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Advanced machine learning for estimating vascular occlusion percentage in patients with ischemic heart disease and periodontitis

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ABSTRACT

Objective: The study aimed to assess the efficacy of advanced machine learning algorithms in estimating the percentage of vascular occlusion in ischemic heart disease (IHD) cases with periodontitis.

Methods: This study involved 300 IHD patients aged 45 to 65 with stage III periodontitis undergoing coronary angiograms. Dental and periodontal examinations assessed various factors. Coronary angiograms categorized patients into three groups based on artery stenosis. Clinical data were processed, outliers were identified, and machine learning algorithms were applied for analysis using the orange tool, including confusion matrices and receiver operating characteristic (ROC) curves for assessment.

Results: The results showed that Random Forest, Naïve Bayes, and Neural Networks were 97 %, 84 %, and 92 % accurate, respectively. Random Forest did exceptionally well in identifying the severity of conditions, with 95.70 % accuracy for mild cases, 84.80 % for moderate cases, and a perfect 100.00 % for severe cases.

Conclusions: The current study, using Periodontal Inflammatory Surface Area (PISA) scores, revealed that the Random Forest model accurately predicted the percentage of vascular occlusion.

1. Introduction

The intricate and significant link between periodontitis, a chronic inflammatory condition affecting oral health, and ischemic heart disease (IHD) has become a focal point in modern medical research [1]. Beyond some shared risk factors, their connection lies in shared inflammatory pathways that contribute to the development of coronary artery stenosis, a hallmark feature of IHD. This growing awareness has prompted exploration into an innovative approach—integrating advanced machine learning techniques to estimate the extent of vascular occlusion, which refers to a condition in which there is a partial or complete obstruction of blood flow in a blood vessel, typically an artery or a vein [2]. This advancement holds promise for refining diagnostic precision and tailoring treatment strategies individually [3–5].

Periodontitis, marked by inflammation within the oral tissues, has demonstrated a remarkable ability to systemically influence the body, including the cardiovascular system. Chronic inflammation is a common thread between periodontitis and coronary artery stenosis that impairs vascular function and accelerates the process of atherosclerosis. Additionally, bacterial by-products originating from oral infections can enter the bloodstream, triggering systemic inflammation and compounding the risk of vascular occlusion. The concept of Periodontal Inflammatory Surface Area (PISA) [6] and its associated inflammatory burden are central to comprehending the systemic impact of periodontitis. PISA quantifies the extent of inflamed periodontal tissue, measuring the overall inflammatory load triggered by periodontitis. This burden exacerbates the process of coronary artery stenosis by intensifying the pro-inflammatory environment [7].

Integrating advanced machine learning marks a significant advancement in predicting vascular occlusion in the context of IHD and periodontitis [3,8]. Machine learning models, trained on diverse datasets encompassing clinical periodontal parameters, can discern intricate patterns and relationships that often elude traditional analytical methods. These models offer the potential to accurately estimate the degree of vascular occlusion, providing clinicians with a powerful tool for early prediction, intervention, and tailored treatment strategies [1].

The current study explores the potential of advanced machine learning in estimating the percentage of vascular occlusion in cases of IHD with periodontitis. By leveraging machine learning's computational capabilities to process complex and heterogeneous data, this study aimed to deepen our understanding of the complex interplay between periodontal inflammatory burden and the development of coronary artery stenosis.

2. Materials and methods

The study involved 300 patients scheduled for coronary angiograms, adhering to defined criteria. The study encompassed patients aged 45 to 65 with at least 20 natural teeth and stage-III periodontitis. Patients with malignancies, tumors, and specific cardiac conditions were excluded. Ethical approval was obtained, and participants provided informed consent. A comprehensive periodontal case history, including demographics, medical records, smoking status, PISA scores, and BMI, was documented pre-coronary angiogram. Patients' BMI was calculated as

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weight in kilograms divided by height in square meters.

Before the coronary angiograms, the patients underwent meticulous dental and periodontal examinations administered by a single examiner. Probing pocket depth, clinical attachment loss, and bleeding on probing (BOP) were gauged at six sites per tooth using a UNC-15 probe. The PISA score, which assessed the extent of inflamed periodontal tissue, was computed via a downloadable spreadsheet.

A coronary angiogram involved inserting a catheter via the radial or femoral route to access the coronary arteries with fluoroscopic guidance. An iodine-containing contrast medium was introduced for imaging, establishing disease severity. Images were digitally recorded and stored.

Patients were categorized based on the coronary artery stenosis observed in their angiogram reports:

- Mild: No or slight evidence of coronary artery stenosis,
- Moderate: Vessels with <50 % coronary artery stenosis (non-critical),
- Severe: Vessels with ≥50 % coronary artery stenosis (critical).

Clinical data were pre-processed, outliers were identified and normalized, and labels were assigned based on vascular occlusion. Using the Orange machine learning tool [1,9], the data were split into training and test sets [9]. Random Forest, Naïve Bayes, and Neural Networks were applied to assess accuracy. Additionally, confusion matrices and ROC curves were generated. A collection of data points, each accompanied by binary labels signifying positive or negative, was given to each classifier. Subsequently, the classifier performed the task of predicting the labels for each data point. The evaluation of these predictions relied on a metric known as the Area Under the Receiver Operating Characteristic (ROC) curve, abbreviated as AUC. This metric served as a means to gauge the accuracy of each classifier's forecasts. The AUC computation offers a succinct summary of a classification model's overall performance. In this context, it is essential to note that higher AUC values indicate more favorable model performance. The AUC metric's values range from 0 to 1, encompassing the entire spectrum of potential model performance outcomes. The Chi-Square test was utilized to analyze the demographic data, and $P < 0.05$ was considered statistically significant.

3. Results

Table 1 outlines the study's demographic data and the distribution of obstruction severity across different demographic factors, including gender, age, and smoking history. Results revealed non-significant associations for gender ($P = 0.84$), age ($P = 0.13$), and smoking history ($P = 0.78$).

The performance of three distinct machine learning models, namely Random Forest, Naive Bayes, and Neural Network, was evaluated using various metrics in this study (Table 2). Random Forest exhibited the highest discrimination ability, as evidenced by its AUC of 0.971. It achieved a Classification Accuracy of 0.9 and demonstrated robust predictive capability with an F1 score of 0.892, Precision of 0.91, Recall of 0.9, and Specificity of 0.912. In contrast, Naive Bayes showed moderate performance with an AUC of 0.844 and a Classification Accuracy of 0.633. While Neural Network also demonstrated good discriminative power with an AUC of 0.92 and a Classification Accuracy of 0.75, it exhibited slightly higher Log Loss at 0.516. These findings provide valuable insights into the comparative performance of machine learning models, aiding in the selection of appropriate models for predictive tasks.

The present study, involving clinical PISA and vascular occlusion percentage, showed good accuracy of 97 %, 84 %, and 92 % for the Random Forest, Naïve Bayes, and Neural Networks (Table 3). The Random Forest classifier demonstrated high accuracy in assessing condition severity, as it achieved 95.70 % accuracy for mild cases, 84.80 % for moderate cases, and a perfect 100.00 % for severe cases, with no false predictions (Table 3). These results showcase the model's effectiveness in distinguishing between severity levels.

4. Discussion

In this study, the Periodontal Inflamed Surface Area (PISA) [5,6] emerges as a vital metric, providing a quantitative measure of the inflammatory burden associated with periodontal diseases. The potential link between PISA and coronary artery stenosis suggests a role for periodontal infections in exacerbating systemic inflammation, contributing to a pro-atherogenic impact on coronary vessels. Elevated PISA scores [6], particularly in conjunction with severe coronary artery stenosis, may indicate a pathophysiological connection, raising the possibility of periodontal pathogens gaining access to the systemic circulation. The release of pro-inflammatory molecules by these pathogens, such as prostaglandins, IL-1, and TNF-α, could further contribute to atherosclerosis, underscoring the intricate link between periodontal health and systemic inflammatory responses.

Supporting these observations, a study by Ketabi et al. [4] found higher clinical parameters in patients with ≥50 % blockage, aligning with the potential relationship between PISA and vascular occlusion. Similarly, Amabile et al.'s study [10] revealed a positive correlation between the severity of coronary artery stenosis and probing pocket depth, emphasizing a potential dose/effect relationship between periodontal conditions and vascular health outcomes.

Furthermore, utilizing advanced machine learning, the study suggests promising prospects for considering PISA as a marker to estimate vascular occlusion. High accuracy rates, particularly with the Random Forest model, in assessing severity levels, including a perfect accuracy of 100.00 % for severe cases, underscore the potential of PISA in precision diagnostics (Table 3). The PISA score provides a quantitative measure of inflammatory burden in periodontal diseases [5]. Higher PISA scores may indicate an exacerbation of systemic inflammation, potentially contributing to atherosclerosis and vascular occlusion [11]. This suggests a relationship between elevated PISA scores and the severity of vascular occlusion in patients with ischemic heart disease and periodontitis [12]. Advanced machine learning models, particularly the

Table 1
Demographic data.

		Severity			Total	*P*-value
		No obstruction	<50 % obstruction	≥50 % obstruction		
Sex	Female	15	16	68	99	0.84 (NS)
	Male	30	38	133	201	
Age	<60	26	38	147	211	0.13 (NS)
	>60	19	16	54	89	
Smoking history	Never	30	37	143	210	0.78 (NS)
	Former	2	4	8	14	
	Current	13	13	50	76	
	Yes	10	22	57	89	
	Yes	10	11	52	73	

NS: Not Significant; $P > 0.05$.

Table 2
Accuracy of the model.

Model	AUC	CA	F1	Precision	Recall	Log Loss	Specificity
Random Forest	0.971	0.9	0.892	0.91	0.9	0.373	0.912
Naive Bayes	0.844	0.633	0.636	0.679	0.633	0.675	0.746
Neural Network	0.92	0.75	0.742	0.761	0.75	0.516	0.795

Table 3
Confusion matrix of the Random Forest model.

	Mild	Moderate	Severe
Mild	95.70 %	3.00 %	0.00 %
Moderate	4.30 %	84.80 %	0.00 %
Severe	0.00 %	12.10 %	100.00 %

Random Forest, demonstrated high accuracy in predicting vascular occlusion based on PISA scores, indicating PISA's potential as a valuable marker in estimating the percentage of vascular occlusion. In clinical settings, the PISA has the potential for diverse applications. It could function as a useful screening tool, particularly for populations with heightened risk factors for coronary artery disease (CAD), such as individuals with periodontitis or systemic inflammatory conditions. Moreover, when incorporated into the diagnostic process for CAD, PISA scores could offer clinicians valuable insights, aiding in the evaluation of risk and development of treatment plans for patients with suspected or confirmed IHD. PISA scores might also contribute to risk stratification, helping identify individuals with a higher likelihood of CAD progression. Additionally, the metric could play a role in treatment planning by suggesting more aggressive periodontal interventions for those with elevated PISA scores. This approach could potentially reduce systemic inflammation and manage cardiovascular risks more effectively [13]. While these applications demonstrate the potential benefits of PISA, it is essential to emphasize that further research and validation studies are crucial to establish its optimal utilization and integration into routine clinical care.

In addition, the study demonstrated a lack of statistically significant differences between the included participants regarding age, sex, and smoking status, further adding robustness to its findings (Table 1). This observation enhances the study's credibility, suggesting that the potential correlation between Periodontal Inflamed Surface Area (PISA) and vascular occlusion is not confounded by demographic or lifestyle factors, reinforcing the notion that PISA could indeed serve as a valuable marker in estimating vascular occlusion for patients with ischemic heart disease and periodontitis.

The study indicates that the model performed well in distinguishing between the severity levels of vascular occlusion, categorized as mild, moderate, and severe. However, moderate cases had the lowest accuracy among the three severity levels. This lower accuracy for moderate cases could be attributed to the challenge of distinguishing between blockages that are not as pronounced as mild or severe cases, making them more difficult to classify accurately. The model indeed predicted the severity of each case, not just a binary outcome. This means it was assigning each patient into one of the three categories: mild, moderate, or severe, based on the percentage of vascular occlusion observed in their coronary angiograms.

While these findings are promising, further validation through additional studies and clinical trials is imperative before conclusively establishing PISA as a marker for estimating vascular occlusion. If validated, the integration of PISA as a diagnostic tool could significantly enhance treatment strategies, allowing clinicians to tailor interventions more effectively and optimize care for individuals with ischemic heart disease and periodontitis. Future studies should include a broader range of clinical variables to enhance the depth of analysis. Specifically, detailed assessments of conditions such as diabetes, dyslipidemia, family history of CAD, obesity, and other relevant comorbidities should be incorporated. These factors are known to have significant impacts on both periodontal health and the progression of CAD. By including such detailed clinical data, future research can improve the study's validity and provide a more nuanced understanding of the patient population. This approach will enable a more precise evaluation of potential confounders and a clearer elucidation of the association between PISA and vascular occlusion in individuals with ischemic heart disease and periodontitis.

5. Conclusion

The current research applied the Random Forest model to predict vascular occlusion using PISA. The study is one of a kind because it identifies a relationship between PISA score and the percentage of vascular occlusion in IHD patients. Future studies with larger sample sizes covering different population groups, healthy and IHD, are recommended to validate the current findings.

Ethical approval

This study was approved by the Ethical Committee of A.B. Shetty Memorial Institute of Dental Sciences (No: ABSM/EC85/2015).

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Data availability statement

The data presented in this study are available upon request from the corresponding author.

CRediT authorship contribution statement

Pradeep Kumar Yadalam: Writing – original draft, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Santhosh B. Shenoy:** Writing – review & editing, Software, Resources, Formal analysis, Data curation, Conceptualization. **Raghavendra Vamsi Anegundi:** Writing – original draft, Validation, Resources, Methodology, Formal analysis, Data curation. **Seyed Ali Mosaddad:** Writing – review & editing, Validation, Investigation. **Artak Heboyan:** Writing – review & editing, Validation, Supervision, Project administration, Investigation.

Declaration of competing interest

The authors declare no competing interest.

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