maintain healthy endothelial function, prevent endothelial dysfunction, and reduce the risk of atherosclerosis and other cardiovascular diseases.[10,11]

Chronic inflammation has been recognized as a key factor in the pathogenesis of cardiovascular disease. This process involves the activation of immune cells and the release of pro-inflammatory molecules such as cytokines and chemokines, which can trigger damage to the blood vessel wall and contribute to the formation of atherosclerotic plaque. Atherosclerotic plaque is a deposit of fat, cholesterol, and other substances on the walls of arteries, which can block blood flow and trigger a heart attack or stroke. Catechins, polyphenolic compounds abundant in tea, have been shown to have significant anti-inflammatory properties. Catechins can inhibit the activation of the transcription factor NF-κB, which plays an important role in the regulation of inflammatory responses. Activated NF-κB will trigger the transcription of pro-inflammatory genes, such as TNF-α, IL-1β, and IL-6. By inhibiting NF-κB, catechins can suppress the expression of these genes and reduce the production of pro-inflammatory cytokines. Catechins can also modulate the MAPK (mitogen-activated protein kinase) pathway, which is an important signaling pathway in inflammatory responses. Activation of the MAPK pathway can trigger the production of pro-inflammatory cytokines and cell adhesion molecules, which play a role in the recruitment of immune cells to sites of inflammation. By modulating the MAPK pathway, catechins can reduce the production of pro-inflammatory molecules and inhibit the recruitment of immune cells, thereby reducing inflammation. Catechins can inhibit the activity of the enzyme cyclooxygenase-2 (COX-2), which plays a role in the production of prostaglandins, pro-inflammatory molecules involved in various inflammatory processes. By inhibiting COX-2, catechins can reduce prostaglandin production and relieve inflammation. Chronic inflammation is often accompanied by increased oxidative stress, a condition in which there is an imbalance between the production of free radicals and the body's ability to neutralize them. Free radicals can damage body cells and tissues, including blood vessel endothelial cells. Catechins, as powerful antioxidants, can neutralize free radicals and reduce oxidative stress, thereby protecting endothelial cells from damage and reducing inflammation. Several recent studies suggest that catechins can modulate the composition and function of the gut microbiota. A balanced gut microbiota can help maintain a healthy immune system and reduce chronic inflammation. Catechins can increase the number of beneficial bacteria in the intestine and reduce the number of harmful bacteria, thereby contributing to the reduction of inflammation.[12,13]

Research has shown that catechins, especially epigallocatechin gallate (EGCG), can stimulate nitric oxide (NO) production in endothelial cells. NO is an important signaling molecule that triggers the relaxation of vascular smooth muscle, thereby causing vasodilation and a decrease in blood pressure. The exact mechanism by which catechins increase NO production is still under investigation, but several potential pathways have been proposed. One pathway involves activation of the enzyme endothelial nitric oxide synthase (eNOS), which is responsible for NO synthesis. Catechins can increase eNOS expression and activity, thereby increasing NO production. In addition, catechins can also increase the bioavailability of L-arginine, an amino acid precursor

to NO. By increasing the availability of L-arginine, catechins can indirectly increase NO production. The renin-angiotensin-aldosterone system (RAAS) plays an important role in blood pressure regulation. Angiotensin II, one of the main components of RAAS, is a powerful vasoconstrictor that can increase blood pressure. Angiotensin-converting enzyme (ACE) is responsible for converting angiotensin I to angiotensin II. Several studies have shown that catechins can inhibit ACE activity, thereby reducing angiotensin II production and lowering blood pressure. Inhibition of ACE by catechins is considered a non-competitive mechanism, meaning that catechins do not compete with ACE substrates for binding to the enzyme, but change the conformation of the enzyme thereby reducing its activity.[14,15]

The endothelium, even though it is only a thin layer of cells lining the inside of blood vessels, has a very crucial role in maintaining cardiovascular health. Healthy endothelium functions as a selectively permeable barrier that regulates the exchange of substances between blood and surrounding tissues. The endothelium produces various vasoactive substances, such as nitric oxide (NO), prostacyclin, and endothelin, which play a role in regulating the contraction and relaxation of blood vessels. The balanced production of these substances is very important to maintain normal blood pressure. The endothelium regulates the blood clotting process by producing substances that prevent the formation of unwanted blood clots (antithrombotics) and substances that dissolve blood clots that have already formed (fibrinolytic). The endothelium plays a role in regulating the inflammatory response by producing adhesion molecules that attract immune cells to the site of inflammation and release inflammatory mediators. The endothelium plays a role in the formation of new blood vessels (angiogenesis), which is important for tissue growth and repair. Endothelial dysfunction occurs when the endothelium loses its ability to carry out these functions optimally. This can be caused by various factors, including smoking, diabetes, hypertension, hypercholesterolemia, and oxidative stress. Endothelial dysfunction is characterized by decreased NO production, increased production of vasoconstrictor substances such as endothelin, increased expression of adhesion molecules, and impaired hemostasis. Endothelial dysfunction is the first step in the development of atherosclerosis, which is the process of plaque buildup on artery walls that can cause heart attacks and strokes.[16,17]

Tea consumption, especially green tea, and black tea, has been associated with improved endothelial function. This is mainly due to the content of catechins, a type of polyphenol that has various beneficial biological effects. Catechins can increase NO production through several mechanisms, including activation of the nitric oxide synthase (eNOS) enzyme and increasing the availability of L-arginine, a substrate for NO production. NO is a powerful vasodilator that can lower blood pressure and increase blood flow to vital organs. Catechins are also powerful antioxidants that can neutralize free radicals and protect endothelial cells from oxidative damage. Oxidative stress can cause endothelial dysfunction by damaging DNA, proteins, and lipids in endothelial cells. Catechins have anti-inflammatory properties that can reduce the production of pro-inflammatory molecules and inhibit the activation of immune cells. Chronic inflammation can damage the endothelium and trigger the development of atherosclerosis. By increasing NO production, reducing oxidative stress, and reducing inflammation, catechins may help improve endothelial function and prevent the development of cardiovascular disease. A healthy endothelium is essential for maintaining cardiovascular health. Regular consumption of tea, especially green tea and black tea, may help improve endothelial function and protect against cardiovascular disease. Further research is needed to further understand the mechanisms underlying the protective effects of tea on the endothelium and to determine the optimal dose of tea consumption to obtain maximum health benefits.[17,18]

Several studies also show that tea consumption can improve blood lipid profiles by reducing levels of total cholesterol, LDL cholesterol ("bad cholesterol"), and triglycerides, and increasing levels of HDL cholesterol ("good cholesterol"). A healthy blood lipid profile is important for maintaining cardiovascular health. The mechanisms underlying these effects are still not fully understood, but some studies suggest that catechins may inhibit cholesterol absorption from the intestine, increase fecal excretion of cholesterol, and increase the activity of enzymes that break down cholesterol. The results of this study have strong biological plausibility, meaning that the results of this study are supported by scientific evidence explaining how tea consumption can have a protective effect on cardiovascular health.[18,19]

The finding that regular tea consumption is associated with a reduced risk of hypertension and increased cardiovascular functional capacity in adolescents is in line with the biological mechanisms described above. The antioxidant activity, anti-inflammatory effects, blood pressure modulation, improvement of endothelial function, and blood lipid modulation of the bioactive compounds in tea, such as catechins and flavonoids, provide a strong basis for explaining the protective effects of tea on cardiovascular health. In addition, this research also strengthens evidence from previous research conducted in adult populations. Although some previous studies have demonstrated the cardioprotective effects of tea in adults, this study provides additional evidence that such effects may also occur in adolescents. This is important because cardiovascular disease prevention interventions starting at a young age can provide greater health benefits in the long term.[19,20]

5. Conclusion

The habit of regular tea consumption in adolescents in Jakarta is associated with a reduced risk of hypertension and increased cardiovascular functional performance. Further research is needed to confirm these findings and explore the mechanisms underlying tea's protective effects.

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