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Analysis of Open Top Roller Machine Effectiveness and Identification of Six Big Losses at PT Perkebunan Nusantara IV Regional IV Unit Usaha Danau Kembar

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ABSTRACT

The six-unit Open Top Roller (OTR) system at PT Perkebunan Nusantara IV Regional IV Unit Usaha Danau Kembar recorded 43 failures and 519 machine-hours of downtime. This study measured OTR effectiveness, identified six big losses, prioritized causes, and proposed maintenance improvements. A quantitative descriptive approach combined machine-hour-based Overall Equipment Effectiveness (OEE), fishbone analysis, Failure Mode and Effects Analysis (FMEA), critical values, and cross-functional validation. Average OEE was 66.75%, comprising 96.52% availability, 69.18% performance efficiency, and 100% quality for outputs accepted for further processing. Reduced speed losses dominated at 29.77%, and nine priority causes were identified. Despite high availability, inconsistent speed control and maintenance constrained output. Five improvements were proposed: component inspection and maintenance intervals, operational readiness checksheets, equipment and workplace cleaning checksheets, raw material preparation and cleaning procedures, and speed and stability monitoring checksheets. These measures target reduced speed and equipment failure losses through more consistent operating and maintenance practices.

Keywords: *OEE, Six Big Losses, Fishbone diagram, FMEA, OTR Machine*.

1. Introduction

The reliability of production machinery is one of the key factors determining a company's ability to maintain smooth operations and control production time losses caused by equipment failures [1]. Conversely, declining machine reliability and the occurrence of equipment disturbances can increase downtime, reduce production speed, and cause resource waste, thereby decreasing production process effectiveness [2]. Therefore, machine conditions must be maintained through planned maintenance to minimize unexpected failures and ensure more stable production processes [3], [4]. In line with this requirement, [5], [6], [7] stated that preventive maintenance practices can reduce downtime, improve equipment reliability, and lower repair costs.

Machine reliability issues were identified in the orthodox black tea processing operation at PT Perkebunan Nusantara IV Regional IV Unit Usaha Danau Kembar. The milling station is located at the initial stage of processing; therefore, disturbances in this section can disrupt the continuity of subsequent processes. Based on 2025 operational data and the downtime Pareto diagram, the Open Top Roller (OTR) system, which consists of six parallel units, recorded the highest accumulated downtime at the milling station, reaching 519 machine-hours (MH) from 43 failure events. Although failure

histories have been recorded, the effectiveness level of the OTR system and the types of losses affecting its performance have not been comprehensively measured.

Measurements of Overall Equipment Effectiveness (OEE) across various production systems indicate that effectiveness values and dominant loss types are not always the same [8], [9], [10]. In study [11], the major losses identified consisted of idling and minor stoppages losses, reduced speed losses, and equipment failure losses, although overall machine performance was considered relatively good. Consistent with these findings, [12] identified reduced speed losses as the largest loss when the OEE value reached 81.46%. In another case, [13] obtained an OEE value of 77.28% for a lathe machine, with breakdown losses accounting for 58.7% as the largest loss, while [14] found idling and minor stoppages losses as the dominant loss in sewing line machine 10, where effectiveness remained below world-class standards. These differences indicate that dominant losses must be determined based on the operational data of each analyzed object.

However, the identification of losses alone does not indicate which causes should be prioritized in developing improvement strategies. Therefore, further analysis is required to link losses with their causes and priority levels. In its application, [14] used a fishbone diagram and Failure Mode and Effects Analysis (FMEA) after identifying losses through OEE and six big losses to investigate causes and develop improvement recommendations. Similarly, [13] applied FMEA in evaluating lathe machine effectiveness. In another study, [15] combined a fishbone diagram, FMEA, and a Pareto diagram to identify 21 production risk causes in mango production and determine 14 priority risks based on the Risk Priority Number (RPN). Overall, these approaches demonstrate that loss identification results can serve as a basis for tracing causes and determining improvement priorities [16], [17], [18].

Nevertheless, among the five previous studies reviewed, no study has measured the effectiveness of a six-unit parallel OTR system based on MH and continued with priority determination using FMEA, critical value, and cross-functional validation. Consequently, system-level information regarding OTR effectiveness, dominant losses, and priority causes as a basis for developing improvement recommendations is still unavailable.

To address this research gap, this study aims to measure the effectiveness of the OTR machine system using MH-based OEE, identify losses through the six big losses approach, investigate the causes of dominant losses using a fishbone diagram, determine priority causes through FMEA, critical values, and cross-functional validation, and develop maintenance system improvement recommendations. Practically, this study contributes by providing information regarding OTR system effectiveness and a basis for determining improvement priorities in a six-unit machine system operating in parallel.

2. Method

2.1 Time and Place of Research

This study employed a quantitative descriptive design and was conducted at the milling workstation of PT Perkebunan Nusantara IV Regional IV Unit Usaha Danau Kembar. The research object and unit of analysis was the OTR machine system, which consists of six parallel units, namely OTR 1 to OTR 6. The operational data analyzed covered the period from January to December 2025 based on MH.

2.2 Data Collection Techniques

Primary data were obtained through observation, interviews, and FMEA questionnaire assessments. The questionnaires were completed by five internal maintenance practitioners consisting of one chief mechanic and four installation mechanics. Secondary data were obtained from company documents and records, including the actual operating time of each unit, production volume, machine capacity, OTR output quality, component failure history, and downtime.

2.4 Data Processing and Analysis Techniques

Data processing began with determining the operating machine-hour (OMH) based on the actual operating time of OTR 1 to OTR 6 and the downtime machine-hour (DMH) based on the accumulated time lost due to disturbances or failures. The planned machine-hour (PMH) was determined by adding OMH and DMH. The system effectiveness was then measured using OEE based on availability, performance efficiency, and quality rate through Equations (1)-(4). The ideal system capacity in the performance efficiency calculation was obtained from the combined ideal capacity of the six OTR units, while the good output used in the quality rate calculation referred to OTR output that was accepted for the subsequent processing stage.

$$\text{OEE} = \text{Availability} \times \text{Performance efficiency} \times \text{Quality rate} \quad (1)$$

$$\text{Availability} = \left(\frac{\text{OMH}}{\text{PMH}}\right) \times 100\% \quad (2)$$

$$\text{Performance efficiency} = \left(\frac{\text{Total Product Processed}}{\text{Kapasitas Ideal}}\right) x100\% \quad (3)$$

$$\text{Quality rate} = \left(\frac{\text{Good output}}{\text{Total Product Processed}}\right) x100\% \quad (4)$$

Information:
OMH = Operating machine hour
PMH = Planned machine hour

The OEE measurement results were analyzed using the six big losses approach. Equipment failure losses and reduced speed losses were calculated using Equations (5)-(6), while rework losses and yield or scrap losses were calculated using Equations (7)-(8). Setup and adjustment losses and idling and minor stoppages losses were not quantitatively calculated because the available historical data did not adequately record the duration of each occurrence.

$$\text{Equipment failure losses} = \left(\frac{\text{DMH}}{\text{PMH}}\right) \times 100\% \quad (5)$$

$$\text{Reduced speed losses} = \left(\frac{\text{OMH} - \text{M} \quad \text{Produksi Ideal}}{\text{PMH}}\right) \times 100\% \quad (6)$$

$$\text{Rework Losses} = \frac{\text{Jumlah Rework} \times \text{Ideal Cycle Time}}{\text{PMH}} \times 100\% \quad (7)$$

$$\text{Yield or Scrap Losses} = \frac{\text{Jumlah Scrap} \times \text{Ideal Cycle Time}}{\text{PMH}} \times 100\% \quad (8)$$

The causes of reduced speed losses and equipment failure losses were identified using a fishbone diagram based on six categories (6M), namely machine, method, material, man, measurement, and environment. Each cause of failure was evaluated using FMEA based on severity (S), occurrence (O), and detection (D). The scores from the five respondents were aggregated using the geometric mean through Equation (9), which was then used to calculate the RPN. The RPN values were compared with the critical value in Equation (10) as an initial screening process.

The final priorities were determined by considering the screening results, RPN values and rankings, severity levels, their relevance to the dominant losses, and validation from three selected internal personnel. These personnel were selected purposively based on their direct involvement and knowledge of the OTR system, consisting of one OTR operator, one processing supervisor, and one mechanic. The three personnel represented the operational, processing, and maintenance functions,

ensuring that priority assessments were not based on a single functional perspective. The final prioritized causes were subsequently used as the basis for developing proposed improvement instruments.

$$\text{Geometric Mean} = \sqrt[n]{(x_1 \times x_2 \times \ldots \times x_n)} \quad (9)$$

$$\text{Critical value} = \sum \frac{\text{RPN}}{\text{Jumlah cause of failure}} \quad (10)$$

3. Results and Discussion

3.1 Result

The operational data of the OTR system, consisting of six parallel units during January to December 2025, showed a total PMH of 15,866.46 MH, OMH of 15,347.46 MH, and DMH of 519.00 MH. All values represent the accumulated MH of the six OTR units analyzed as a single integrated system at the milling station. The recapitulation presented in Table 1 shows that the monthly average values of availability, performance efficiency, quality rate, and OEE were 96.52%, 69.18%, 100%, and 66.75%, respectively, while the annual aggregated values were 96.73%, 68.30%, 100%, and 66.07%, respectively. The highest monthly OEE value occurred in May at 78.86%, whereas the lowest value was recorded in March at 53.85%.

Table 1. Recapitulation of OEE Indicator Calculation Results for the OTR Machine System in 2025

Month	PMH	OMH	DMH	Availability (%)	Performance efficiency (%)	Quality rate (%)	OEE (%)
January	816,00	807,00	9,00	98,90	66,61	100	65,87
February	1.798,18	1.771,18	27,00	98,50	66,45	100	65,45
March	2.182,47	2.137,47	45,00	97,94	54,99	100	53,85
April	1.621,76	1.581,76	40,00	97,53	66,75	100	65,11
May	1.556,09	1.534,09	22,00	98,59	79,99	100	78,86
June	1.451,44	1.380,44	71,00	95,11	67,39	100	64,09
July	1.097,85	995,85	102,00	90,71	72,99	100	66,21
August	967,45	876,45	91,00	90,59	69,54	100	63,00
September	1.185,87	1.160,87	25,00	97,89	67,80	100	66,37
October	1.062,91	1.040,91	22,00	97,93	77,22	100	75,62
November	1.281,90	1.226,90	55,00	95,71	70,80	100	67,76
Desember	844,54	834,54	10,00	98,82	69,60	100	68,78
Average	—	—	—	96,52	69,18	100	66,75
Annual Aggregate	15.866,46	15.347,46	519,00	96,73	68,30	100	66,07

The quality rate value of 100% indicates that all recorded OTR process outputs were accepted for continuation to the subsequent process based on the available data. During the observation period, no OTR outputs were recorded as rejected (reject), reprocessed (rework), or discarded (scrap). This value is limited to the acceptance criteria of OTR process outputs and does not indicate that the final tea product quality reached 100%.

The six big losses calculation summarized in Table 2 shows that the monthly average of reduced speed losses reached 29.77%, while the annual aggregated value was 30.68%. Meanwhile, equipment failure losses had a monthly average of 3.48% and an annual aggregated value of 3.27%. The highest value of reduced speed losses occurred in March at 44.09%, while the lowest value occurred in May at

19.72%. In contrast, the highest equipment failure losses occurred in August at 9.41%, whereas the lowest value was recorded in January at 1.10%.

Table 2. Measurable Loss Calculation Results for the OTR Machine System in 2025

Month	Equipment failure losses (%)	Reduced speed losses (%)	Rework Losses (%)	Yield or scrap losses (%)
January	1,10	33,03	0	0
February	1,50	33,05	0	0
March	2,06	44,09	0	0
April	2,47	32,43	0	0
May	1,41	19,72	0	0
June	4,89	31,02	0	0
July	9,29	24,50	0	0
August	9,41	27,59	0	0
September	2,11	31,52	0	0
October	2,07	22,31	0	0
November	4,29	27,95	0	0
Desember	1,18	30,04	0	0
Average	3,48	29,77	0	0
Annual Aggregate	3,27	30,68	0	0

The values of rework losses and yield or scrap losses in Table 2 were recorded at 0% because no reprocessed outputs or scrap were identified in the OTR process outputs during the observation period. Meanwhile, setup and adjustment losses and idling and minor stoppages losses were not quantitatively calculated because the available information regarding the duration of each occurrence was insufficient.

The maintenance history data presented in Figure 1 show that the OTR machine system experienced 43 failure events with a total accumulated downtime of 519 MH during 2025. The components recorded as experiencing failures and becoming the focus of this study included bearings, v-belts, and electric motors. The identified component failures consisted of worn, broken, loose, or jammed bearings; loose or slipping v-belts; and electric motors experiencing overheating or burnout, requiring a rewinding process.

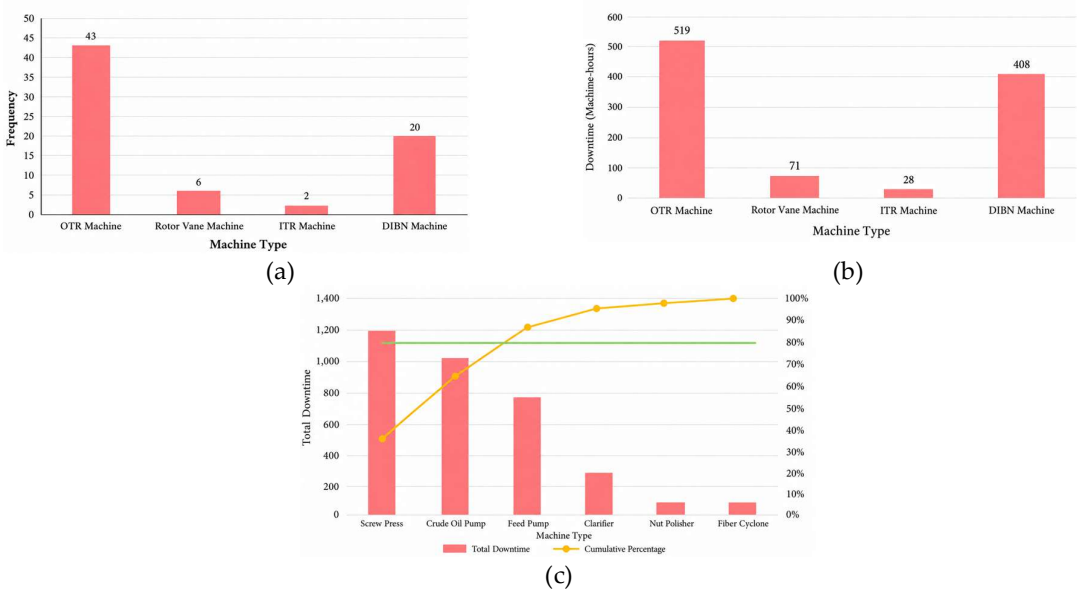


Figure 1. Historical Failure Frequency (a), Total Downtime by Machine Type (b), and Downtime Pareto Diagram in 2025 (c)

The investigation of loss causes using a fishbone diagram based on the 6M categories resulted in 10 failure causes for reduced speed losses and 12 failure causes for equipment failure losses. All identified causes were subsequently evaluated using FMEA based on the S, O, and D parameters by five respondents consisting of one chief mechanic and four mechanics. The scores for each parameter from the five respondents were aggregated using the geometric mean to obtain the RPN for each failure cause.

The initial screening was conducted using critical values of 84.30 for reduced speed losses and 145.34 for equipment failure losses. For reduced speed losses, four causes that met the initial screening criteria were unrecorded machine speed reduction with an RPN of 167.88, inaccurate machine rotation monitoring with an RPN of 143.55, uneven material feeding into the OTR with an RPN of 92.88, and leaf clumping during entry into the OTR with an RPN of 84.68. For equipment failure losses, seven causes that met the initial screening criteria were unscheduled lubrication with an RPN of 248.15, dust accumulation around the machine with an RPN of 229.75, irregular machine condition inspection with an RPN of 219.03, delayed reporting of failure symptoms with an RPN of 217.80, inconsistent initial machine inspection with an RPN of 174.67, poor workplace cleanliness with an RPN of 172.43, and repairs being performed only after failures occurred with an RPN of 150.11.

Validation of the causes and priority determination results was conducted by three company personnel consisting of one OTR operator, one processing supervisor, and one mechanic. For reduced speed losses, inaccurate machine rotation monitoring and uneven material feeding into the OTR were not classified as priorities because they were considered inappropriate based on the validation results.

Table 3. Validation Results and Final Priority Determination of Failure Causes

Types of Losses	Causes of Failure	Severity	RPN	Critical Value	Initial Screening	Validation Results	Final Priority
Reduced speed losses	The decrease in engine speed was not recorded.	6,52	167,88	84,30	Qualify	In accordance	Priority
Reduced speed losses	Leaves clump together upon entering the OTR.	5,75	84,68	84,30	Qualify	In accordance	Priority
Reduced speed losses	Machine settings vary between operators.	6,35	83,26	84,30	Not Qualify	In accordance	Priority
Equipment failure losses	Unscheduled lubrication	6,09	248,15	145,34	Qualify	In accordance	Priority
Equipment failure losses	Dust is accumulating around the machine.	6,32	229,75	145,34	Qualify	In accordance	Priority
Equipment failure losses	Non-routine inspection of engine condition	6,38	219,03	145,34	Qualify	In accordance	Priority
Equipment failure losses	Initial engine inspections have not been consistent.	6,32	174,67	145,34	Qualify	In accordance	Priority
Equipment failure losses	The work area is not clean enough.	5,55	172,43	145,34	Qualify	In accordance	Priority
Equipment failure losses	Repairs were carried out after damage occurred.	6,38	150,11	145,34	Qualify	In accordance	Priority

Conversely, inconsistent machine adjustment between operators remained a priority despite not passing the initial screening because it was considered relevant through validation and was assessed

based on its severity level and its relationship with machine speed stability. For equipment failure losses, delayed reporting of failure symptoms was not classified as a priority because it was considered inappropriate. Based on these results, nine priority failure causes consisting of three causes related to reduced speed losses and six causes related to equipment failure losses are presented in Table 3.

The nine priority failure causes presented in Table 3 served as the basis for developing five proposed improvement instruments summarized in Table 4. These instruments consist of an inspection and maintenance interval standard for OTR machine components, an OTR machine operational readiness check sheet, an OTR machine and workplace cleaning check sheet, a standard operating procedure (SOP) for raw material preparation and cleaning, and an OTR machine speed and stability monitoring check sheet.

Table 4. Details of Proposed Improvement Instruments for the OTR Maintenance System

Types of Losses	Causes of Priority Failure	Improvement Proposal Instrument	Person responsible	Frequency	Proof of Implementation	Monitoring Indicators
Reduced speed losses	Leaves clump together upon entering the OTR.	SOP for Raw Material Preparation and Cleaning	OTR Operator	Every process	SOP for raw material preparation and cleaning	Number of material intake disruption incidents
Reduced speed losses	Machine settings varied between operators, and reductions in machine speed were not recorded.	OTR Machine Speed and Stability Monitoring Checksheet	OTR Operator	Every process	Machine speed and stability monitoring checklist	Number of engine speed drop events
Equipment failure losses	Machine condition inspections are not routine, lubrication is unscheduled, and repairs are performed after a breakdown occurs.	Inspection and Maintenance Interval Standards for OTR Engine Components	OTR Operator	Daily, weekly, monthly, and conditional	Engine component inspection and maintenance checklist	Number of engine component failure incidents
Equipment failure losses	Initial engine inspections have not been consistent.	OTR Machine Operational Readiness Checklist	OTR Operator	Before operating the machine	Machine operation readiness checklist	Compliance with pre-operation engine inspection procedures
Equipment failure losses	Dust has accumulated around the machine, and the work area is not clean.	OTR Machine and Work Area Cleaning Checklist	OTR Operator	Before and after production	Machine and work area cleaning checklist	Compliance with cleaning machines and work areas

3.4 Discussion

The main findings of this study indicate that the effectiveness of the OTR machine system has not yet reached an optimal level because performance efficiency was the lowest component, while reduced speed losses represented the largest measurable loss. The high availability value indicates that most of the planned operating time was available for production; however, the system was unable to achieve output according to its ideal capacity during that period. These findings place process speed stability and machine failure prevention as the main focus areas for improving the OTR system.These results indicate that the greater the energy expenditure of workers, the longer the rest period required to restore the body's physiological condition. Therefore, the rest period required for 18-year-old crop harvesters is higher than for 4-year-old crop harvesters.

These findings indicate that the decline in OTR system effectiveness was not only caused by component failures but also by inconsistencies in operational practices, recording activities, maintenance procedures, initial inspections, and workplace cleanliness [19]. Unrecorded speed reductions make performance changes difficult to trace, while variations in machine adjustments among operators may result in inconsistent operating conditions. Unscheduled lubrication, irregular inspections, and repairs performed only after failures occur indicate that maintenance activities are still predominantly reactive rather than preventive. The prioritization of inconsistent machine adjustment among operators, despite its RPN value being slightly below the critical value, confirms that final priority determination is not solely based on RPN values but also considers severity, company conditions, and cross-functional validation results.

The results of this study are consistent with [12], which identified reduced speed losses as the largest loss. These findings are also partially consistent with [11], as both reduced speed losses and equipment failure losses were identified as significant losses. The application of a fishbone diagram in [18] and FMEA in [16], [17]. to identify causes and determine priorities is similar to the approach used in [15]. In contrast, the results of this study differ from [13], which identified breakdown losses as the largest loss, and [14], which found idling and minor stoppages losses as the dominant loss. These differences indicate that dominant losses must be determined based on the operational data of each analyzed object. Meanwhile, a full comparison with [14] cannot be conducted because the duration of idling and minor stoppages in the OTR system has not been adequately recorded [20].

The strength of this study lies in the analysis of six parallel OTR units as a single MH-based system and the sequential application of OEE, six big losses, fishbone diagram, FMEA, critical values, and cross-functional validation. This study also used nine priority causes as the basis for developing five improvement instruments equipped with responsible personnel, implementation frequency, implementation evidence, and monitoring indicators. However, this study has limitations because the durations of setup and adjustment and idling and minor stoppages were not available, while quality measurement was limited to the acceptance of OTR outputs for the subsequent process and did not represent the final tea product quality. The final validation also involved only three internal personnel representing operational, processing, and maintenance functions; therefore, the validation results were based on a limited number of assessors. Furthermore, this study did not include the implementation of the proposed improvement instruments and subsequent OEE remeasurement, so changes in system performance after implementation cannot yet be confirmed.

Practically, this study can serve as a basis for standardizing inspection, maintenance, cleaning, material preparation, and OTR system speed monitoring through the five developed improvement instruments. Theoretically, the findings provide an overview of the combined application of OEE, six big losses, fishbone diagram, and FMEA in a six-parallel-machine system based on MH.

4. Conclusion

Based on the research findings, the following conclusions were drawn

1. Evaluation of OTR system effectiveness. The six-unit Open Top Roller (OTR) system achieved an average Overall Equipment Effectiveness (OEE) of 66.75%, consisting of 96.52% availability, 69.18% performance efficiency, and a 100% quality rate for outputs accepted for further processing. Despite high availability, the system had not achieved its ideal production capacity, primarily due to low performance efficiency.
2. Identification of dominant equipment losses. The six big losses analysis identified reduced speed losses as the largest measurable loss, accounting for 29.77%. The OTR system also recorded 43 failure events and accumulated 519 machine-hours of downtime. These results indicate that operating speed and equipment failures were important factors affecting machine performance.
3. Identification of priority causes. The fishbone and Failure Mode and Effects Analysis (FMEA) identified nine priority causes associated with equipment performance losses. These included inconsistent speed control, inadequate machine-condition recording, irregular maintenance activities, insufficient initial inspections, and poor workplace cleanliness.
4. Development of maintenance improvement proposals. Five improvement instruments were proposed: an OTR component inspection and maintenance interval standard, an operational readiness checksheet, a machine and workplace cleaning checksheet, a standard operating procedure for raw material preparation and cleaning, and a speed and stability monitoring checksheet. These instruments are intended to improve operating consistency, strengthen preventive maintenance, and address reduced speed and equipment failure losses.

Declaration of AI Use

The author states that ChatGPT was used to a limited extent to assist with language editing and grammar checking during the preparation of the manuscript. The author bears full responsibility for all scientific content, data analysis, interpretation of results, and conclusions. All editing assisted by ChatGPT has been reviewed and verified by the author.

Author Contributions

Conceptualization, Taufik and Wisnel; methodology, Taufik; formal analysis, Taufik and Putri Hadi; investigation, Taufik and Wisnel; data curation, Putri Hadi; writing—original draft preparation, Taufik; writing— review and editing, Wisnel. All authors have read and agreed to the published version of the manuscript.

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