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Cost Modeling of Construction Safety Management System on Road Project in South Papua Province, Indonesia

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Abstract

The implementation of the Construction Safety Management System (CSMS) in road construction projects in Indonesia, particularly in South Papua Province, continues to face significant challenges due to limited guidance and inconsistent safety cost estimation. A key element of CSMS is proper safety budgeting, yet many project estimators lack adequate understanding of how these costs should be calculated. This study aims to estimate safety budgets for asphalt road construction projects using a cost modeling approach based on road length and width. Research data were obtained from cost budget plans, price quantity lists, unit price analyses, and as-built drawings. Descriptive analysis was applied to determine the proportion of safety costs, followed by multiple linear regression to develop a predictive model relating CSMS costs to road dimensions. The findings show that the average CSMS cost accounts for 1.17% of the total project value. The regression results indicate that safety costs increase with project scale. Each additional kilometer of road adds approximately IDR 29.5 million (USD 1,845), and each additional meter of road width adds approximately IDR 8.6 million (USD 537). These results provide practical guidance for contractors and procurement authorities in allocating safety budgets more accurately and strengthening compliance with construction safety regulations.

Keywords: Safety management system, Cost components, Road construction, Safety cost, Model prediction.

1. Introduction

Road infrastructure development connects remote areas with centers of economic activity, creating new business opportunities and enhancing national competitiveness [1]. However, this sector also entails substantial risks, particularly in regions with challenging geographic and infrastructure conditions, such as South Papua, Indonesia [2]. Road construction projects in South Papua remain highly vulnerable to occupational accidents due to complex terrain and limited accessibility [3]. These risks are further intensified by the inadequate implementation of the Construction Safety Management System (CSMS) [4].

CSMS encompasses all engineering activities intended to support construction work in achieving safety, health, and sustainability standards by protecting workers, construction processes, the environment, and surrounding communities [5], [6]. In Indonesia, CSMS is regulated under the Ministerial Regulation of Public Works and Housing Number 10 of 2021 [7]. Proper implementation of CSMS is essential for reducing workplace accidents and creating a safer work environment by enforcing standardized safety procedures [8].

Despite its importance, CSMS implementation is often perceived as increasing project costs [9]. This perception frequently leads to resistance, particularly in projects with limited budgets [10], [11]. Several studies have shown that although CSMS requires additional investment, it significantly reduces long-term liabilities and prevents costly accidents [12]-[14]. The financial and human losses resulting from accidents often far exceed the initial safety investment [15], [16]. Therefore, a comprehensive evaluation of CSMS cost components is necessary to understand better their implications for both project costs and safety performance [17], [18].

The obligation to include CSMS cost estimation in procurement documents was introduced in 2020 through the Ministerial Regulation of Public Works and Housing Number 21 of 2019 and later updated by Regulation Number 10 of 2021. The present study was conducted in one of Indonesia's outermost provinces, where the technical guidance for construction service providers has progressed relatively slowly. As a result, the formal inclusion of CSMS costs in procurement documents in this province began only in 2021. Consequently, some contractors in South Papua Province did not fully comply with

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the Ministry's guidelines and tended to allocate very low CSMS costs to reduce bid prices. At the same time, procurement committees often lacked sufficient understanding to assess the feasibility of contractors' proposed CSMS budgets.

This study aims to develop a construction safety cost model for asphalt road projects based on the correlation between safety costs and road dimensions, namely length and width. The findings are expected to assist procurement committees in evaluating the reasonableness of safety budgets proposed in contractor bids by considering project characteristics. In addition, this study aims to provide practical insights for contractors and policymakers on the efficient allocation of safety costs to support the effective implementation of CSMS in road construction projects, particularly in South Papua Province.

2. Literature Review

2.1. Road Construction Project

A road construction project encompasses planning, design, and field execution activities to develop or improve road infrastructure [19]. The work may include constructing new roads, increasing the capacity of existing routes, and performing maintenance or reconstruction on damaged sections [20].

2.2. Correlation Between Safety Costs and Accident Reduction

The relationship between accident-prevention costs and workplace accidents in the construction sector has been a focus of research in recent years. Several studies found that higher investment in accident prevention is associated with lower accident rates in construction projects [21], [22]. Supporting evidence from Indonesia indicates that, with a high level of OHS implementation (73.63%), the risk of workplace accidents can be reduced to a low probability, with an average risk of 1.62. In that case, the allocated OHS budget was 0.64% of the contract value [23]. Data from the Social Security Administration also confirmed this trend, showing that the construction sector accounted for 25% of total workplace accidents in Indonesia, with companies that comply with OHS Management Systems experiencing a 50% reduction in accidents [24]. However, the effectiveness of accident-prevention measures is also influenced by other factors, such as safety training, the use of Personal Protective Equipment (PPE), and regulatory compliance. Usukhbayar [25] emphasized that safety investment must be supported by effective program implementation and a strong safety culture. Overall, these findings demonstrate that adequate investment in safety can substantially reduce workplace accidents in the high-risk construction sector.

2.3. Compliance with Safety Guidelines in the Indonesian Construction Sector

Compliance with Occupational Health and Safety (OHS) guidelines in the Indonesian construction sector is constrained by legal, institutional, and operational factors. From a regulatory perspective, Law No. 1 of 1970 and the Ministerial Regulation of Public Works and Housing No. 10 of 2021 provide a clear legal framework for the implementation of OHS. However, weak law enforcement and inconsistent field inspections continue to limit practical application [26]. The compliance level among contractors in Indonesia also varies notably across project types. For example, low-risk construction projects implement OHS Norms, Standards, Procedures, and Criteria at rates of 56.10%-58.06%, which is considered insufficient. In contrast, medium- and high-risk projects exhibit higher implementation levels, ranging from 61.86% to 84.28%. Furthermore, 80% of large-scale road contractors have achieved good compliance with established safety standards [27].

Qolbi and Muliawan [28] examined the relationship between safety climate perception and workers' compliance with OHS programs. Among 108 respondents, 54.63% of workers complied with OHS programs. Factors such as perceived priority, risk acceptance, communication, and trust in the implementation process were significantly associated with compliance. Workers with a positive perception of these factors were 4.7 times more likely to comply than those with a moderate perception.

However, other studies indicate that occupational safety policies are not yet consistently implemented in practice. Suraji [29] reported that the level of safety policy implementation in building projects in Indonesia remains low, with many project teams not fully applying approved safety policies. The study also identified frequent weaknesses in safety planning and design, as well as deviations in the application of safety management systems when compared to international standards.

2.4. Cost-Benefit Analysis of Safety Investment

Lestari et al. [30] evaluated 15 cases of occupational safety and health interventions to assess whether the implementation of OHS provided significant benefits. The results showed that 13 of the 15 studies reported a positive return on investment from OHS implementation, with the primary benefit being reduced illness-related absenteeism. Several cases also reported increased productivity and quality of work.

Thiede and Thiede [31] assessed whether investment in preventive measures by insurance companies in Colombia reduced the rate of work-related injuries and generated a positive return on that investment. The study found that investment in OHS significantly reduced the number of work injuries, avoided costs of $3,949,957, and was worthwhile from the insurer's perspective.

Furthermore, Mustard developed a methodology to estimate employers' financial returns from occupational safety and health (OHS) spending in Ontario, Canada. The study found that the average return on OHS spending was positive, with a ratio ranging from 1.24 to 2.14, indicating that investment in OHS can provide significant financial benefits to companies [32].

2.5. Cost Component of Construction Safety Management System

Based on Ministerial Regulation of Public Works and Housing No. 10 of 2021, the cost structure for implementing a CSMS comprises nine main cost components [33]-[37]. These components, summarized in Table 1, serve as references for further analysis.

Compared with neighboring countries, Australia, Singapore, and Malaysia generally adopt similar approaches to estimating construction safety costs, with a focus on accident prevention and worker protection. Estimating construction safety costs in Australia, Singapore, and Malaysia involves several key components, each governed by the laws and national standards of each country. In Australia, costs include safety training, procurement of personal protective equipment (PPE), safety inspections and audits, safety management systems, insurance, and safety equipment and signs. Standards such as the Work Health and Safety (WHS) Act 2011 and AS/NZS 4801 serve as references for its implementation.

Meanwhile, in Singapore, safety costs include Workplace Safety and Health (WSH) training, supervision by certified safety officers, use of safety technology such as IoT sensors, and worker health and well-being programs. Regulations such as the WSH Act and supervision by the Workplace Safety and Health Council (WSHC) are the basis for its implementation.

In Malaysia, construction safety costs are regulated by the Occupational Safety and Health Act 1994 (OSHA) and the Factories and Machinery Act 1967. Cost components include certification training (e.g., Green Card), procurement of PPE, supervision by Safety and Health Officers (SHO), routine inspections by DOSH, and safety awareness programs. In addition, risk management and insurance are also essential parts of cost estimation. All three countries emphasize the importance of training, the use of PPE, and safety management systems to reduce the risk of workplace accidents.

Table 1. CSMS cost component.

No.	Functional Component	Main Scope of Costs
1	CSMS documentation	Safety plans, work procedures, and periodic safety reports
2	Safety training & promotion	Safety induction, briefings, toolbox meetings, campaigns, and safety drills
3	Protective equipment	Safety net, helmets, gloves, harnesses, eye and hearing protection.
4	Insurance and licensing	Equipment inspection, certification, and operational permits
5	Safety personnel	Safety officers, emergency responders, first aid, and health staff
6	Medical & emergency facilities	First aid equipment, health rooms, ambulances, and emergency medical tools
7	Traffic control & safety devices	Temporary signs, warning devices, cones, and traffic control tools
8	Expert consultancy	Geotechnical, structural, electrical, and other safety-related experts
9	Safety risk control & monitoring	Inspections, fire protection, alarms, environmental, and safety monitoring

3. Methodology

3.1. Research Strategy

The research focuses on developing a predictive model that examines the relationship between CSMS costs and road dimensions. The data were obtained from several contracting firms involved in road construction projects and include CSMS-related documents, such as price recap sheets, quantity lists, unit price analyses, shop drawings, and as-built drawings.

Two analytical stages were conducted. First, descriptive analysis was used to determine the proportion of each CSMS cost component. Second, multiple linear regression was used to develop a model explaining the association between road length and width and variations in CSMS costs.

3.2. Data Collection

Secondary data were obtained from companies and local government offices in the capital of South Papua, with formal authorization for data collection. Eleven bidding documents for asphalt road maintenance projects (2022–2023) were reviewed. Among them, only five papers accounted for CSMS costs in accordance with the guidelines, whereas the remaining six underestimated safety budgets by accounting only for Personal Protective Equipment (PPE).

PPE alone is insufficient to fulfill CSMS requirements because, according to Ministerial Regulation of Public Works and Housing No. 10 of 2021, road construction is classified as a medium to high-risk construction activity, requiring contractors to account for all nine CSMS cost components.

3.3. Data Analysis

Multiple linear regression models were used to test the hypothesis [26].

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + e \qquad (1)$$

Description:

Y = CSMS cost

α = Constant (set to 0 because CSMS costs are assumed to be fully explained by road dimensions)

$\beta_{1,2}$ = Regression coefficient

X_1 = Road length (meter)

X_2 = Road width (kilometer)

E = Error term

Multiple linear regression was used to assess the degree to which road length and width explain variations in CSMS costs. The analysis follows standard statistical assumptions, including linearity in parameters (i.e., coefficients combine linearly even when variables are transformed), normality of the residuals, absence of multicollinearity, and homoscedasticity. These assumptions were examined to ensure the validity of the regression model.

4. Result and Discussion

4.1. Overview

The data for this study come from the CSMS Cost document for road projects in South Papua, as shown in Table 2.

Table 2. Road project in South Papua.

Project	CSMS Cost	%
A1	USD 12.023.75	1.503
A2	USD 43.546.88	1.202
A3	USD 19.843.75	2.041
A4	USD 4.046.88	0.392
A5	USD 12.442.51	0.693
Average		1.166

Table 2 shows that Project A3 has the highest percentage value at 2.041%, with a CSMS cost of USD 19,843.75. In contrast, Project A4 has the lowest percentage value at 0.392%, with a CSMS cost of USD 4,046.88. The average CSMS percentage across all projects is 1.166%. Project A1 has a rate of 1.503%, Project A2 has 1.202%, and Project A5 has 0.693%. These values indicate that CSMS cost estimation practices in South Papua remain inconsistent, suggesting that many estimators have a limited understanding of how to calculate CSMS-related expenditures.

Accurate CSMS estimation is vital because underestimated safety costs can lead to insufficient safety measures, increasing the risk of accidents, operational delays, and non-compliance with regulatory requirements [40]-[44].

The percentage of CSMS cost represents the budget share allocated to construction safety relative to the total project cost. This indicator is used to assess whether sufficient funds have been allocated to the nine CSMS components in accordance with applicable safety standards and to support auditing and cost control.

The Ministry of Public Works and Housing recommends that OHS costs range from 1.5% to 2.5% of the total project value, as stated in Circular Letter No. 10 of 2018. However, studies from other countries report lower percentages. Hamid et al. [38] found that OHS costs in Johor, Malaysia, range from 0.15% to 1.08%, with an average of 0.41%. A study from India estimated that 0.672% of the contract value represents an optimal OHS investment [39]. These lower percentages may reflect differences in regulatory frameworks, labor costs, project scale, and enforcement intensity.

4.2. Data Grouping

Data grouping shows that two projects include eight CSMS cost components. Project A1 does not include expert consultancy, while Project A4 does not include traffic signs and equipment. Meanwhile, three road projects include only seven CSMS cost components. Project A2 excludes insurance, licensing, and expert consultancy. Project A3 also excludes insurance, licensing, and specialist consultancy, while Project A5 excludes socialization, promotion, and training, as well as specialist consultancy. The component numbering is given in Table 1.

Table 3. Indicators of the CSMS cost component

Project	Cost Component
A1	(1), (2), (3), (4), (5), (6), (7), (9)
A2	(1), (2), (3), (5), (6), (7), (9)
A3	(1), (2), (3), (5), (6), (7), (9)
A4	(1), (2), (3), (4), (5), (6), (8), (9)
A5	(1), (3), (4), (5), (6), (7), (9)

These omissions indicate that several projects have not fully implemented the nine mandatory CSMS cost components, potentially reducing the effectiveness of safety management during construction.

4.3. Amount of CSMS Cost Component

The proportion of each CSMS cost component reflects its budget contribution to total CSMS expenditure. The allocation varies across projects depending on operational priorities. As shown in Table 4, safety personnel receive the largest share of CSMS costs (53.249%), indicating the labor-intensive nature of safety supervision in road projects. In contrast, expert consultancy has the smallest allocation (0.041%), likely because such services are typically used only periodically. These results confirm that most CSMS funds are allocated to direct supervision and traffic safety, whereas strategic components, such as expert consultancy, remain underfunded.

Table 4. Total percentage of CSMS cost components.

Cost Component	Average Cost	%
CSMS documentation	USD 971.88	1.057
Safety training & promotion	USD 3,656.25	3.978
Protective equipment	USD 7,766.26	8.450
Insurance and licensing	USD 5,781.25	6.291
Safety personnel	USD 48,937.50	53.249
Medical & emergency facilities	USD 1,762.50	1.918
Traffic control & safety devices	USD 17,896.88	19.473
Expert consultancy	USD 37.50	0.041
Safety risk control & monitoring	USD 5,093.75	5.542
Total average percentage		1.166

4.4. Comparative Relationship between CSMS Cost and Project Road Length and Width

The relationship between CSMS costs and road dimensions is examined using multiple linear regression to assess the influence of road length and width on the allocation of safety costs. In this model, CSMS cost (Y) is expressed in Indonesian Rupiah (IDR), and the independent variables are road length (X_1) and road width (X_2), both measured in meters. For normalization and analytical convenience, all CSMS cost values are scaled by dividing them by IDR 1 million. The descriptive characteristics of each variable are summarized in Table 5.

Table 5. Variable characteristics.

Project	Cost (Y) (IDR)	Length-km (X1)	Width-m (X2)
A1	192,38	6,474	4,237
A2	317,50	3,568	8,500
A3	696,75	20,000	9,000
A4	64,75	1,050	8,000
A5	199,08	7,585	9,500

4.4.1. Coefficient table

The coefficients table in regression analysis provides essential information about the effect of the independent variables on the dependent variable. Each row in this table represents one variable in the regression model, and the columns provide information on the estimated coefficients and related statistics, such as the standard error, t-statistic, and p-value. The results of the model test are presented in Table 6.

Table 6. Coefficient table result.

	Coefficients	Std. Error	T-stat	P-value	Lower 95%	Upper 95%
X1	29,53	7,49	3,94	0,03	5,69	53,35
X2	8,59	9,40	0,91	0,43	-21,32	38,52

Road length (X1) has a statistically significant effect at the 5% significance level, as indicated by the p-value (0.029), which is lower than 0.05. This confirms that X1 significantly influences the CSMS cost. In contrast, road width (X2) is not statistically significant ($p = 0.43$).

However, X2 should not be automatically excluded, as statistical significance alone does not dictate practical or theoretical relevance. Retaining X2 may be justified to avoid omitted variable bias or preserve theoretical integrity [45], [46]. The American Statistical Association cautions against dichotomizing results solely based on p-values, advocating instead a holistic interpretation that integrates statistical metrics, domain knowledge, and research objectives [46]. Hence, variable retention hinges on a nuanced evaluation of bias risks, collinearity, and the model's purpose (prediction vs. explanation). Therefore, the X2 is maintained in the model with the following considerations:

a. Theoretical Significance: The road width variable has a strong theoretical basis; keeping it in the model may make more sense even though it is not statistically significant.

b. Sample Size: In small samples, variables that are actually important can have significant p-values due to lack of statistical power.

c. Model Purpose: For predictive models where insignificant variables may still improve prediction accuracy

4.4.2. Regression statistics

Based on Table 7, the regression model indicates a strong relationship. The Multiple R value represents the correlation coefficient between the dependent variable (Y) and the independent variables (X1 and X2). This value indicates the strength of the linear relationship between these variables [47]. A Multiple R value of 0.974 indicates a strong, positive correlation between the independent and dependent variables. A value close to 1 indicates a strong relationship between the two variables.

The R-squared (coefficient of determination) or coefficient of association indicates the percentage of the variability in the dependent variable (Y) that is explained by the independent variables (X1 and X2). In this case, the value is 0.949, meaning that approximately 94.9% of the variation in the dependent variable (Y) is explained by the regression model, indicating that the model performs well in explaining the variability of the research data.

The Adjusted R^2 reflects the regression model's explanatory power after accounting for the number of independent variables and the sample size. Due to the minimal number of observations ($n = 5$), the Adjusted R^2 decreases to 0.5987, or approximately 59.87%. This reduction indicates that, after accounting for model complexity, the model's explanatory capability is only moderate. This limitation highlights that the substantial R^2 value should be interpreted with caution, as the small sample size may reduce the stability and generalizability of the regression results. Future studies with larger datasets are therefore required to improve the robustness and reliability of the proposed CSMS cost model.

Table 7. Regression statistics.

Regression Statistics	
Multiple R	0,974
R-square	0,949
Adjusted R-square	0,599
Standard Error	106,448
Observations	5

4.4.3. ANOVA

Analysis of variance (ANOVA) decomposes the total variation in the data into components attributable to different sources of variation. The ANOVA results for the regression model are presented in Table 8.

Table 8. Analysis of variance.

	df	SS	MS	F	Significance F
Regression	2	633108,9	316554,5	27,94	0,04
Residual	3	33993,4	11331,14		
Total	5	667102,3			

The ANOVA results for the multiple linear regression model yield an F-statistic of 27.94 ($p = 0.03$). Because this value is lower than the 5% significance level (0.05), the regression model is statistically significant. This indicates that the independent variables jointly provide a significantly better explanation of CSMS cost variation than a model without explanatory variables. Consequently, at least one independent variable (X1 or X2) has a statistically significant effect on the dependent variable (Y) within the scope of this study.

4.4.4. Multiple Linear Regression Model

Multiple linear regression is applied to model the relationship between the dependent variable (Y) and the independent variables (X1 and X2). The objective of this analysis is to assess how the independent variables influence or predict the dependent variable. The regression results are presented in Table 9.

$$Y = 29{,}527X1 + 8{,}597X2 + e \qquad (2)$$

Table 9. Regression model result.

Project	β_1	β_2	Y2	Difference
A1	29,53	8,60	227,590	
A2			178,425	
A3			667,914	34,77%
A4			99,778	
A5			305,633	

Based on the regression output generated in Microsoft Excel, the intercept (β0) is set to 0, indicating that the regression line passes through the origin. The coefficient of road length (β1) is 29.5, meaning that for every one-kilometer increase in road length (X1), the CSMS cost (Y) is predicted to increase by approximately IDR 29.5 million (USD 1,845), assuming road width (X2) remains constant.

The coefficient of road width (β2) is 8.6, indicating that for every one-meter increase in road width (X2), the CSMS cost (Y) is predicted to increase by approximately IDR 8.6 million (USD 537), assuming road length (X1) remains constant.

The regression model assumes a positive linear relationship, meaning that increases in the independent variables are associated with higher CSMS costs. The predicted CSMS cost values derived from the model are compared with the actual values to evaluate model performance. The difference between predicted and actual values is expressed as absolute error, which quantifies the magnitude of prediction error. The relationship between CSMS cost, road length, and road width is illustrated in Fig. 1.

The comparison of actual and predicted values indicates that the model performs well across several projects, particularly A1, A3, and A4, where the expected values closely match the actual CSMS costs. Larger deviations are observed for Projects A2 and A5, indicating that the model slightly underestimates CSMS costs for these cases. This suggests that although road length and width account for a substantial portion of the variation in CSMS costs, other factors may also influence cost levels in specific projects.

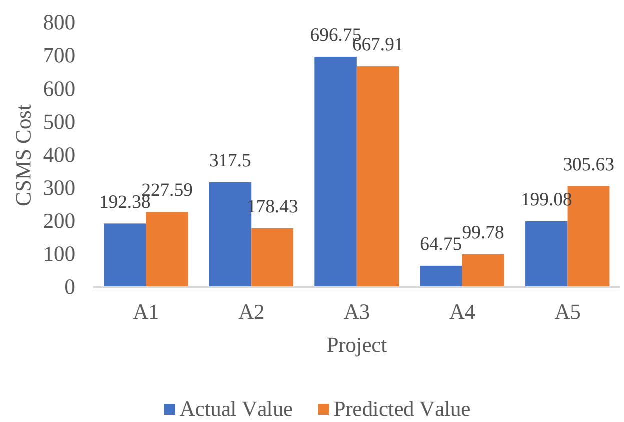

Figure 1. The result of the difference between the actual Y value and the predicted Y value.

Due to data limitations, the results of this study cannot yet be generalized statistically to other regions or to different types of road projects. Nevertheless, the findings provide a useful preliminary reference for procurement committees in estimating reasonable CSMS costs based on the geometric dimensions of asphalt road projects.

5. Conclusions

The research results show that the average CSMS cost accounts for 1.166% of total project costs. The distribution of CSMS cost components consists of 1.06% for CSMS documentation, 3.98% for safety training and promotion, 8.45% for protective equipment, 6.29% for insurance and licensing, 53.25% for safety personnel, 1.92% for medical and emergency facilities, 19.47% for traffic control and safety devices, 0.04% for expert consultancy, and 5.54% for safety risk control & monitoring. This distribution indicates that most CSMS funds are allocated to direct safety supervision and traffic control, whereas strategic components, such as expert consultancy, receive minimal funding.

The CSMS cost prediction model based on multiple linear regression is expressed as Y=29,527X1+8,597X2+e, where both regression coefficients are positive. The coefficient β1 indicates that every additional 1 km of road length increases CSMS costs by approximately IDR 29.5 million (USD 1,845). In contrast, β2 suggests that every additional 1 m of road width increases CSMS costs by approximately IDR 8.6 million (USD 537).

This model can serve as a practical tool for procurement committees to evaluate the reasonableness of contractors' proposed safety costs based on project dimensions, thereby supporting more effective implementation of workplace safety programs. Future studies should strengthen the model by incorporating additional factors, such as terrain difficulty, labor costs, project duration, and contractor experience.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

M. Asad Abdurrahman and Anggun Meranti Yuwandari Baswetan proposed the research problem, developed the theory, and performed the computations.

M Asad Abdurrahman and Rosmariani Arifuddin verified the analytical methods, conducted the investigations, and supervised the findings.

All three authors discussed the results and contributed to the final manuscript.

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