Article

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Significance of Pulse Oximetry Monitoring in the Early Prediction of Respiratory Distress Syndrome in Neonates With Low Birth Weight

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Background: Respiratory distress syndrome (RDS) is a common clinical condition in preterm infants, complicated by pulmonary inflammation and edema. Early identification remains challenging due to limitations in conventional diagnostics. This study aims to explore the clinical significance of pulse oximetry monitoring in predicting RDS in low birth weight (LBW) neonates.
Methods: This retrospective analysis included 140 LBW neonates admitted to Zhongshan Hospital of Xiamen University between February 2022 and March 2023. The patients were divided into an RDS group (n = 51) and a non-RDS group (n = 89) based on the RDS diagnostic criteria. Furthermore, based on the severity of RDS, they were categorized into mild, moderate, and severe RDS subgroups. Additionally, based on surfactant therapy, patients in the RDS group were divided into the surfactant and non-surfactant subgroups. Baseline clinical characteristics were compared between the two groups. Similarly, pulse oximetry, heart rate, and respiratory rate were analyzed among the patients. Univariate and multivariate logistic regression analyses were performed to identify independent risk factors for RDS diagnosis. The clinical significance of combined heart rate, respiratory rate, 1-minute Apgar score, and the ratio of peripheral oxygen saturation to fraction of inspired oxygen (SpO_2/FiO_2) in predicting RDS was assessed using receiver operating characteristic (ROC) curve analysis.
Results: Compared to the non-RDS group, the RDS group had significantly higher heart rate and respiratory rate at 6 h ($p < 0.001$) and lower SpO_2 and SpO_2/FiO_2 ($p = 0.017$, $p < 0.001$). Additionally, the surfactant group showed a significantly higher SpO_2/FiO_2 ratio at 6 h, 12 h, and 24 h, compared to the non-surfactant group ($p < 0.05$). Multivariate logistic regression analysis identified heart rate ($p = 0.042$) and respiratory rate ($p = 0.009$), as independent risk factors, while 1-minute Apgar score ($p = 0.037$) and SpO_2/FiO_2 (6 h) ($p = 0.005$) were identified as independent protective factors for predicting RDS in LBW neonates. The ROC curve analysis revealed that the combined prediction model had an area under the curve of 0.995.
Conclusion: In conclusion, heart rate and respiratory rate were identified as independent risk factors, whereas 1-minute Apgar score and SpO_2/FiO_2 were independent protective factors for RDS in LBW neonates. The combined predictive model shows reliable diagnostic performance, underscoring the clinical significance of pulse oximetry monitoring in early RDS identification.

Keywords: low birth weight; respiratory distress syndrome; pulse oximetry; SpO_2/FiO_2; predictive model

Introduction

Low birth weight (LBW) represents a birth weight of less than 2500 g and is a major risk factor for neonatal morbidity and mortality [1]. Every year, over 200,000 infants are born with LBW worldwide, with more than 90% of these births occurring in developing countries [2].

Respiratory distress syndrome (RDS) is a common complication in preterm infants, primarily caused by underdeveloped lungs and insufficient pulmonary surfactant [3,4]. In some cases, preterm infants may also experience pulmonary inflammation and edema, which can exacerbate the severity of RDS [5]. RDS is primarily characterized by hypoxemia and respiratory distress, which can progress to severe acidosis and other complications if not identified and treated early [6,7]. Its diagnosis typically relies on clinical manifestations, imaging studies, and blood gas analysis [8]. However, these diagnostic methods may encounter delays or operational challenges in some cases. Clinically, early administration of surfactants and mechanical ventilation has been shown to significantly improve the prognosis of neonatal RDS [9]. However, while mechanical ventilation improves oxygenation, it also carries the risk of lung injury, particularly when high concentrations of oxygen or prolonged ventilatory support are required [10]. Therefore, balancing therapeutic efficacy and potential side effects is crucial while managing RDS to achieve optimal outcomes.

Pulse oximetry is a non-invasive, convenient, and cost-effective tool that enables early detection of hypoxemia through real-time monitoring of peripheral oxygen

saturation (SpO_2) [11]. The World Health Organization (WHO) recommends its use as a standard method for neonatal health management. Pulse oximetry has been widely used for identifying neonatal hypoxemia and managing oxygen therapy, helping to reduce the incidence of neonatal-related complications [12].

Despite its extensive application in health-care settings ranging from intensive care units to delivery rooms and neonatal screening, pulse oximetry still has certain limitations. For example, this technology is less sensitive to hyperoxemia and may not accurately reflect changes in oxygen partial pressure when blood oxygen levels are high [13]. Additionally, the calibration data of pulse oximeters are based on healthy adults, which may lead to inaccuracies when applied to preterm infants. Furthermore, monitoring results can be influenced by motion artifacts and abnormal blood flow, potentially compromising measurement accuracy [14]. These limitations underscore the need for further research to explore its role in specific diseases and to optimize its application strategies.

This study aims to investigate the significance of pulse oximetry in neonatal RDS and systematically evaluate its clinical utility in predicting RDS by integrating physiological parameters such as heart rate and respiratory rate. The findings are expected to provide theoretical support for optimizing neonatal monitoring strategies and practical guidance for improving the accuracy of RDS diagnosis.

Materials and Methods

Study Subjects and Groups

This retrospective analysis recruited 140 LBW infants admitted to Zhongshan Hospital of Xiamen University between February 2022 and March 2023. Written informed consent was obtained from the parents or legal guardians of all participants. The study protocol was approved by the Ethics Committee of Zhongshan Hospital of Xiamen University (2023-146), and adhered to the principles of the Declaration of Helsinki.

All infants were divided into an RDS group (n = 51) and a non-RDS group (n = 89) based on their RDS diagnosis as outlined in the *Practice of Neonatology* [15]. Based on the ratio of arterial partial pressure of oxygen to the fraction of inspired oxygen (PaO_2/FiO_2) value, infants in the RDS group were sub-grouped into a mild RDS group (200 mmHg $<$ PaO_2/FiO_2 $\leq$ 300 mmHg; n = 16), a moderate RDS group (100 mmHg $<$ PaO_2/FiO_2 $\leq$ 200 mmHg; n = 25), and a severe RDS group (PaO_2/FiO_2 $\leq$100 mmHg; n = 10). Additionally, based on surfactant therapy, infants in the RDS groups were divided into two subgroups: the surfactant group (n = 18) and the non-surfactant (n = 33) group.

Inclusion and Exclusion Criteria

The inclusion criteria for patient selection were as follows: (1) infants whose gestational age $<$37 weeks; (2) neonates with birth weight $<$2500 g; (3) infants in the RDS group who meet the RDS diagnostic criteria [16] as outlined in the *Practice of Neonatology*; and (4) PaO_2/FiO_2 ratio $\leq$300 mmHg, with Positive End-Expiratory Pressure (PEEP) $\geq$5 cm H_2O.

Exclusion criteria included infants with (1) combined congenital heart disease, (2) congenital anomalies, (3) congenital developmental malformations of the respiratory system, (4) hematological disorders, (5) abnormal renal or hepatic functions, (6) a state of shock; and (7) who passed away within the first 24 hours after birth.

Clinical Data Collection

Clinical information of the infants was collected, including sex, gestational age (in weeks), birth weight (in grams), and Apgar scores at 1 and 5 min after birth. Furthermore, maternal information, such as advanced maternal age, mode of delivery, and parity, was also recorded. The Apgar score assesses a newborn's condition at birth based on skin color, heart rate, reflexes, muscle tone, and respiration. Each item is scored from 0–2, with a total score of 0 to 10; lower scores indicate greater levels of distress [17].

When the neonates were calm, awake, and breathing spontaneously, the measurement site was sterilized with alcohol pads to remove any blood, amniotic fluid, and vernix. Peripheral SpO_2 was then measured using a pulse oximeter (M8001A, Philips, Tokyo, Japan), with SpO_2 recorded from the right upper limb, along with simultaneous measurements of heart and respiratory rates.

Statistical Analysis

Statistical analysis was performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA). Normality was assessed using the Shapiro-Wilk test. Data following normal distribution were presented as mean $\pm$ standard deviation (SD), while non-normally distributed data were expressed as the median and interquartile range (IQR). Group comparisons were conducted using an independent sample *t*-test or the Mann-Whitney *U* test. Moreover, multiple-group comparisons were performed using one-way Analysis of variance (ANOVA), followed by post hoc analysis with the least significant difference (LSD) test. Categorical variables were expressed as frequency (%) and analyzed using the Chi-square test.

Several clinical parameters served as independent variables, with the occurrence of RDS as the dependent variable (1 = RDS, 0 = no RDS). Univariate logistic regression analysis was performed to evaluate factors associated with RDS. , including both independent risk factors (odds ratio$>$1) and independent protective factors (odds ratio $<$1). The predictive performance of SpO_2 for RDS in

Table 1. Comparison of baseline characteristics between the RDS and non-RDS groups.

Variable	RDS group (n = 51)	Non-RDS group (n = 89)	$\chi^2/t/z$	p-value
Sex, n (%)			2.629	0.105
Male	33 (64.71)	45 (50.56)		
Female	18 (35.29)	44 (49.44)		
Birth weight (g), (mean ± SD)	1540.94 ± 84.4	1733.09 ± 155.26	8.166	<0.001
1 min-Apgar score (median, IQR)	3 (2–4)	8 (7–9)	579.5	<0.001
5 min-Apgar score (median, IQR)	5 (3–8)	8 (7–9)	1022	<0.001
Mode of delivery, n (%)			2.313	0.128
Cesarean section	19 (37.25)	45 (50.56)		
Vaginal delivery	32 (62.75)	44 (49.44)		
Parity, n (%)			0.416	0.519
1	45 (88.24)	75 (84.27)		
2	6 (11.76)	14 (15.73)		
Gestational age (weeks), (mean ± SD)	31.53 ± 2.5	31.78 ± 2.0	0.629	0.531
Advanced maternal age, n (%)			1.756	0.185
Yes	21 (41.18)	47 (52.81)		
No	30 (58.82)	42 (47.19)		
Heart rate (6 h), (mean ± SD)	144.96 ± 7.85	130.91 ± 9.09	–9.236	<0.001
Respiratory rate (6 h), (mean ± SD)	63.12 ± 4.73	47.43 ± 7.97	–12.815	<0.001

Note: RDS, respiratory distress syndrome; SD, standard deviation; IQR, interquartile range.

LBW infants was assessed using receiver operating characteristic (ROC) curve analysis. A p-value of <0.05 was considered statistically significant.

Results

Comparison of Baseline Characteristics Between the Two Groups

This study recruited 140 patients, including 89 in the non-RDS group and 51 in the RDS group. There were no significant differences between the two groups in terms of sex distribution ($p = 0.105$), mode of delivery ($p = 0.128$), or gestational age ($p = 0.531$). However, the birth weight was significantly lower in the RDS group than in the non-RDS group ($p < 0.001$). Additionally, the RDS group showed a substantial reduction in the 1-minute and 5-minute Apgar scores compared to the non-RDS group ($p < 0.001$). In contrast, the heart rate and respiratory rate were significantly higher in the RDS group ($p < 0.001$). Moreover, there were no significant differences between the two groups in terms of advanced maternal age proportion ($p = 0.185$) or parity ($p = 0.519$) (Table 1).

Analysis of Pulse Oxygenation Parameters

We focused on the oxygenation parameters of neonates within the first 6 h after birth in both the RDS and non-RDS groups. The results showed that SpO_2 was significantly lower in the RDS group than in the non-RDS group (93.74 ± 3.66% vs. 95.31 ± 3.71%, $p = 0.017$), while FiO_2 requirements were substantially higher in the RDS group (50.39 ± 5.85% vs. 43.10 ± 3.79%, $p < 0.001$). Additionally, the SpO_2/FiO_2 ratio was significantly lower in the RDS group compared to the non-RDS group (188.79 ± 25.61 vs. 222.85 ± 21.67, $p < 0.001$).

Furthermore, significant differences were observed in SpO_2, FiO_2, and SpO_2/FiO_2 ratio among RDS groups of different severity ($p < 0.001$). Compared to the mild RDS group, SpO_2 progressively decreased, FiO_2 requirements increased, and the SpO_2/FiO_2 ratio declined in the moderate and severe RDS groups ($p < 0.05$) (Table 2).

Effect of Surfactant Therapy on Oxygenation in RDS Neonates

Furthermore, neonates in the RDS group were categorized into the surfactant (n = 18) and non-surfactant (n = 33) groups based on whether they received surfactant therapy. Comparing oxygenation parameters between these two groups revealed no significant difference in SpO_2 before treatment. However, SpO_2 increased over time in both groups after treatment, with the surfactant group demonstrating significantly higher SpO_2 at 3 h, 6 h, and 12 h ($p < 0.05$) (Fig. 1A). In parallel, FiO_2 requirements gradually decreased in both groups after treatment, with the surfactant group showing a significantly lower FiO_2 at 12 h and 24 h ($p < 0.05$) (Fig. 1B). Additionally, the SpO_2/FiO_2 ratio was considerably higher in the surfactant group at 6 h, 12 h, and 24 h compared to the non-surfactant group ($p < 0.05$ for all), indicating greater improvement in oxygenation (Fig. 1C).

Factors Associated With RDS Occurrence in LBW Neonates

The univariate logistic regression analysis identified the following factors significantly related to the occurrence of RDS in LBW infants: heart rate (6 h) ($p < 0.001$), res-

Table 2. Comparison of oxygenation parameters within the first 6 h of birth between the groups.

Group	n	SpO_2 (%)	FiO_2 (%)	SpO_2/FiO_2
RDS group	51	93.74 ± 3.66	50.39 ± 5.85	188.79 ± 25.61
Non-RDS group	89	95.31 ± 3.71	43.10 ± 3.79	222.85 ± 21.67
t		2.422	–8.949	8.366
p-value		0.017	<0.001	<0.001
RDS Severity				
Mild	16	96.92 ± 2.43	44.65 ± 3.59	218.30 ± 17.92
Moderate	25	94.16 ± 3.43*	50.21 ± 4.86*	189.23 ± 19.51*
Severe	10	91.08 ± 2.78*	54.27 ± 5.53*#	169.67 ± 20.35*#
F		11.658	12.005	19.166
p-value		<0.001	<0.001	<0.001

*$p < 0.05$ vs. Mild group; #$p < 0.05$ vs. Moderate group. SpO_2, peripheral oxygen saturation; FiO_2, fraction of inspired oxygen.

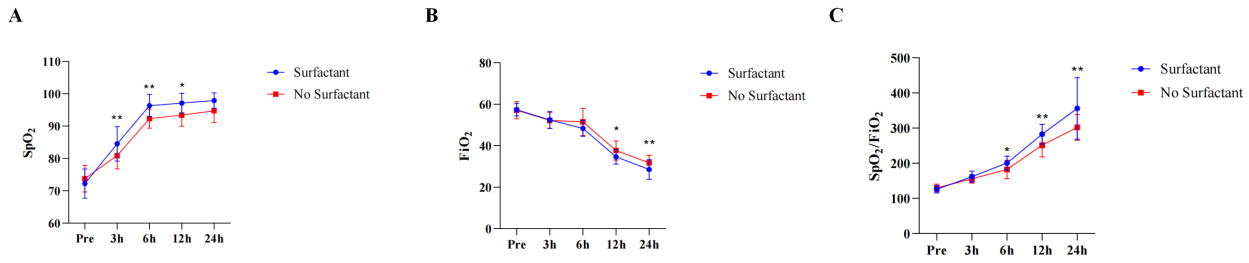

Fig. 1. Comparison of oxygenation parameters between surfactant and non-surfactant groups in RDS infants with low birth weight (LBW). (A) SpO_2, (B) FiO_2, and (C) SpO_2/FiO_2 were assessed at baseline (Pre), and at 3 h, 6 h, 12 h, and 24 h after treatment in infants who received or did not receive surfactant therapy. Surfactant group (n = 18), non-surfactant group (n = 33). *$p < 0.05$; **$p < 0.01$ vs. non-surfactant group.

piratory rate (6 h) ($p < 0.001$), 1-minute Apgar score ($p < 0.001$), 5-minute Apgar score ($p < 0.001$), and SpO_2/FiO_2 (6 h) ($p < 0.001$).

Subsequent multivariate logistic regression analysis revealed that heart rate ($p = 0.042$) and respiratory rate ($p = 0.009$) were independent risk factors, whereas 1-minute Apgar score ($p = 0.037$), and SpO_2/FiO_2 (6 h) ($p = 0.005$) were identified as independent protective factors for the occurrence of RDS in LBW neonates (Table 3).

The Receiver Operating Characteristic Curve Analysis

ROC curve analysis indicated that heart rate, respiratory rate, 1-minute Apgar score, and SpO_2/FiO_2 had superior diagnostic performance in predicting the occurrence of RDS in LBW infants. The combined predictive model (orange) achieved an area under the curve of 0.995 (95% CI: 0.987–1.000, $p < 0.001$) (Fig. 2). Detailed diagnostic metrics for each predictor are provided in **Supplementary Table 1**.

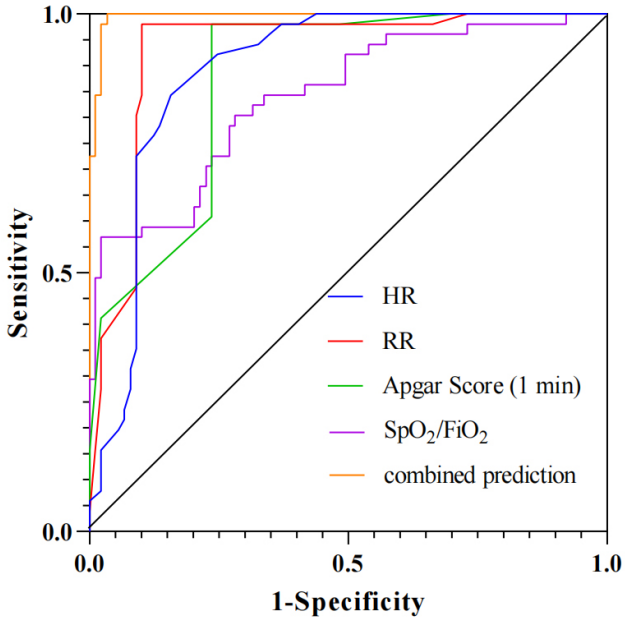

Fig. 2. The receiver operating characteristic (ROC) curve for the combined prediction of RDS in LBW infants. HR, heart rate; RR, respiratory rate.

Discussion

RDS is a common condition among preterm infants, usually caused by lung underdevelopment and insufficient active substances on the alveolar surface [8]. It is the leading cause of respiratory failure and death in neonates. Clin-

Table 3. Univariate and multivariate analysis for predicting RDS.

Variables	Univariate		Multivariate	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Sex	0.558 (0.275–1.133)	0.107		
Mode of delivery	1.722 (0.852–3.481)	0.130		
Birth weight	2.172 (0.851–5.545)	0.105		
Advanced maternal age	1.599 (0.797–3.206)	0.186		
Parity	0.714 (0.256–1.991)	0.520		
Heart rate (6 h)	1.188 (1.121–1.258)	<0.001	1.191 (1.006–1.409)	0.042
Respiratory rate (6 h)	1.314 (1.206–1.432)	<0.001	1.542 (1.116–2.130)	0.009
1 min-Apgar score	0.493 (0.395–0.614)	<0.001	0.269 (0.078–0.925)	0.037
5 min-Apgar score	0.697 (0.604–0.806)	<0.001	1.710 (0.773–3.782)	0.185
Gestational age	1.865 (0.635–5.475)	0.257		
SpO_2/FiO_2 (6 h)	0.937 (0.916–0.959)	<0.001	0.887 (0.816–0.964)	0.005

OR, odds ratio.

ically, diagnosing RDS usually relies on clinical symptoms, chest imaging, and blood gas analysis results [8]. Prompt and precise prediction and diagnosis are particularly crucial for managing LBW infants once RDS develops. Research has shown that preterm infants with RDS have lower and unstable arterial blood pressure and reduced arterial oxygen saturation, resulting in impaired cerebral oxygenation compared to those without RDS [18]. Additionally, neonates with RDS often experience shortness of breath and an increased respiratory rate [19]. After receiving surfactant therapy, preterm infants with RDS usually demonstrate an alleviation in heart and respiratory rates, higher SpO_2, and improved overall respiratory status [20].

Pulse oximetry monitoring plays a crucial role in effectively managing RDS [21]. A study by Seddon *et al.* [22] investigated the feasibility and accuracy of using pulse oximetry for continuous respiratory monitoring in preterm infants in a home setting. They reported that the photoplethysmographic signal from the pulse oximeter could accurately determine the respiratory rate, which was consistent with the measurements from traditional respiratory inductance plethysmography bands. This suggests that pulse oximetry can be an effective tool for monitoring respiratory status in preterm infants at home. The study also demonstrated that low birth weight neonates who developed RDS had significantly lower birth weights and Apgar scores (at 1 and 5 min after birth) compared to those without RDS. Moreover, at the 6-h time point, both heart and respiratory rates increased, while SpO_2 decreased in the RDS group. Furthermore, as the severity of RDS increased, SpO_2 gradually decreased, and FiO_2 requirements increased, with the lowest SpO_2/FiO_2 ratio observed in the severe RDS group. Further analysis of the impact of surfactant treatment on oxygenation within 24 h revealed that the surfactant group showed a faster increase in SpO_2 and a more pronounced decrease in FiO_2 requirements, suggesting improved oxygenation and reduced oxygen dependency following surfactant treatment.

A retrospective study analyzed continuous pulse oximetry monitoring data of neonates with RDS in the neonatal intensive care unit (NICU). They found that higher heart rate variability and initial FiO_2 were significantly associated with an increased risk of NICU admission. Continuous monitoring of heart rate, oxygen saturation, birth weight, and delivery method was observed as independent variables, demonstrating strong predictive performance for discharge time [23]. Our study observed 1 min-Apgar score, heart rate, respiratory rate, and SpO_2/FiO_2 ratio as independent risk factors for predicting RDS in LBW infants. These observations suggest that combining the monitoring of heart rate, respiratory rate, and SpO_2 offers superior diagnostic performance for predicting RDS.

It is worth noting that while this study primarily focused on the value of pulse oximetry monitoring in the early RDS prediction and dynamic changes in oxygenation parameters, its impact on long-term outcomes needs further investigation. Bronchopulmonary dysplasia (BPD), a chronic pulmonary complication in preterm infants, has been closely associated with early-onset RDS [24]. Therefore, early and effective interventions may help alleviate pulmonary inflammation, reduce the duration of mechanical ventilation and high-concentration oxygen therapy, and ultimately decrease the incidence of BPD.

Despite certain promising outcomes, this study has several limitations. First, being a single-center retrospective study, the sample size was relatively small, and no formal power analysis was performed for subgroup comparisons. Second, this study primarily evaluated the early changes in oxygenation parameters in RDS infants without assessing long-term outcomes or their associations with other chronic complications. Furthermore, maternal health conditions (e.g., gestational hypertension, diabetes) were not included in the exclusion criteria, possibly introducing residual confounding effects. Thus, future multi-center, large-scale, prospective studies, combined with long-term follow-up data, would enhance the study rigor, thereby enhancing the clinical applicability of the findings.

Conclusion

In summary, this study identifies the 1-minute Apgar score, heart rate, respiratory rate, and SpO_2/FiO_2 as independent risk factors for predicting RDS in LBW neonates, and their combined assessment can improve the diagnostic accuracy of RDS. Furthermore, pulse oximetry monitoring within the first 24 h of birth can effectively predict the occurrence of RDS, providing valuable clinical guidance for early diagnosis and treatment decisions.

Abbreviations

RDS, respiratory distress syndrome; LBW, low birth weight; SpO_2, peripheral oxygen saturation; FiO_2, fraction of inspired oxygen;ROC, receiver operating characteristic; HR, heart rate; RR, respiratory rate; IQR, interquartile range; SD, standard deviation; LSD, least significant difference.

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding authors on reasonable request.

Author Contributions

LC: Conceptualization; Data curation; Formal analysis; Writing - original draft; Writing - review & critical revision. XY: Data curation; Methodology; Writing - original draft; Writing - review & critical revision. BJ: Conceptualization; Data curation; Methodology; Writing - review & critical revision. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Written informed consent was obtained from the parents or legal guardians of all participants. The study protocol was approved by the Ethics Committee of Zhongshan Hospital of Xiamen University (2023-146), and adhered to the principles of the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.24976/Discov.Med.202537198.109.

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