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Original Article

Pressure Asymmetries and Low Back Pain in Pregnancy: A Smart Insole-Based Analysis

Jennara Wongpalee[1], Soodkhet Pojprapai[2*], Amornlert Phanvatr[1], Piyaphun Nunta[3], Anon Seedapeng[3], Supalak Luadlai[4], Dipak Kumar Agrawal[2], Patcharin Jantata[5]

[1] Division of Maternal Newborn Nursing and Midwifery, Faculty of Nursing, Maejo University, Chiang Mai, Thailand

[2] School of Ceramic Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand

[3] Health Development Section, Faculty of Liberal Arts, Maejo University, Chiang Mai, Thailand

[4] Business Psychology Area, Faculty of Psychology, Chulalongkorn University, Bangkok, Thailand

[5] Obstetrics and Gynecology Division, Antenatal Care Clinic, Sansai Hospital, Chiang Mai, Thailand

Abstract

Background: Low back pain is a common condition affecting pregnant women that arises from hormonal and biomechanical changes that alter posture, gait, and balance. Traditional studies focus on general biomechanical adaptations, often neglecting dynamic plantar pressure changes, left-right foot asymmetries, and their link to low back pain.

Objectives: To study the effects of plantar pressure analysis on walking and balance, and to explore the relationship between plantar pressure and low back pain in pregnant women.

Methods: This was a cross-sectional study of 85 pregnant women recruited through simple random sampling and participated in a 10-meter walk test using SuraSole insoles to collect plantar pressure data across eight-foot zones. Data were analyzed using descriptive statistics, paired *t* test assessed plantar pressure differences between the left and right feet in the pregnant women, and Pearson correlation, paired measurements, and relationships involving continuous variables.The Scheffe' method was used to test the mean of each pair of means. The relationship between low back pain and plantar pressure using a multiple linear regression analysis.

Results: Pregnant women exhibited significantly higher plantar pressure in the forefoot and heel zones ($P < .05$). Pregnant participants showed significantly greater plantar pressure in the left heel, medial forefoot, and medial midfoot than the right side ($P < .01$), reflecting left-side dominance. Plantar pressure positively correlated with gestational age and body mass index. Heel pressure was strongly associated with lower back pain, while toe and forefoot zones showed weaker correlations.

Conclusions: Pregnancy affects plantar pressure distribution and foot asymmetry. Increased plantar pressure, particularly in the heel zone, strongly correlates with low back pain. Left- right foot asymmetries in the pregnant women emphasize the need for targeted interventions, such as improving gait mechanics and suitable shoes and promoting walking exercises to reduce low back pain during pregnancy.

Keywords: Plantar pressure, Low back pain, Pregnant women, Smart insole

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*** Corresponding Author:** soodkhet@g.sut.ac.th

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Introduction

Low back pain is a common issue among pregnant women, impacting a substantial number of individuals during pregnancy.[1,2] This discomfort largely stems from the hormonal and biomechanical changes that occur throughout pregnancy. Increased levels of relaxin,

a hormone associated with pregnancy, cause ligament laxity and stretching of the sacroiliac joint.[3] These changes can lead to structural modifications, such as increased lumbar lordosis.[4] As a result, the spine, pelvis, and intervertebral discs may be affected, often causing discomfort in the lumbar region, coccyx, and pelvis, which can radiate down to the legs and feet.[5] Low back pain typically starts early in pregnancy and worsens during the second and third trimesters.[6, 7]

Pregnancy also induces significant musculoskeletal adaptations, including changes in posture, joint stability, and gait mechanics. As gestational age progresses, increased body weight and hormonal fluctuations shift the center of gravity forward, causing compensatory spinal curvature and joint laxity.[5, 8] These adjustments, particularly in the pelvis and lower limbs, result in biomechanical stress, reduced stability, and discomfort.[6, 9] The additional weight gain during pregnancy increases pressure on the lower back, pelvic joints, and lower extremities, heightening the risk of low back pain.[10] Common issues include low back pain, leg cramps, and foot discomfort, affecting gait and balance.

Dynamic plantar pressure and walking mechanics undergo significant changes during pregnancy. The expanding uterus and associated weight gain increase pressure on the feet, leading to structural modifications such as flatfoot and decreased arch height.[11] These alterations impact plantar pressure distribution and vertical ground reaction forces, resulting in an unstable gait and a higher risk of falls.[6] Studies have shown that plantar pressure rises throughout the trimesters, with notable shifts observed in the heel and forefoot zones.[12, 13] These adaptations correlate with alterations in gait, including a decrease in step length, an increase in double support time, and a greater reliance on the plantar fascia for maintaining stability.[14-17]

This study utilized wireless pressure sensor-embedded insoles (SuraSole) to analyze dynamic plantar pressure while walking and its relationship to balance and low back pain in pregnant women. The research examined correlations with gestational age, weight gain, body mass index (BMI), and asymmetries in left-right foot pressure during pregnancies. The insights gained from this study aim to inform targeted interventions, such as physiotherapy and footwear modifications, to alleviate low back pain, improve gait mechanics, and enhance women's overall quality of life during pregnancy.

Methods

Study Design and Participants

This cross- sectional study examined plantar pressure distribution and its relationship to low back pain in the pregnant women. The sample included 85 pregnant women recruited through simple random sampling and quota sampling using Yamane's formula.[18]

Pregnant participants were included if they were aged 16 to 45 years, had a normal pregnancy between 12 to 40 weeks of gestation, and total weight gain during pregnancy not exceeding 16 kg. These thresholds were selected based on the prior studies indicating their influence on plantar pressure and gait mechanics. Participants with musculoskeletal conditions, high-risk pregnancies, or histories of foot or spinal surgeries were excluded to minimize confounding factors.

This study was conducted at Sansai Hospital, Thailand, with the approval from Human Research Ethics Committee at Maejo University All participants were required to agree to and sign an informed consent form prior to data collection.

Instruments

Plantar pressure data were collected using the SuraSole (Figure 1). These insoles feature 8 strategically placed force sensitive resistor (FSR) sensors. The sensor zones, including toes (great toe, lesser toes), forefoot (medial forefoot, central forefoot, lateral forefoot), midfoot (medial midfoot, lateral midfoot), and heel. Data were transmitted wirelessly via Bluetooth to the SuraSole Med application for analysis.

Low back pain was assessed using numerical pain rating scale (NPRS), a validated 10-point linear scale. Scores range from 0 (no pain) to 10 (worst pain imaginable), (1-3 indicating mild pain, 4-6 moderate pain, and 7-9 severe pain). The scale is divided into 10 equal segments along a 10-centimeter line for the precise scoring.[19, 20]

Demographic and pregnancy-related data, gestational age, weight gain including BMI, walking patterns, balance assessments, were collected via a validated questionnaire.

Quality Assessment of Instruments

The SuraSole smart insole system underwent rigorous safety validation in compliance with IEC-62304 and IEC-60601-1 standards, conducted by National Electronics and Computer Technology Center (NECTEC) and Electrical and Electronic Products Testing Center (PTEC). Additional calibration was performed using a universal testing machine (UTM: Puller SK-10-500N press digital, SHSIWI) and validated against a force plate (Kistler Instrumente 187 AG, Winterthur, Switzerland) under ISO/IEC 17025 standards.[21] The reliability of the questionnaire and the insole system was tested in a pilot study involving 19 pregnant women, achieving a Cronbach α of 0.92.

Data Collection Procedure

Participants attended a single session at the antenatal clinic. The process involved the following steps: 1) obtaining written informed consent after explaining the research objectives and procedures; 2) completing a demographic and pregnancy-related questionnaire, including the NPRS), to assess low back pain; and 3) wearing calibrated SuraSole smart insoles and performing a 10-meter walk test. Each participant walked back and forth once, and mean plantar pressure values were recorded for analysis (Figure 2).

Figure 1. The SuraSole Smart Insole and the SuraSole Med Application

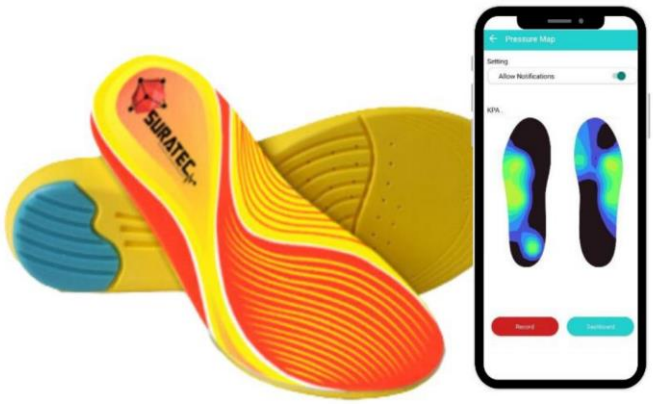
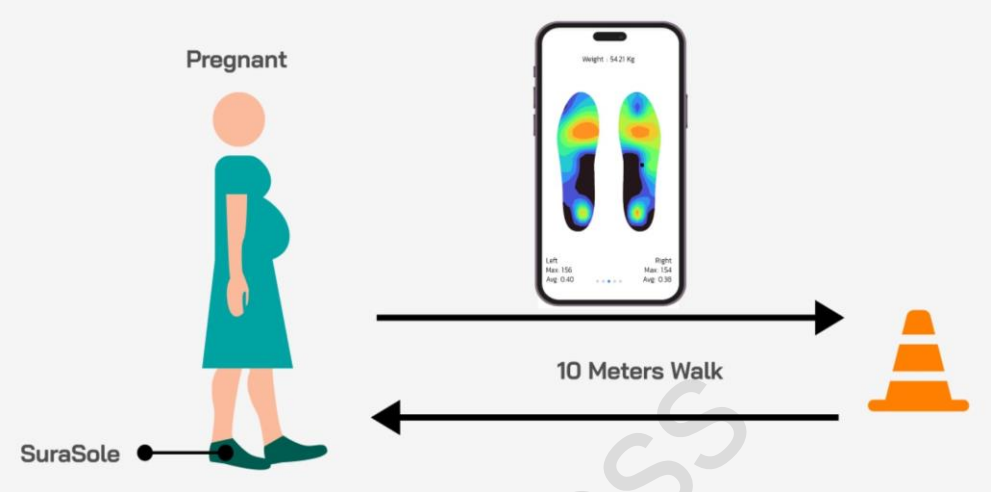


Figure 2. Plantar Pressure Data Collection During a 10-Meter Walk Using SuraSole Smart Insoles and SuraSole Med Application



Statistical Analysis

Data were analyzed using SPSS version 27. 0 (IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp; 2020). Descriptive statistics for personal data, paired *t* tests assessed plantar pressure differences between the left and right feet, focusing on the key zones such as medial forefoot, medial midfoot, and heel. Pearson correlation examined the relationships among plantar pressure, gestational age, and low back pain. Multiple regression analyses for gestational age, body weight and BMI were performed.

Moderation analysis determined whether plantar pressure influenced the relationship between gestational age and low back pain. These statistical methods were chosen for their effectiveness in analyzing group comparisons, paired measurements, and relationships involving continuous variables. Statistical significance was set at $P < .05$.

Results

The study population had an average age of 27.85 years and an average weight of 65.76 kg. Among the participants, 42.35% had a normal BMI. The distribution of trimesters was as follows: 70.59% in the third trimester, 22.35% in the second trimester, and 7.06% in the first trimester. Regarding low back pain, 83.53% of participants reported experiencing it. Among them, 81.69% had moderate pain, 9.86% had mild pain, and 8.45% had severe pain. Additionally, 34.08% of participants in the third trimester reported moderate pain and 3.55% had severe pain.

This study also examines differences in plantar pressure between the left and right feet during pregnancy. The findings are organized into the following categories: correlation between plantar pressure and gestational variables; left vs right foot plantar pressure differences in pregnant women; and relationships between plantar pressure, gestational age, and low back pain.

Correlation Between Plantar Pressure and Gestational Variables

For the left foot, no significant correlations were found between plantar pressure zones and gestational age for the left foot. However, strong positive correlations were identified with body weight and BMI, particularly in the forefoot and heel zones. These findings underscore the influence of overall weight gain on plantar pressure during pregnancy. Detailed correlation coefficients are presented, the correlation patterns across left foot zones, illustrating strong relationship with the weight and BMI (Table 1).

For the right foot, no significant correlations were found with gestational age. However, plantar pressure exhibited significant positive correlations with body weight in all zones except the great toe and with BMI in all zones except the great toe and medial midfoot. These results highlight the dominant role of body weight and BMI in plantar pressure changes. Detailed correlation coefficients showed strong correlation patterns across right foot zones with weight and BMI (Table 2).

Across both feet, plantar pressure showed no significant correlation with gestational age, while weight and BMI emerged as stronger predictors. The absence of significant correlations with gestational age may suggest that plantar pressure is more strongly influenced by overall weight gain and BMI during pregnancy rather than pregnancy duration.

Left vs Right Foot Plantar Pressure Differences in Pregnant Women

Significant left-side plantar pressure dominance was observed in third-trimester pregnancies. This asymmetry, particularly in the medial forefoot, midfoot, and heel zones, reflects compensatory weight distribution due to fetal positioning and pelvic tilt.

The left medial forefoot exhibited significantly higher pressure compared to the right side (mean [SD], 83.97 [23.55] vs 74.49 [18.61] kPa; $P < .001$). This difference indicates asymmetrical propulsion and balance adjustments during walking.

The left midfoot also showed significantly higher pressure compared to the right (mean [SD], 4.60 [7.59] vs 2.85 [5.64] kPa; $P = .003$). While the differences in pressure between the midfoot zones are smaller, they still reflect the midfoot's role in stabilizing weight-bearing during walking.

The left heel presented significantly higher pressure than the right heel (mean [SD], 88.96 [20.50] vs 72.91 [17.93] kPa; $P < .001$), suggesting a compensatory shift in weight to maintain balance.

Relationships Between Plantar Pressure, Gestational Age, and Low Back Pain

The relationship between plantar pressure and low back pain was analyzed, with key results for the heel zone (Figures 3 and 4). Among all zones, the heel zone showed the strongest and most consistent association with low back pain. In contrast, the forefoot and midfoot zones exhibited weaker and less consistent correlations. No significant correlation between plantar pressure of the toe zone (great toe, lesser toes) and low back pain was found.

Moderate correlations with low back pain were found in the forefoot, particularly for the high-weight distribution. However, these trends were inconsistent.

Moderate correlations between midfoot pressure and low back pain were also noted in the midfoot, but they were less consistent compared to the heel zone.

Heel zone (high heel pressure) was strongly associated with increased low back pain and amplified spinal strain.

Moderate weight distribution in the heel corresponded to a balanced increase in low back pain, while low weight distribution was linked to the least amount of low back pain.

Table 1. Correlation Among Left Foot Plantar Pressure, Gestational Age, Weight, and Body Mass Index

Variable	Great Toe	Lesser Toes	Medial Forefoot	Central Forefoot	Lateral Forefoot	Medial Midfoot	Lateral Midfoot	Heel
Gestational age	0.050	-0.055	0.056	-0.034	0.026	0.121	0.084	0.060
Body weight	0.199	0.273*	0.373*	0.504*	0.364*	0.192	0.415*	0.457*
Body mass index	0.181	0.264*	0.398*	0.487*	0.343*	0.251*	0.369*	0.373*

* $P < .01$

Table 2. Correlation Among Right Foot Plantar Pressure, Gestational Age, Weight, and Body Mass Index

Variable	Great Toe	Lesser Toes	Medial Forefoot	Central Forefoot	Lateral Forefoot	Medial Midfoot	Lateral Midfoot	Heel
Gestational age	0.017	0.026	0.041	0.096	0.091	-0.054	0.056	0.013
Body weight	-0.170	0.362*	0.304*	0.471*	0.283*	0.203*	0.463*	0.472*
Body mass index	-0.095	0.268*	0.347*	0.489*	0.382*	0.189*	0.481*	0.422*

* $P < .01$

Figure 3. The Relationship Between Gestational Age and Low Back Pain in Each Group for the Left Heel Zone

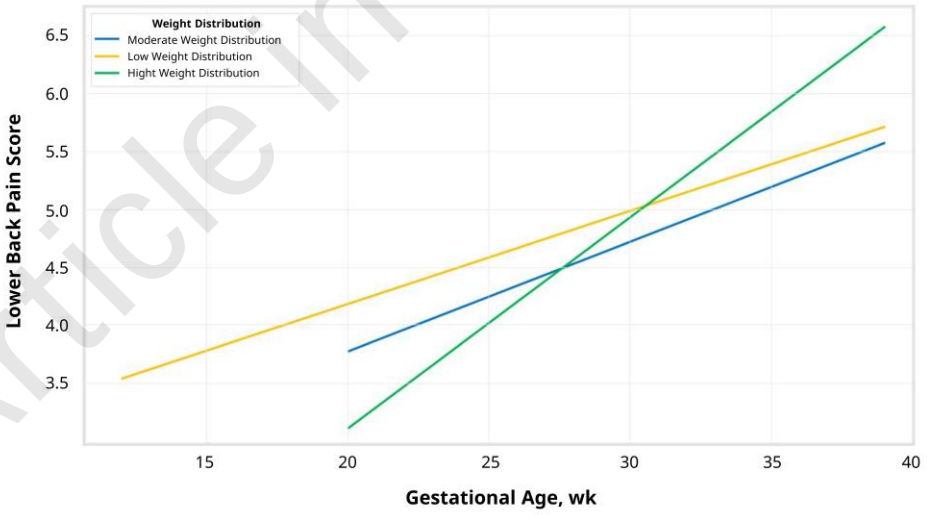
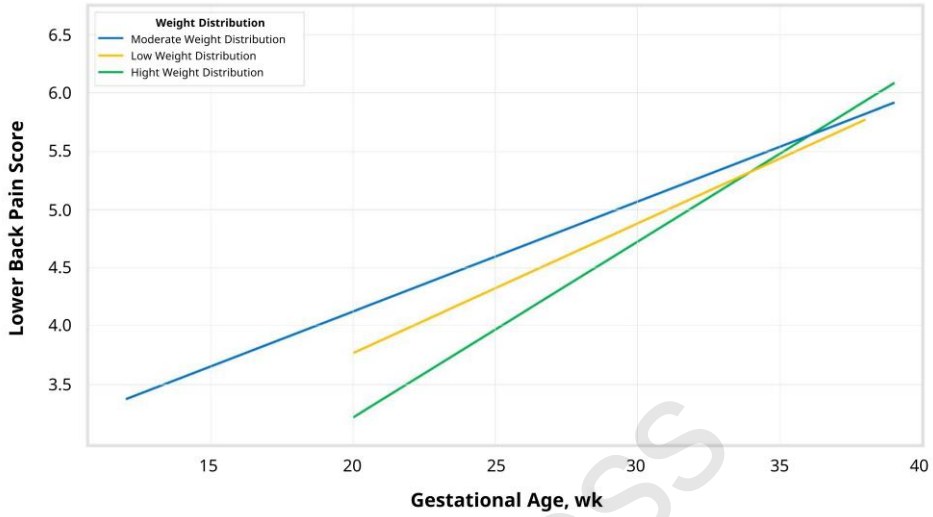


Figure 4. The Relationship Between Gestational Age and Low Back Pain in Each Group for the Right Heel Zone



Discussion

This study investigated plantar pressure differences and its relationship with walking, balance, and low back pain in the pregnant women. The findings revealed significant increases in plantar pressure across specific foot zones in pregnant women. The left great toe, medial forefoot, and left heel exhibited the most notable differences. Among all zones, the heel consistently showed the strongest correlation with low back pain, underscoring its role in compensatory load distribution during pregnancy.

Pressure differences between the left and right feet highlighted left-side dominance, particularly in the heel, medial forefoot, and medial midfoot zones, consistent with previous findings.[22, 23] These findings suggest that pregnancy-induced gait adjustments are concentrated in the forefoot and heel zones, which bear the brunt of compensatory mechanisms to maintain balance.

Biomechanical Adaptations

The observed plantar pressure changes align with known musculoskeletal adaptations during pregnancy. Flattening of the midfoot arch and increased forefoot pressure reflected the structural changes caused by weight gain and altered center of gravity. Increased lumbar lordosis and backward upper body tilt are common compensatory postural adjustments, helping to maintain stability and reduce the risk of falls.[22, 24]

The heel zone emerged as a critical area of focus, with high heel pressure contributing significantly to lumbar strain and the prevalence of low back pain,[25, 26] particularly in the second and third trimesters. These findings emphasize the need to address heel pressure in interventions targeting pregnancy-related discomfort.

Plantar Pressure and Low Back Pain

A strong correlation was found between gestational age and low back pain, mediated by plantar pressure. However, across both feet, plantar pressure showed no significant

correlation with gestational age, while weight and BMI emerged as stronger predictors.[22, 25] Increased heel pressure, particularly in the high-weight distribution, amplified lumbar strain and back pain. Left foot plantar pressure, especially in the heel zone, played a notable role, likely reflecting compensatory strategies to balance the growing uterus. These findings underscore the bilateral adjustments in the weight distribution during pregnancy, offering valuable insights for clinical care.

Pressure Distribution Across Zones

The heel zone showed a strongest correlation with low back pain. Elevated heel pressure amplifies lumbar strain, suggesting a need for heel-targeted interventions, such as cushioning or orthotic support.

The toe zone demonstrated minimal correlation with low back pain, indicating its primary role in balance and propulsion rather than spinal strain.

The forefoot zone showed moderate but inconsistent correlations with low back pain, likely mediated through gait mechanics rather than direct spinal loading.

Importantly, the relationship between heel zone plantar pressure and low back pain was consistent across different gestational ages, highlighting the critical role of heel pressure in contributing to back pain. These findings emphasize the need for targeted interventions to alleviate discomfort and improve maternal well-being.

Clinical Implications

These findings offer practical insights into mitigating pregnancy-related discomfort including 1) footwear modifications: enhanced heel cushioning and arch support can redistribute plantar pressure and reduce spinal strain; 2) physiotherapy: targeted exercises focusing on posture correction and pelvic alignment can reduce lumbar lordosis and mitigate low back pain; and 3) preventive monitoring: regular assessment of plantar pressure distribution and early interventions can mitigate the risk of flatfoot development and associated discomfort.

Conclusions

This study found that pregnancy significantly increases plantar pressure, particularly in the heel, medial forefoot, and medial midfoot zones, with the heel zone exhibiting the strongest correlation with low back pain. Left-right foot asymmetries in pregnant women further highlight the role of compensatory weight distribution during gait.

These findings underscore the importance of targeted interventions, such as footwear modifications and physiotherapy, to manage plantar pressure and reduce low back pain during pregnancy. Proper exercise should be promoted for a safe pregnancy. Future research should explore the long-term benefits of dynamic plantar pressure monitoring and orthotic solutions to improve gait mechanics and the overall quality of life of pregnant women.

Additional Information

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Ethics Approval: This study was approved by the Maejo University Human Research Ethics Committee (No. 5T004/66 on 16 June 2023). Written informed consent was obtained from all participants prior to data collection.

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Conflict of Interest: The authors declare no conflict of interest in this study.

Author Contributions:
Conceptualization: Jennara Wongpalee, Soodkhet Phojpapai
Data Curation: Jennara Wongpalee, Amornlert Phanvatr, Piyaphun Nunta, Anon Seedapeng, Patcharin Jantata
Formal Analysis: Jennara Wongpalee, Soodkhet Phojpapai, Amornlert Phanvatr
Funding Acquisition: Jennara Wongpalee
Investigation: Jennara Wongpalee, Soodkhet Phojpapai, Amornlert Phanvatr, Piyaphun Nunta, Anon Seedapeng
Methodology: Jennara Wongpalee, Soodkhet Phojpapai, Anon Seedapeng
Project Administration: Jennara Wongpalee, Soodkhet Phojpapai
Resources: Jennara Wongpalee, Soodkhet Phojpapai, Amornlert Phanvatr, Patcharin Jantata
Software: Soodkhet Phojpapai, Dipak Kumar Agrawal
Supervision: Jennara Wongpalee, Soodkhet Phojpapai
Validation: Jennara Wongpalee, Soodkhet Phojpapai, Dipak Kumar Agrawal
Visualization: Jennara Wongpalee, Supalak Luadlai, Dipak Kumar Agrawal
Writing – Original Draft: Jennara Wongpalee, Supalak Luadlai, Dipak Kumar Agrawal
Writing – Review & Editing: Supalak Luadlai, Dipak Kumar Agrawal

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