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Comparative Assessment of Pavement Distress on Wangandawa Road Using Pavement Condition Index, Surface Distress Index, and Bina Marga Methods

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ABSTRACT: Pavement wear in tropical areas stemmed from intense rainfall, varying traffic volumes, and scarce upkeep funds, so solid evaluation techniques were essential for smart maintenance scheduling. In this work, we compared three key methods for assessing pavement condition: the Pavement Condition Index (PCI), Surface Distress Index (SDI), and Indonesia's Bina Marga standard, all tested on one flexible pavement stretch. What set this study apart from earlier research mostly focused on a single approach, was its examination of how these methods differed in sensitivity, their impact on decision-making, and how consistently they aligned when applied to the same road section. We divided a 660-meter portion of Wangandawa Road into seven 100-meter segments and surveyed them using standard visual inspections for pavement distress. PCI scores ranged from 45 to 100 (average 71.0), indicating conditions from fair to excellent and showing sharp differences between segments. SDI scores ranged from 0 to 80, classifying conditions as good to moderate, whereas the Bina Marga method classified every segment under Priority A maintenance, showing no variation. When we compared the three approaches, PCI proved more sensitive in identifying fine-scale distress patterns, while SDI and Bina Marga demonstrated greater practicality for rapid network-level assessments. These findings supported the continued use of visual inspection methods for pavement evaluation in tropical regions and highlighted the importance of selecting an appropriate index for practical decision-making. PCI was suitable for detailed planning of rehabilitation and reconstruction, whereas SDI or Bina Marga were more suitable for quick assessments and routine maintenance planning.

KEYWORDS: Pavement condition assessment; maintenance prioritization; surface distress evaluation; flexible pavement; comparative methodology.

1. Introduction

Road infrastructure formed the backbone of regional connectivity, economic productivity, and social mobility. Efficient transportation networks facilitated the movement of goods and people, reduced logistics costs, and supported local economic growth. Well-maintained pavements ensured traffic safety, riding comfort, and long-term infrastructure durability. Conversely, pavement deterioration disrupted transport efficiency, increased vehicle operating costs, and heightened accident risks—particularly in rapidly developing countries experiencing increasing traffic volumes and infrastructure expansion [1, 2]. Flexible pavements were subjected to continuous environmental loads and traffic stresses, which accelerated structural deterioration over time. In tropical regions such as Indonesia, pavement performance was strongly influenced by heavy rainfall, temperature fluctuations, and inadequate drainage. These conditions gradually weakened the pavement structure, allowing moisture infiltration and intensifying defects such as cracking, rutting, potholes, and surface deformation [3]. In addition, heavy vehicles imposed substantial loads on the pavement, particularly on collector and alternative routes that accommodated traffic diversion during congestion or maintenance activities [4].

To maintain adequate serviceability, road authorities conducted routine pavement inspections that guided appropriate maintenance and rehabilitation actions. Such evaluations provided both quantitative measurements and qualitative observations to support infrastructure management and budget allocation decisions. Globally, engineers classified pavement conditions into categories ranging from excellent to severely deteriorated based on visible distress indicators [5]. Therefore, reliable assessment methods became essential for producing objective evaluations and identifying priority locations for maintenance. Various pavement condition assessment methods have been developed, but in this study several widely used approaches were applied to support pavement management decisions. The Pavement Condition Index (PCI) was widely recognized internationally for its standardized scoring system based on detailed identification and severity classification of pavement distress. This method provided a comprehensive representation of pavement condition and enabled consistent comparison among different road sections [6]. However, PCI required extensive field surveys and detailed data analysis, which sometimes limited its application in resource-constrained environments.

The Surface Distress Index (SDI), in contrast, emphasized rapid visual inspection focusing on surface distress indicators such as crack coverage and pothole distribution. Its simplified procedure allowed faster field assessment and easier implementation compared with PCI, making it suitable for routine inspections. However, the method sometimes failed to capture minor or early-stage damage [7]. In Indonesia, the Bina Marga method developed by the Ministry of Public Works and Housing was widely applied to determine maintenance priorities for national and regional roads. This approach integrated pavement condition indicators with traffic loading considerations to support infrastructure maintenance planning [8]. Although it was practical for policy implementation, its methodological framework sometimes produced condition interpretations that differed from analytical indices such as PCI and SDI.

Previous studies on pavement condition evaluation generally applied a single assessment method or conducted limited comparisons without systematic validation under identical field conditions [9, 10]. Consequently, applying different methods to the same road segment often produced inconsistent maintenance recommendations. Such inconsistencies potentially resulted in inefficient resource allocation, delayed interventions, or premature maintenance actions.

Furthermore, existing research rarely examined the sensitivity of different assessment methods in detecting localized pavement distress, particularly in tropical environments where deterioration patterns were often uneven. Understanding the sensitivity of each method was important because it influenced how damage was identified, interpreted, and prioritized for maintenance. The lack of comparative validation across multiple assessment methods within a single road corridor therefore represented an important research gap in pavement management practice. Wangandawa Road in Tegal Regency served as an important secondary route connecting southern Adiwerna with Talang and Slawi Districts. Field observations indicated various forms of pavement deterioration, including potholes, longitudinal cracking, and localized surface depressions that reduced driving comfort and increased accident risks, particularly for motorcycles. Given its functional importance and observable distress conditions, the road provided an appropriate case study for evaluating the reliability of different pavement assessment methods.

Unlike previous studies that mainly documented pavement conditions, this research conducted a comparative evaluation of PCI, SDI, and the Bina Marga method on the same road segments. Applying the three approaches within identical field conditions allowed analysis of their sensitivity to localized damage, identification of variations in condition ratings, and examination of how these differences influenced maintenance prioritization. This study contributed through three main aspects: the direct application of three commonly used assessment methods under identical field conditions; quantitative comparison of their ability to detect localized pavement distress; and evaluation of how methodological differences affected maintenance decisions for flexible pavements in tropical environments.

Based on the conceptual differences among the three methods, this study hypothesized that assessment approaches involving detailed distress quantification, such as PCI, demonstrated higher sensitivity in detecting localized deterioration compared with rapid visual-based indices such as SDI and policy-oriented approaches such as the Bina Marga method. Consequently, differences in methodological structure were expected to produce variations in maintenance priority recommendations. Therefore, this study aimed to compare PCI, SDI, and the Bina Marga method on Wangandawa Road in order to evaluate how each approach assessed pavement condition, interpreted deterioration patterns, and influenced maintenance prioritization. The findings were expected to support more effective pavement management strategies and evidence-based maintenance planning, particularly in tropical regions where pavement deterioration occurred rapidly.

2. Materials and Methods

To size up the road surface, this study used a quantitative setup based on standard visual surveys. We ran three proven methods—Pavement Condition Index (PCI), Surface Distress Index (SDI), and Bina Marga—across the exact same sections. That way, everything stayed consistent for a fair head-to-head on how they pick up issues in real field settings.

2.1. Study area and sampling unit definition.

The research was conducted along a 660 m flexible pavement section of Wangandawa Road located in Tegal Regency, Indonesia. In accordance with standardized pavement inspection procedures outlined in ASTM D6433, the investigated road section was divided into seven sample units with an approximate length of 100 m per segment. Sticking to standard sampling units gives us the detail needed to catch spotty damage, all while lining up with global PCI guidelines. Breaking the road into shorter, workable stretches also sharpens field measurements and makes it easier to stack up the different methods along the same corridor [10–13].

2.2. Data collection procedure.

Primary data came from structured visual inspections of the pavement, sticking to ASTM D6433 for spotting distress and national guidelines for SDI surveys. Along each marked-out sample unit, we logged surface wear details: the type of issue, how bad it was, and its spread whether by area or length. Common problems spotted included potholes, lengthwise cracks, crosswise cracks, raveling, rutting, and old patch jobs. To boost trustworthiness and cut down on personal bias, the survey team got hands-on training with official distress manuals beforehand. Several inspectors did independent checks, hashing out any differences with follow-up visits. We stuck closely to PCI and SDI classification rules, using uniform forms to keep records straight across every section. These visual methods hold up well for broad network assessments, they're straightforward and solid when backed by tight quality checks [14–16].

2.3. PCI method.

The PCI gauges road health by combining distress types, their severity, and how widespread they are into a score from 0 (total failure) to 100 (top shape). Here, we followed ASTM D6433 steps for flexible pavements [10]. Distress density represents the proportion of pavement deterioration relative to the inspected sample unit and forms the basis for determining pavement condition reduction. The density of area-related distress was calculated using Equation (1), while length-related distress density was determined using Equation (2).

$$\text{Density (\%)} = \frac{\text{Ad}}{As} \times 100 \quad (1)$$

$$\text{Density (\%)} = \frac{\text{Ld}}{As} \times 100 \quad (2)$$

where Ad denotes total distress area, As represents sample unit area, and Ld indicates total distress length within the inspected segment. The calculated density values were subsequently used to determine the Deduct Value (DV) by correlating distress density and severity levels with standardized PCI deduct curves. Each distress type possesses an independent deduct relationship reflecting its influence on pavement structural performance. The Total Deduct Value (TDV) was obtained by summing all individual deduct values corresponding to identified distress types.

To avoid overestimation resulting from cumulative distress interaction, TDV values were adjusted using PCI correction curves to obtain the Corrected Deduct Value (CDV) in accordance with ASTM procedures [14]. The PCI value for each pavement segment was calculated using Equation (3).

$$PCI = 100 - CDV \quad (3)$$

The overall PCI value representing the evaluated road section was determined as the average PCI value of all sample units using Equation (4).

$$\text{PCIf} = \sum \frac{\text{PCIs}}{N} \quad (4)$$

where PCI_f represents the final PCI value, PCI_s denotes the PCI value of each sample unit, and *N* indicates the number of evaluated segments. The resulting PCI values were interpreted using standardized pavement condition classifications presented in Table 1, which categorize pavement performance from failed to excellent conditions [15].

Table 1 Pavement quality classification.

PCI Range	Rating	Colour
85-100	Excellent	Dark Green
70-85	Very Good	Light Green
55-70	Good	Yellow
40-55	Fair	Light Red
25-40	Poor	Medium Red
Oct-25	Very Poor	Dark Red
00-10	Failed	Dark Grey

2.4. SDI.

SDI sizes up pavement by quick visual checks on visible wear. It factors in things like crack length and width, pothole count, and rut depth, each weighted to build the total score per national guidelines. We used the breakdown in Table 2 for rating each distress type. The cumulative SDI value represents pavement surface performance and enables rapid classification of pavement condition for maintenance planning purposes within road management systems [16, 17].

Table 2. SDI scoring.

No.	Distress Type	Category	Sub-Category (X)	Score Calculation
A	Crack Area			
1		None	–	–
2		< 10%	–	5
3		10%–30%	–	20
4		> 30%	–	40
B	Crack Width			
1		None	–	–
2		Fine < 1 mm	–	–
3		Medium 1–3 mm	–	–
4		Wide > 3 mm	–	$SDI_a \times 2$
C	Number of Holes			
1		None	–	–
2		< 10 per 100 m	–	SDI_b + 15
3		10–50 per 100 m	–	SDI_b + 75
4		> 50 per 100 m	–	SDI_b + 225
D	Holes Due to Vehicle Wheels			
1		None	–	–
2		> 1 cm deep	0.5	SDI_c + 5 × X
3		1–3 cm deep	2	SDI_c + 5 × X
4		> 3 cm deep	4	SDI + 20

2.5. Bina Marga pavement assessment method.

The Bina Marga method represents the official pavement evaluation framework employed in Indonesia for determining maintenance priority levels within road infrastructure management systems. This method integrates pavement distress conditions with traffic characteristics expressed as Average Daily Traffic (ADT or LHR) and functional road classification to generate maintenance recommendations. Based on the evaluation outcomes, pavement treatment strategies are categorized into routine maintenance, periodic maintenance, rehabilitation, or reconstruction. For pavement ratings, this study drew on criteria from Indonesia's Ministry of Public Works and Housing, summed up in Table 3. That keeps our findings in line with national standards for deciding on maintenance [18–20].

Table 3 Pavement condition assessment.

SDI Value	Damage Category
< 50	Good
50–100	Moderate
100–150	Light Damage
> 150	Heavy Damage

2.6. Comparative and sensitivity analysis.

To compare PCI, SDI, and Bina Marga head-to-head, we analyzed results from the same road sections. Sensitivity to local damage got measured via stats like average scores, standard deviation, and coefficient of variation (CV). A higher CV signals that a method picks up on uneven wear spots more sharply. Furthermore, segment ranking comparisons were conducted to examine agreement levels among assessment methods in determining maintenance prioritization outcomes. This analytical approach enables objective evaluation of methodological consistency and provides insight into how methodological differences influence pavement maintenance decision-making processes.

3. Results and Discussion

3.1. Field observation results.

Fieldwork covered the full 660 m flexible pavement stretch on Wangandawa Road, split into seven even 100 m chunks (as detailed in Section 2). Figure 1 shows typical distress spotted on-site, with survey measurements feeding straight into our PCI, SDI, and Bina Marga calculations. Visual checks turned up key distress types: lengthwise and crosswise cracks, alligator patterns, patches from past fixes and digs, plus slick aggregate spots.

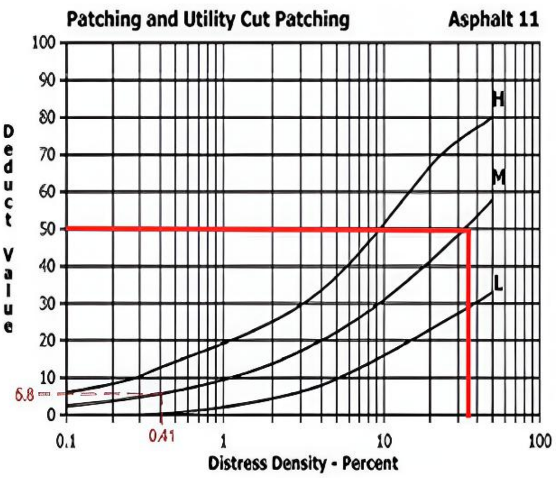

Figure 1. Patches and utility cut patching DV curve (asphalt 11).

Damage wasn't even across the stretch—hotspots tied to heavy traffic and weather took the brunt. Sections with lots of trucks showed worse cracking and shine, pointing to asphalt fatigue building up over time.Cracking took center stage here, matching earlier studies that flag fatigue cracks as the top sign of trouble in flexible pavements [21]. We've seen this patchy spread before in city roads hammered by mixed traffic [22]. Locally in Indonesia, patched spots often fail again because repairs skimped on structural fixes [23]. Field findings on Wangandawa Road back this up: wear varies sharply by segment, so blending multiple evaluation methods makes sense to nail both local hot spots and bigger-picture repair needs.

3.2. PCI method results.

PCI evaluation was performed following the procedure described in Section 2.3. Distress density for each pavement segment was first calculated using Equation (1), after which DV were determined using standard PCI deduct curves shown in Figures 1–3. The TDV obtained from individual distress contributions was corrected using the relationship illustrated in Figure 4, and the final PCI score for each segment was computed using Equation (2).

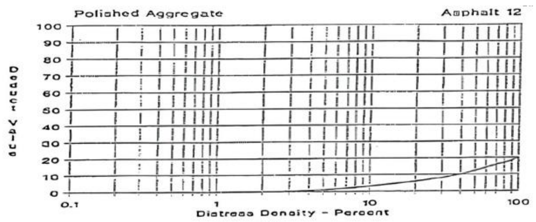

Figure 2. Polished Aggregate DV curve (Asphalt 12).

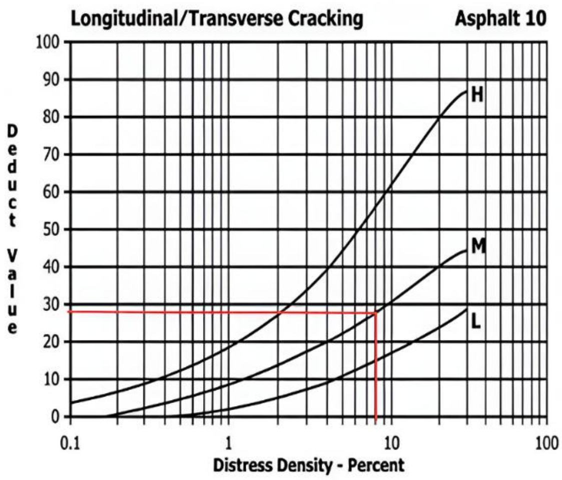

Figure 3. Longitudinal/transverse cracking DV curve (asphalt 10).

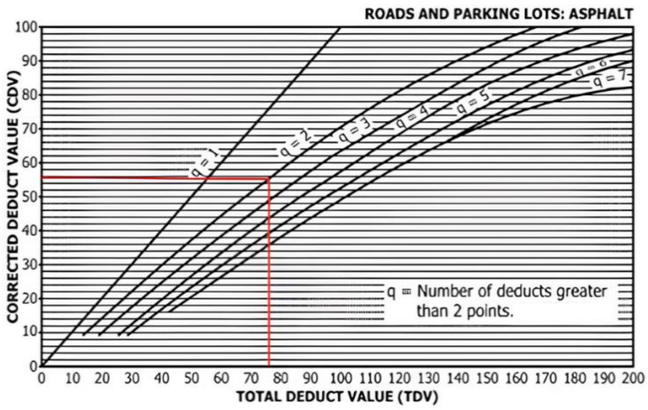

Figure 4. CDV vs. TDV chart (roads and parking lots: asphalt)

Take Segment 1 in Table 4: patches and utility cuts topped the density at 37%, then lengthwise/crosswise cracks at 8.35%, with polished aggregate barely registering. All that patching jacked up the deducts, dragging down the PCI score for the stretch.

Table 4. Distress density calculation for segment 1.

Segment	Type of Distress	Severity Class	Total	Density
1	Patching and Utility Cut Patching	Medium	171,85	37%
	Polished Aggregate	Medium	0,78	0,17%
	Longitudinal/Transverse Cracking	High	38,4	8,35%

Table 5 lays out PCI scores across segments, spanning 45 (fair shape) to 100 (excellent). That spread highlights how uneven performance runs along this road.

Table 5. PCI values and recommended actions for wangandawa road.

Segment	PCI Value	Rating	Recommended Action
1	45	Fair	Major Maintenance
2	62	Good	Preventive Maintenance + Minor Rehabilitation
3	62	Good	Preventive Maintenance + Minor Rehabilitation
4	100	Excellent	Preventive Maintenance
5	82	Very Good	Preventive Maintenance
6	80	Very Good	Preventive Maintenance
7	66	Good	Preventive Maintenance + Minor Rehabilitation

This variability confirms the high sensitivity of PCI toward distress severity and spatial extent. Previous studies demonstrated that PCI analysis effectively distinguishes localized deterioration requiring targeted maintenance strategies [24]. Comparative investigations further confirmed that PCI-based evaluation provides greater discrimination capability than simplified visual condition indices [25]. Studies link this kind of patchiness more to spotty traffic loads than even wear over time [22]. Overall, PCI puts Wangandawa Road in "Good" territory, but those rough local spots call for targeted fixes first.

3.3. SDI method results.

SDI checks used the four key parameters from Section 2.4—crack area and width, pothole count, rut depth—with ratings per Table 2. Table 6 sums up scores per segment. Most fell into Good-to-Moderate buckets (0-80 range). Segment 1 topped the list from fair crack spread plus widths over 3 mm; others showed light wear. Against PCI, SDI stayed flatter across segments. That tracks with its focus on broad surface looks over fine severity details. Past work notes SDI shines for quick network scans but can gloss over local structural woes [26], while holding steady for big-picture planning [27]. Consequently, SDI evaluation suggests that routine maintenance is generally sufficient across the study area; however, its lower sensitivity may limit its ability to detect early-stage structural failures identified through PCI analysis.

Table 6. SDI score and maintenance recommendation for each segment.

Segment	SDI Value	Damage Category	Recommended Maintenance
1	80	Moderate	Routine Maintenance
2	80	Moderate	Routine Maintenance
3	80	Moderate	Routine Maintenance
4	0	Good	Routine Maintenance
5	10	Good	Routine Maintenance
6	40	Good	Routine Maintenance
7	40	Good	Routine Maintenance

3.4. Binamarga.

The Bina Marga assessment incorporated pavement distress counts together with traffic characteristics expressed as Average Daily Traffic (LHR), following national evaluation procedures described in Section 2.5. Distress distribution for each segment is summarized in Table 7. The results indicate that longitudinal and transverse cracking constituted the most dominant distress type across the study area, consistent with PCI and SDI findings. Averaging distress scores with Road Class 5 traffic put every segment in Priority A—time for regular upkeep. While PCI dives into density and severity, Bina Marga leans toward ops decisions by mixing traffic role with damage frequency. Studies point out it excels at policy-level ranking over deep structural dives [28], proving handy for managing roads at scale in emerging networks [26]. Thus, Bina Marga provides practical maintenance prioritization aligned with national infrastructure management frameworks, although with reduced analytical sensitivity compared to PCI.

Table 7. Pavement distress count for each segment (Bina Marga Method).

Segment	Type of Distress	Total Distress Count
1	Longitudinal/Transverse Cracking	14
	Patching and Utility Cut Patching	7
	Polished Aggregate	5
2	Alligator Cracking	1
	Longitudinal/Transverse Cracking	6
	Patching and Utility Cut Patching	1
	Polished Aggregate	6
3	Longitudinal/Transverse Cracking	8
	Polished Aggregate	11
4	Polished Aggregate	9
5	Longitudinal/Transverse Cracking	2
	Polished Aggregate	14
6	Longitudinal/Transverse Cracking	3
	Polished Aggregate	6
7	Longitudinal/Transverse Cracking	2
	Polished Aggregate	7
Average Distress Count	—	**6.375**

3.5. Comparative analysis.

A comparative summary of pavement condition evaluation results obtained from PCI, SDI, and Bina Marga methods is presented in Table 8. SDI and Bina Marga line up here—both call for routine fixes across the board, signaling Wangandawa Road still holds up network-wide. Other studies have seen this match between quick visual tools and national systems [25]. PCI, though, swung wider—from Fair to Excellent.

Table 8. Comparison of pavement condition results (SDI, PCI, Bina Marga).

Segment	SDI Value	SDI Category	PCI Value	PCI Rating	Bina Marga Score	Bina Marga Priority
1	80	Moderate	45	Fair	10	Priority A
2	80	Moderate	62	Good	10	Priority A
3	80	Moderate	62	Good	10	Priority A
4	0	Good	100	Excellent	10	Priority A
5	10	Good	82	Very Good	10	Priority A
6	40	Good	80	Very Good	10	Priority A
7	40	Good	66	Good	10	Priority A

Segment 1 stands out: it flagged deep structural issues that SDI and Bina Marga glossed over. Research backs this—PCI's edge comes from weighing density and severity [24]. Each method brings its own angle: PCI drills into structural details via numbers, SDI checks surface looks fast, and Bina Marga weighs damage against traffic needs for priorities. Experts push multi-tool setups to boost decision trust and road longevity [21]. Blending PCI, SDI, and Bina Marga delivers the full picture—precision, speed, and real-world planning. It sharpens upkeep strategies for city roads.

4. Conclusions

This work sized up a 660 m stretch of Wangandawa Road with PCI, SDI, and Bina Marga. On-site, we found heavy cracking (lengthwise and crosswise), patch failures from fixes and digs, worn slick surfaces, plus local dips. These findings indicate that pavement deterioration is primarily surface-related; however, several segments also demonstrate early indications of structural weakening caused by repetitive traffic loading and environmental exposure. The comparative analysis shows that each assessment method provides different levels of sensitivity in describing pavement performance. PCI gave the finest breakdown—from Fair to Excellent—spotting severity and density per segment. That lets agencies nail priorities: from prevention to full rebuilds. SDI speeds up big surveys, while Bina Marga fits national policy and on-the-ground calls. Key takeaway: sticking to one method risks off-base decisions. Better to lead with PCI for depth, back it with SDI for quick scans, and Bina Marga for compliance. This mix boosts efficiency, smart spending, and long-term road care. In the end, the study hands local teams clear pointers on picking tools by goals, budget, and detail needs. Future research is recommended to include longer road networks, structural capacity testing, traffic growth prediction,and life-cycle cost analysis to strengthen decision-making models for pavement maintenance and rehabilitation planning.

Author Contribution

This study was completed with contributions distributed among all authors. Suprapto Hadi provided supervision throughout the research process. Ikbarul Zikri was responsible for data collection and conceptualization. Antika Tri Cahyanti contributed to writing and data analysis.Nasywa Maulidya Putri worked on methodology development and data analysis. Nurina Vidya Ayuningtyas contributed to data collection and methodology. Raditya Faris Nailulloh contributed to methodology and conceptualization. All authors reviewed the manuscript and approved the final version for publication.

Competing Interest

All authors should disclose any financial, personal, or professional relationships that might influence or appear to influence their research.

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