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Cariogram-Based Dental Caries Risk Assessment: A Cross-Sectional Statistical Validation of Sector Values Against Caries Severity, Plaque Index, and ICDAS Score

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ABSTRACT: Objectives: This study aimed to (1) compare Cariogram sector values between low-risk and very-high-risk individuals, (2) assess the association of plaque index and ICDAS score with caries severity, (3) evaluate the diagnostic accuracy of individual Cariogram sectors in distinguishing carious from non-carious subjects, and (4) identify predictors of caries severity through ordinal logistic regression.

Materials and Methods: Across-sectional sample of 512 subjects was analyzed — 256 with active caries (stratified as Mild, n=96; Moderate, n=60; Severe, n=100) and 256 caries-free controls. Non-parametric tests (Mann-Whitney U; Kruskal-Wallis with D wass-Steel-Critchlow-Fligner post hoc comparisons) were used given non-normal data distributions. Chi-square tests examined associations between categorical clinical variables and severity. Receiver Operating Characteristic (ROC) analysis with Youden's Index determined optimal cut-off values, and ordinal logistic regression identified independent predictors of severity.

Results: All five Cariogram sectors differed significantly between low-risk and very-high-risk groups (all $p < .001$). Each sector achieved complete separation between the caries and non-caries groups in ROC analysis (AUC = 1.00). Ordinal logistic regression showed that higher darkbluesectorvalues (OR=0.325, 95%CI:0.256–0.400) and redsectorvalues (OR=0.117, 95%CI:0.065–0.189) were independently associated with reduced odds of severe caries (both $p < .001$), while the blue sector approached but did not reach significance (OR=1.123, $p = .062$). The model explained 76.6% of variance in severity (McFadden's $R^2 = 0.766$). Plaque Index and ICDAS score were both significantly associated with caries severity ($\chi^2 = 28.647$ and 8.927 , respectively; $p < .05$).

Conclusions: Cariogram sector values, particularly the dark blue (dietary) and red (bacterial susceptibility) sectors, were strongly and independently associated with caries severity in this sample, supporting the Cariogram's value as a risk-stratification instrument. Because the caries and non-caries groups in this analysis represented extremes of risk rather than a continuous clinical population, the perfect diagnostic separation observed should be interpreted as internal validation rather than a generalisable estimate of real-world diagnostic accuracy.

1. INTRODUCTION

Dental caries remains one of the most prevalent chronic non-communicable diseases worldwide, affecting populations across all age groups and socioeconomic strata. Despite its well-understood aetiology, accurate risk prediction continues to pose a

clinical challenge because caries is fundamentally a multi factorial disease, its development depending on a complex interplay between diet, oral hygiene, salivary function, host susceptibility, bacterial ecology, and the availability of preventive interventions such as fluoride. The Cariogram, developed by Bratthall and Hänsel Petersson¹, represents a pioneering attempt to synthesise these multiple risk determinants into a single, visually intuitive probability estimate. The tool allocates a circular diagram into five colour-coded sectors, each reflecting a distinct dimension of caries risk. The green sector quantifies the overall estimated chance of avoiding caries, functioning as the primary outcome variable. The remaining four sectors — dark blue (diet and frequency of sugar intake), red (bacterial load and susceptibility to caries), blue (general health conditions and medication use), and yellow (fluoride programme adherence) — encapsulate the modifiable and non-modifiable upstream determinants.

Despite its widespread clinical adoption, the Cariogram's statistical performance across objectively defined caries severity categories requires rigorous empirical validation. Most earlier studies evaluated the tool using surrogate severity measures or small convenience samples. The present study addresses this gap by applying a broad suite of statistical methods — including non-parametric group comparisons, chi-square tests of association, multi-level post hoc analyses, ordinal logistic regression, and ROC-based diagnostic evaluation — to a sample of 512 participants with and without active caries.

The specific aims of this study were to characterize the distribution of Cariogram sector values across low-risk and very-high-risk groups; to examine whether plaque index and ICDAS score distributions are associated with clinical caries severity; to determine the diagnostic accuracy and optimal cut-off values of each Cariogram sector; and to identify which sectors independently predict caries severity after controlling for other factors.

2. MATERIALS AND METHODS

2.1. Study Design and Sample

This investigation employed a cross-sectional analytical design conducted at the Department of Pedodontic and Preventive Dentistry, Faculty of Dental Sciences MS Ramaiah University of Applied Sciences between November 2023 and October 2024. Ethical approval was obtained from University Ethics Committee of Human Trials, Ramaiah University of Applied Sciences (RUAS), reference number (UECHT/2016-18/PGDT/PE05). The study sample consisted of 512 participants, divided equally into two groups: 256 individuals diagnosed with active dental caries (Caries group) and 256 caries-free controls (non-caries group). The case group included children diagnosed with ECC on clinical examination, and the control group included children without any clinical signs of dental caries. Frequency matching of controls to cases was done according to the age (within a 3 months range) and sex to have similarity between the two groups. Children were not included in case they had: recent antibiotic usage in the last three months, had a history of dentoalveolar trauma, systemic, hematologic or developmental disease, or psychological or behavioral issues that could influence clinical examination. The cases and controls were both recruited in the same clinical environment at the time of the study to reduce the chances of selection bias. Within the Caries group, participants were further stratified by clinical severity into three categories — Mild ($n = 96$), Moderate ($n = 60$), and Severe ($n = 100$) — based on standardised clinical examination criteria. Written informed consent was obtained from all participants [or their legal guardians, if applicable].

2.2. Cariogram Assessment

Each participant underwent a full Cariogram assessment¹, which generated percentage scores across five sectors. The green sector (Chance of Avoiding Caries) is inversely related to overall risk; higher values indicate a greater probability of remaining caries-free. The dark blue sector reflects dietary habits (frequency and ferment ability of sugar intake), the red sector encapsulates susceptibility-related factors including bacterial load (*Streptococcus mutans* counts and buffer capacity), the blue sector represents circumstances related to systemic diseases and xerogenic medications, and the yellow sector captures the degree of fluoride exposure and programme adherence.

2.3. Clinical Indices

Plaque accumulation was recorded using the Silness-Löe Plaque Index², dichotomised as PI1 (low-to-moderate plaque) or PI2 (heavy plaque). Caries severity at the lesion level was coded using the International Caries Detection and Assessment System (ICDAS)³, with scores of 5 and 6 indicating established cavitated lesions of moderate and severe depth, respectively. Overall severity was classified at the participant level into Mild, Moderate, or Severe categories, as described above.

2.4. Statistical Analysis

Normality was assessed using the Shapiro-Wilk test; because Cariogram sector values consistently violated normality assumptions, non-parametric procedures were used throughout. Comparisons between the Caries and Non-caries groups were conducted using the Mann-Whitney U test. Comparisons across the four severity categories (Severe, Moderate, Mild, No Caries) were performed using the Kruskal-Wallis Htest, with Dwass-Steel-Critchlow-Fligner (DSCF) pairwise post hoc tests applied to identify specific between-group differences while controlling the familywise error rate. Associations between categorical clinical variables (Plaque Index, ICDAS score) and caries severity were evaluated using Pearson's Chi-Square test. Receiver Operating Characteristic (ROC) curve analysis was conducted for each Cariogram sector to quantify diagnostic discrimination; area under the curve (AUC) was calculated alongside 95% confidence intervals, and optimal cut-off thresholds were identified using Youden's Index ($J = \text{Sensitivity} + \text{Specificity} - 1$)⁴. An ordinal logistic regression model was fitted with severity category as the dependent variable to identify independent predictors. Model fit was evaluated using McFadden's pseudo- R^2 and the Akaike Information Criterion (AIC). Analyses were performed using the Statistical Package of the Social Sciences (SPSS) software, version XX (IBM Corp., Armonk, NY, USA). All analyses used a two-tailed significance threshold of $\alpha = 0.05$.

3. RESULTS

3.1. Cariogram Profile: Low-Risk vs. Very-High-Risk Groups

Table 1 presents descriptive statistics for each Cariogram sector across the two risk strata. In the low-risk group, the green sector — representing the probability of avoiding caries — showed a median of 78% (IQR: 78–81%). In the very-high-risk group, the same sector fell to a median of 8% (IQR: 5–10%).

Conversely, sectors associated with pathological drivers were substantially elevated in the very-high-risk group. The dark blue (dietary risk) sector showed a median of 13% (IQR: 11–15%) versus 5% (IQR: 5–5%) in the low-risk group. The blue sector (general health circumstances) was especially pronounced, with a median of 59% (IQR: 58–59%) in the very-high-risk group compared with 9% (IQR: 9–9%) in the low-risk cohort — the largest absolute inter-group difference observed. Yellow sector values (fluoride programme) were low in the low-risk group (median = 1%) and higher in the very-high-risk group (median = 7%).

Table 1 Cariogram Sector Values by Risk Category (N = 256 per group)

Sector	Risk Category	N	Q1 (%)	Median (%)	Q3 (%)
Green(Chance of Avoiding Caries)	Low Risk	256	78	78	81
Green(Chance of Avoiding Caries)	Very High Risk	256	5	8	10
Darkblue (Diet)	Low Risk	256	5	5	5
Darkblue (Diet)	Very High Risk	256	11	13	15
Red(Susceptibility)	Low Risk	256	5	7	7
Red(Susceptibility)	Very High Risk	256	13	14	14.75
Blue(Circumstances)	Low Risk	256	9	9	9
Blue(Circumstances)	Very High Risk	256	58	59	59

Yellow(Fluoride)	Low Risk	256	1	1	1
Yellow(Fluoride)	VeryHigh Risk	256	6	7	7

Note. IQR=interquartilerange. All between-group differences were statistically significant ($p < .001$; see Table 2).

Mann-Whitney U test results confirmed that every sector differed significantly between risk categories (Table 2). Z-scores ranged from -19.85 (green) to -21.32 (yellow), and all p-values were $< .001$.

Table 2 Mann-Whitney U Test Statistics: Low-Risk vs. Very-High-Risk Groups

Cariogram Sector	Mann-Whitney U	Wilcoxon W	Z	p-value
Green	0	32,896	-19.853	$< .001$
Darkblue	0	32,896	-20.363	$< .001$
Red	0	32,896	-19.936	$< .001$
Blue	0	32,896	-20.705	$< .001$
Yellow	0	32,896	-21.323	$< .001$

Note. A Mann-Whitney U of 0 indicates no rank overlap between the two groups' distributions on that sector.

3.2. Association of Clinical Indices with Caries Severity

A significant association was observed between Plaque Index and caries severity ($\chi^2(2) = 28.647$, $p < .001$; Table 3). Among participants with mild caries, 68.75% had a PI score of 1 (low-to-moderate plaque), compared with 36.67% among those with moderate caries and 33.00% among those with severe caries — a gradient consistent with a dose-responsive role for bacterial accumulation in caries progression. The likelihood ratio chi-square ($G^2 = 29.182$, $p < .001$) and linear-by-linear association test ($\chi^2 = 24.829$, $p < .001$) corroborated this dose-response relationship.

The distribution of ICDAS lesion scores also differed significantly across severity categories ($\chi^2(2) = 8.927$, $p = .012$; Table 3). Among mildly affected participants, 75.00% had ICDAS score 5 lesions (dentinal caries without obvious cavitation), compared with 60.00% of the moderate group and 55.00% of the severe group. Correspondingly, ICDAS score 6 (extensive cavitation) was most prevalent in the severe group (45.00%), rising from 25.00% in the mild group.

Table 3 Cross-Tabulation of Plaque Index and ICDAS Score by Caries Severity (N = 256)

Clinical Index	Mild (n=96)	Moderate (n=60)	Severe (n=100)	Total (n=256)	χ^2 (df=2)	p
PI1 (Low-Moderate plaque)	66 (68.75%)	22 (36.67%)	33 (33.00%)	121 (47.27%)	28.647	$< .001$
PI2 (Heavy plaque)	30 (31.25%)	38 (63.33%)	67 (67.00%)	135 (52.73%)		
ICDAS Score 5 (dentinal, no cavity)	72 (75.00%)	36 (60.00%)	55 (55.00%)	163 (63.67%)	8.927	.012

ICDAS Score 6 (extensive cavitation)	24 (25.00%)	24 (40.00%)	45 (45.00%)	93 (36.33%)		
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Note. PI=Plaque Index; ICDAS=International Caries Detection and Assessment System. Cell percentages represent proportion within severity category.

3.3. Cariogram Sector Values Across Severity Levels

Kruskal-Wallis H tests revealed significant differences across the four severity categories (Severe, Moderate, Mild, No Caries) for every Cariogram sector (all $p < .001$; Table 4). The largest H statistic was observed for the yellow sector ($H = 487$), followed by dark blue ($H = 447$), green ($H = 434$), blue ($H = 430$), and red ($H = 430$).

The green sector showed a monotonic decline as severity increased, from a median of 78% in the no-caries group to 10% in mild, 7% in moderate, and 5% in severe disease. The dark blue sector increased monotonically with severity, rising from 5% (no caries) to 11% (mild), 14.5% (moderate), and 15% (severe). The red sector showed a less consistent pattern: severe disease was associated with the highest red sector value (median 15%), while moderate disease (median 13%) was lower than mild disease (median 14%).

DSCF post hoc comparisons showed that nearly all pair wise combinations of severity categories differed significantly for the green, dark blue, red, and yellow sectors. The exception was the Severe-versus-Moderate comparison for the dark blue sector ($W = 0.86$, $p = .93$), suggesting that dietary risk profiles plateau beyond a threshold level in more severely affected subgroups. For the blue sector, no significant differences were observed among the three caries-affected subgroups (all $p > .05$), although all three differed markedly from the no-caries group (all $p < .001$), suggesting the blue sector functions more as a marker of caries presence than as a graded indicator of severity.

Table 4 Cariogram Sector Values by Caries Severity Category

Sector	No Caries Median (IQR)	Mild Median (IQR)	Moderate Median (IQR)	Severe Median (IQR)	H (df=3)	p
Green	78(78–81)	10(8–10)	7(6–8)	5(5–7)	434	<.001
Dark blue	5(5–5)	11(11–13)	14.5(13–16)	15(13–15)	447	<.001
Red	7(5–7)	14(13–14)	13(13–13)	15(14–15)	430	<.001
Blue	9(9–9)	59(58–59)	59(58–59)	59(58–59)	430	<.001
Yellow	1(1–1)	7(7–7)	6.5(6–7)	6(6–6)	487	<.001

Note. Kruskal-Wallis H test, $df = 3$ for all sectors. P osthoc pairwise comparisons (DSCF) confirmed significant differences between most severity pairs (see text for exceptions).

3.4. Diagnostic Accuracy of Cariogram Sectors (ROC Analysis)

ROC analysis was performed for each of the five Cariogram sectors to determine their ability to discriminate between the Caries and Non-caries groups. All five sectors achieved complete discrimination, with $AUC = 1.00$ (95% CI: 1.00–1.00) and $p < .001$ for each; sensitivity and specificity were both 100% (95% CI: 98.57%–100%) across all sectors (Table 5).

Optimal cut-off values, determined using Youden's Index, were as follows: dark blue sector $\leq 41\%$ (classifying participants with 41% or below as caries-positive); green sector $\geq 9.5\%$ (caries-positive); red sector $\geq 10.5\%$ (caries-positive); blue sector $\geq 34.5\%$ (caries-positive); and yellow sector $\geq 3.5\%$ (caries-positive). These thresholds resulted in complete classification accuracy,

with no false positives or false negatives for any sector.

Table 5 ROC Analysis: Diagnostic Accuracy of Cariogram Sectors (N = 512)

Sector	AUC	95%CI	Sensitivity	Specificity	Optimal Cut-off	p
Darkblue	1.00	1.00–1.00	100%	100%	$\leq 41\%$	<.001
Green	1.00	1.00–1.00	100%	100%	$\geq 9.5\%$	<.001
Red	1.00	1.00–1.00	100%	100%	$\geq 10.5\%$	<.001
Blue	1.00	1.00–1.00	100%	100%	$\geq 34.5\%$	<.001
Yellow	1.00	1.00–1.00	100%	100%	$\geq 3.5\%$	<.001

Note. Cut-off based on Youden's Index. PPV=100%, NPV=100% for all sectors. Overall model accuracy = 100% (95% CI: 99.28%–100%).

3.5. Ordinal Logistic Regression: Predictors of Caries Severity

An ordinal logistic regression model was fitted with caries severity category (Severe > Moderate > Mild > No Caries) as the dependent variable. The overall model demonstrated a strong fit, with a McFadden's pseudo- R^2 of 0.766 (Deviance=295, AIC=307), indicating that the predictors accounted for approximately 76.6% of the variance in severity classification.

Among the three predictors entered—dark blue, red, and blue sectors—the dark blue and red sectors were statistically significant at the conventional $\alpha=0.05$ threshold (Table 6). Each one-unit percentage increase in the dark blue sector was associated with a 67.5% reduction in the odds of greater severity (OR = 0.325, 95% CI: 0.256–0.400, $p < .001$). The red sector showed an even stronger protective effect: each one-unit increase reduced the odds of more severe disease by 88.3% (OR = 0.117, 95% CI: 0.065–0.189, $p < .001$). The blue sector approached but did not reach statistical significance (OR = 1.123, 95% CI: 0.958–1.256, $p = .062$).

Table 6 Ordinal Logistic Regression: Predictors of Caries Severity (N = 512)

Predictor	β (Estimate)	SE	Z	p	Odds Ratio	95%CI
Darkblue Sector	-1.125	0.113	-9.93	<.001	0.325	0.256–0.400
Red Sector	-2.147	0.268	-8.02	<.001	0.117	0.065–0.189
Blue Sector	0.116	0.062	1.87	.062	1.123	0.958–1.256

Note. Model fit: Deviance = 295, AIC = 307, McFadden's $R^2 = 0.766$. Dependent variable order: Severe | Moderate | Mild | No Caries. N = 512.

4. DISCUSSION

The present study offers a comprehensive empirical evaluation of the Cariogram tool's statistical performance across multiple

analytical frameworks. Three overarching findings emerge from the data.

First, the complete separation of Cariogram sector distributions between the low-risk and very-high-risk groups — evidenced by Mann-Whitney U values of 0 across all five sectors — indicates that the tool captured genuinely distinct risk profiles within this sample. The green sector's decline from a median of 78% in low-risk individuals to 8% in the very-high-risk group represents an almost tenfold reduction in the estimated protective margin, a magnitude of difference that is clinically meaningful: a dark blue sector value at or below the empirically derived cut-off of 41% could reasonably prompt intensified preventive counselling.

Second, the perfect AUC values (1.00) observed across all five sectors must be interpreted with caution. Complete diagnostic separation of this kind is rarely seen with real clinical data drawn from a continuous risk spectrum, and here it most plausibly reflects the sampling design: the two comparison groups (low-risk and very-high-risk, or caries versus non-caries) were defined at opposite ends of the risk distribution rather than sampled consecutively from an undifferentiated clinical population. In this dataset, the Non-caries group's green values (72–81%) did not overlap at all with the Caries group's values (4–10%), so non-overlap was, in effect, built into the group definitions. These diagnostic accuracy statistics therefore demonstrate internal consistency of the Cariogram's sector construction rather than an estimate of the tool's discriminative performance in an unselected, general dental practice population, where scores would be expected to overlap considerably more. Prospective validation in a consecutively recruited, unselected sample is needed before these cut-offs are applied clinically.

Third, the ordinal logistic regression results carry implications for preventive dentistry within the limits of this sample. The finding that each percentage-point increase in the dark blue sector was associated with an approximately 68% reduction in the odds of severe caries underscores the potential relevance of dietary counselling as a preventive lever, since dietary sugar frequency and ferment ability — the primary drivers of the dark blue score — are modifiable behaviours. Similarly, the red sector's 88% odds reduction per unit increase reflects the contribution of salivary buffering capacity and *Streptococcus mutans* counts, both of which are, in principle, targets for antimicrobial and salivary-stimulating interventions.

The blue sector's marginal non-significance ($p = .062$) in the severity regression, despite complete diagnostic discrimination in the ROC analysis, illustrates the distinction between diagnostic and prognostic value in this data set: the blue sector reliably separated caries-affected from caries-free participants, but its contribution to graded severity prediction within the caries-affected group was weaker. This discrepancy may partly reflect the narrow spread of blue sector values among caries-affected individuals (IQR 58–59%), which leaves limited variance for regression modelling. Studies with a wider range of blue sector scores, or sample enriched for systemic comorbidities, may help clarify this relationship.

The association between Plaque Index and caries severity ($\chi^2 = 28.647$, $p < .001$), with heavy plaque affecting 67.00% of severe cases compared with 31.25% of mild cases, is consistent with the established role of biofilm accumulation in caries progression². Clinically, this finding is consistent with recommending more frequent professional prophylaxis and reinforced oral hygiene instruction for patients in the moderate-to-high Cariogram risk categories. The ICDAS findings—with deep cavitated lesions (score 6) rising from 25.00% to 45.00% with increasing severity — are consistent with the expected natural history of untreated caries.

4.1. Limitations

Several limitations should be acknowledged. The extreme-groups design (very-high-risk versus low-risk, and caries versus non-caries) inflates the apparent separation between groups and likely accounts for the perfect AUC values reported here; these cut-offs and accuracy estimates should not be extrapolated to unselected clinical populations without prospective validation. The balanced case-control structure (256 caries versus 256 non-caries) sets prevalence at 50%, which differs from real-world prevalence and can affect the transportability of the ROC-derived cut-offs. The cross-sectional design precludes causal inference; longitudinal data are needed to establish whether Cariogram risk categories prospectively predict incident caries. Measurement error and inter-examiner variability in Cariogram scoring were not quantified. Finally, the demographic and geographic characteristics of the study population are not detailed here and should be reported to allow readers to judge generalisability.

5. CONCLUSION

This study provides statistical evidence, within as ample selected to represent extremes of risk, for an association between Cariogram sector values and both caries presence and caries severity. The dark blue (dietary) and red (bacterial susceptibility) sectors emerged as the strongest independent predictors of severity, with each percentage-point improvement associated with meaningful reductions in the odds of severe disease. Rather than being interpreted as a general-population diagnostic accuracy estimate, the complete discrimination observed here should be understood as a consequence of the extreme-groups design; the Cariogram's clinical utility as a risk-stratification instrument warrants confirmation in prospective, consecutively recruited samples that better reflect everyday clinical case-mix.

Future research should validate the reported cut-off values in unselected, prospectively recruited populations, examine the Cariogram's predictive validity over longitudinal follow-up, and investigate the responsiveness of sector values to preventive interventions.

ETHICAL APPROVAL

Ethical approval (reference number UECHE/2016-18/PGDT/PE05) was obtained from the University Ethics Committee of Human Trials, Ramaiah University of Applied Sciences (RUAS). Written informed consent was obtained from all participants [or their legal guardians] prior to enrolment.

AUTHOR CONTRIBUTIONS

AMK: Conceptualization, study design, data collection, data curation, formal analysis, interpretation of results, manuscript drafting, and correspondence.

TS: Methodology, statistical analysis, interpretation of data, and critical review of the manuscript.

DG: Conceptualization, methodology, supervision, critical revision of the manuscript, and final approval.

All authors have read and approved the final version of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors confirm that no artificial intelligence (AI)-assisted technologies were used at any stage of this study, including study design, data collection, analysis, interpretation, or manuscript preparation.

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