The Potential Association between Tuberculosis and Periodontitis: Implications for Public Health

Ashek Elahi Noor[1,2], Boyapati Ramanarayana[3] and Enis Veseli[4*]

[1]Department of Dental Public Health, Sapporo Dental College and Hospital, Dhaka, Bangladesh
[2]Department of Dental Research, Center for Global Health Research, Saveetha Institute of Medical and Technical Sciences, Chennai, India
[3]Department of Periodontology, Sibar Institute of Dental Sciences, Takkellapadu, Guntur, India
[4]Department of Prosthodontics, Dental School, Faculty of Medicine, University of Pristina, Pristina, Kosovo

Abstract

Tuberculosis and periodontitis are two chronic diseases that have traditionally been viewed as unrelated. However, emerging research indicates a potential association between these conditions, which are significant public health concerns. Tuberculosis, caused by Mycobacterium tuberculosis, primarily affects the lungs but can manifest systemically. Periodontitis is a chronic inflammatory disease of the supporting tissues of the teeth, driven by oral pathogens. Both diseases share common risk factors such as smoking, diabetes, malnutrition, and HIV co-infection, which may exacerbate the bidirectional relationship between the immune system and systemic inflammation. This paper explores the potential pathophysiological connections between tuberculosis and periodontitis and discusses the implications for public health strategies. A literature review was conducted to identify studies linking tuberculosis and periodontitis, focusing on shared immunological pathways, risk factors, and systemic inflammatory processes. Epidemiological studies examining co-occurrence of the diseases in high-risk populations were also analyzed. The findings suggest that chronic inflammation caused by periodontitis may exacerbate systemic conditions like tuberculosis by increasing levels of circulating inflammatory markers, such as C-reactive protein, IL-6, and TNF-α. Likewise, individuals with tuberculosis may have a weakened immune system, increasing their susceptibility to periodontal infections. Shared risk factors, particularly smoking, diabetes, and malnutrition, further amplify the burden of both diseases. The immunological dysregulation present in tuberculosis, particularly in the case of immune exhaustion, may impair the body's response to periodontal pathogens, leading to worse oral health outcomes. By adopting a more integrated approach to patient care, dental professionals can help mitigate the systemic impacts of these diseases, reduce the burden of tuberculosis in affected populations, and improve overall patient outcomes.

Keywords: *Tuberculosis, periodontitis, public health, inflammation, immune system.*

INTRODUCTION

Tuberculosis and periodontitis present significant global health challenges, each carrying implications for individuals and communities on a global scale. Although traditionally viewed as separate conditions, recent research has brought to light a potential correlation between these prevalent health issues [1-3]. Tuberculosis, caused by Mycobacterium tuberculosis, is the most widespread infectious disease worldwide. Approximately one-third of the global population harbors latent tuberculosis, making it the leading infectious cause of death, claiming 1.4 million lives in 2015 [1].

On the other hand, periodontitis is a chronic inflammation of the gums that leads to the destruction of tooth-supporting structures and can result in tooth loss due to bacterial infection [2].

The relationship between tuberculosis and periodontitis is complex and involves interactions between immunological, microbial, and systemic health factors. Studies have shown that chronic aspiration of bacteria in the oral cavity to the lower respiratory tract increases the risk of developing systemic diseases, particularly respiratory infections, including bacterial pneumonia, bronchitis, Chronic Obstructive Pulmonary Disease (COPD), and lung abscess [3].

Interestingly, patients with tuberculosis exhibit a correlation with periodontal conditions [4]. Individuals with poor dental health are more likely to develop COPD, even after controlling for factors such as age, sex, and smoking [5]. This suggests a possible connection between poor dental health. Therefore, it is essential to evaluate the periodontal health of individuals infected with tuberculosis, especially in endemic areas and underdeveloped countries, where tuberculosis remains a public health issue. Both diseases involve intricate interactions with the immune system and share several similarities. Tuberculosis triggers a chronic inflammatory response that compromises the immune system. Similarly, is a chronic inflammatory disease of the gums, primarily caused by bacterial infections, which have the potential to exacerbate systemic inflammation and influence the course of tuberculosis [6, 7].

The cytokine profile is a pivotal factor linking tuberculosis and periodontitis. Periodontitis is associated with elevated levels of pro-inflammatory cytokines such as TNF-α, IL-1 beta, and IL-6, which may play significant roles in tuberculosis pathology [8-10].

*Corresponding author: Enis Veseli, Department of Prosthodontics, Dental School, Faculty of Medicine, University of Pristina, Pristina, Kosovo, E-mail: enis.veseli@uni-pr.edu
Received: August 03, 2024; Revised: October 08, 2024; November 07, 2024
DOI: https://doi.org/10.37184/lnjpc.2707-3521.7.29

  ISSN: 2708-9134 (Online) Liaquat National Journal of Primary Care 2025; 7(2): 192-196

This shared cytokine profile suggests a bidirectional influence, where periodontitis could contribute to the systemic inflammatory burden in patients, while tuberculosis-induced immune dysregulation may worsen periodontal disease. Multiple studies have provided epidemiological evidence supporting the association between tuberculosis and periodontitis [11-14].

Prevalence studies have demonstrated that individuals with tuberculosis have a higher occurrence of periodontitis than that in the general population. Immunosuppression caused by tuberculosis renders the gums more vulnerable to infection and inflammation, leading to an increased prevalence of periodontitis. Furthermore, case-control studies have indicated that patients with periodontitis are more prone to tuberculosis. Chronic inflammation in periodontitis may serve as a reservoir that impairs the body's ability to control latent tuberculosis infection [9, 10].

Clinical observations have revealed that patients with tuberculosis often exhibit poor oral health, including high rates of periodontitis. Factors such as malnutrition, reduced saliva production, and overall compromised health, which are common in tuberculosis patients, contribute to these observations [11].

In addition, medications used for tuberculosis treatment, such as isoniazid and rifampicin, can have side effects that affect oral health, including dry mouth, which increases the risk of periodontitis [12].

Although current evidence supports an association between tuberculosis and periodontitis, it is important to note that direct causality has not been definitively established. Systematic reviews have emphasized the necessity for further longitudinal studies to gain a better understanding of these connections. Evidence-based research emphasizes the significance of integrated healthcare approaches, recognizing that managing periodontal health could have positive implications for patients with tuberculosis. Future research should explore these connections to develop comprehensive treatment strategies that effectively address both conditions. To effectively address the global burden of tuberculosis and periodontitis, it is crucial to enhance prevention and treatment strategies.

While Artificial Intelligence has improved early detection of oral diseases, [15]. public health education should also stress the importance of dental health for overall well-being and its potential links to other systemic diseases.

Identifying the association between tuberculosis and periodontitis presents an opportunity to improve patient care and prevention strategies. As we aim to address these prevalent health concerns on a global scale, we must recognize the impact of periodontal health on tuberculosis, and vice versa. By promoting interdisciplinary collaboration and continued research, better outcomes can be achieved in patients with both tuberculosis and periodontitis.

PATHOPHYSIOLOGY

Both tuberculosis and periodontitis involve immune responses that can become dysregulated, leading to chronic inflammation. In tuberculosis, the host immune system responds to Mycobacterium tuberculosis by activating macrophages and T-cells, forming granulomas. In periodontitis, oral pathogens elicit an inflammatory response characterized by the release of pro-inflammatory cytokines such as interleukin-1 (IL-1), tumor necrosis factor-alpha (TNF-α), and others. These cytokines are also central to tuberculosis pathogenesis, suggesting that chronic periodontitis could exacerbate tuberculosis or vice versa by perpetuating a systemic inflammatory state.

Periodontitis is not just a localized disease; the persistent bacterial load and inflammation can lead to increased systemic levels of inflammatory mediators like C-reactive protein (CRP). This systemic inflammatory burden may impair immune defenses, potentially increasing susceptibility to tuberculosis. Tuberculosis, in turn, could suppress immune functions, making the host more vulnerable to periodontal infections. Both diseases involve immune exhaustion and an imbalance in pro- and anti-inflammatory cytokine levels, weakening host defenses over time. Several common risk factors link tuberculosis and periodontitis.

Smoking: Tobacco use is a well-established risk factor for both tuberculosis and periodontitis. Smoking impairs respiratory immunity, increasing the risk of tuberculosis infection, and also negatively affects oral health by altering the local immune environment and encouraging the growth of periodontal pathogens.

Diabetes: Diabetics are more susceptible to both tuberculosis and periodontitis due to impaired immune responses and poor wound healing.

Malnutrition and Socioeconomic Status: Both diseases are more prevalent in impoverished populations, where malnutrition and poor access to healthcare facilitate the progression of these infections. Malnutrition impairs the immune system's ability to respond effectively to both tuberculosis and periodontal pathogens.

HIV Coinfection: HIV weakens the immune system, making individuals more susceptible to both tuberculosis and periodontitis. The interplay between HIV, tuberculosis, and periodontitis is especially complex and may exacerbate disease severity in co-infected individuals [14, 16].

LITERATURE REVIEW

According to Swain *et al.* explain that this comprehensive review provides insights into the global burden of tuberculosis, risk factors, and immune responses. It discusses tuberculosis's systemic effects, which are

important when exploring potential links to oral diseases such as periodontitis [1] whereas Jing *et al.* stated this study investigates the correlation between periodontal health and tuberculosis in a high-risk population. It highlights how chronic periodontitis might contribute to tuberculosis susceptibility through shared inflammatory pathways [17, 18]. According to Kassahun *et al.* this article focuses on the systemic implications of periodontitis, highlighting its association with several systemic diseases, including tuberculosis. It argues for oral healthcare's role in integrated public health strategies targeting both systemic infections and periodontal disease [19]. Srivastava *et al.* describe how periodontitis is linked to systemic diseases like tuberculosis through shared risk factors such as smoking and diabetes. It emphasizes the role of medical practitioners in managing the bidirectional impact of these conditions [20].

Furthermore, Kohale *et al.* discuss how periodontitis contributes to systemic inflammation and the potential for it to exacerbate diseases such as tuberculosis. It advocates for holistic care approaches to manage both periodontal and systemic conditions [21]. Cairo *et al.* review the associations between periodontitis and various systemic conditions, proposing mechanisms through which periodontitis may influence diseases like tuberculosis. It underscores the need for interdisciplinary care in managing systemic and oral health simultaneously [22]. Jha *et al.* stated that the article outlines the global burden of tuberculosis and explores future directions for tuberculosis care, prevention, and research. While not focused on oral health, it provides crucial context for understanding how systemic conditions like tuberculosis could intersect with chronic inflammatory diseases such as periodontitis [23].

Moreover, Acunzo *et al.* express that the systematic review discusses the relationship between periodontal disease and respiratory infections, indirectly suggesting how the inflammatory burden from periodontitis might exacerbate infectious diseases like tuberculosis [24]. Strom *et al.* focus on the bidirectional relationship between diabetes and periodontitis, providing insight into how shared systemic risk factors for periodontitis may also influence tuberculosis, particularly in high-risk populations like diabetics [25].

IMPLICATIONS FOR PUBLIC HEALTH

Early Screening and Dual Disease Management: The potential connections between tuberculosis and periodontitis suggest the need for integrated health strategies. Periodontal health assessments could be incorporated into tuberculosis screening programs, particularly in high-risk populations such as smokers, diabetics, and individuals living in tuberculosis-endemic regions.

Addressing Systemic Inflammation: Public health policies should emphasize controlling chronic inflammation through better management of periodontitis. Strategies like oral hygiene education, routine dental care, and periodontal treatment may reduce systemic inflammation, potentially lowering tuberculosis susceptibility in vulnerable populations.

Holistic Disease Prevention Programs: Prevention programs targeting common risk factors such as smoking cessation and diabetes management could benefit both tuberculosis and periodontitis control efforts. A multi-pronged approach addressing these modifiable risk factors could have a significant impact on reducing the burden of both diseases.

Integration of Dental and Medical Care: Strengthening collaboration between dental and medical professionals is crucial for early detection and management. In tuberculosis-endemic areas, dental professionals could play a role in identifying individuals at risk of tuberculosis through signs of poor oral health, while medical professionals managing tuberculosis patients should consider their oral health status as part of comprehensive care.

RECOMMENDATIONS FOR DENTISTS AND DENTAL HYGIENISTS

Early Detection and Risk Assessment

Dentists should include tuberculosis risk assessments as part of their routine health history evaluations, especially for patients in high-risk populations (*e.g.* those with diabetes, smokers, or those from tuberculosis-endemic regions). Inquiry about tuberculosis exposure, symptoms (chronic cough, fever, night sweats, weight loss), and medical history can help in identifying at-risk individuals. Dental hygienists, as frontline oral health providers, can assess patients' periodontal status and be alert for signs of periodontitis. Hygienists should ask questions related to systemic health conditions, including tuberculosis, as poor periodontal health may indicate a systemic condition or compromised immune function.

Oral Health as a Gateway to Systemic Health

Dentists should promote the concept that good oral health contributes to overall systemic health. Educating patients about how untreated periodontal disease can exacerbate systemic conditions, including tuberculosis, is crucial. For tuberculosis patients, dentists should emphasize the importance of maintaining optimal oral hygiene to minimize the inflammatory burden on the immune system. Hygienists play a critical role in educating patients about proper oral hygiene techniques and their impact on general health. Highlighting the connection between systemic infections like tuberculosis and oral health will help patients understand the importance of periodontal care as a preventive measure.

Cross-Disciplinary Collaboration

Dentists should work closely with medical professionals, particularly in tuberculosis-endemic areas, to ensure comprehensive care. Referral systems between dental and medical providers can help manage patients with co-existing conditions like tuberculosis and periodontitis. For instance, tuberculosis patients could be referred for periodontal evaluations, while patients with severe periodontitis could be referred for tuberculosis screening. Hygienists should collaborate with public health initiatives, participating in community health outreach programs that screen for both oral diseases and tuberculosis. By linking dental hygiene services with tuberculosis control programs, hygienists can contribute to integrated disease prevention efforts.

Infection Control and Patient Safety

Dentists need to maintain stringent infection control protocols, especially in clinics where tuberculosis prevalence is high. Tuberculosis can be transmitted in healthcare settings, and dental care providers must be trained to recognize the signs of active tuberculosis. Proper ventilation, personal protective equipment, and sterilization practices are essential to prevent tuberculosis transmission in dental clinics. Hygienists should follow rigorous infection control procedures, especially when dealing with high-risk patients. This includes the use of appropriate masks (*e.g.* N95 respirators) when treating individuals who may have tuberculosis, as well as ensuring that patients are screened for tuberculosis symptoms before undergoing routine dental care.

Patient Education and Public Health Advocacy

Dentists can act as public health advocates by educating patients about the connections between tuberculosis and oral health. In areas where tuberculosis is prevalent, dentists should offer guidance on how managing oral infections, especially periodontitis, can help reduce overall systemic inflammation and the risk of complications from tuberculosis. Dental hygienists are ideally placed to offer preventive advice and promote public health. Hygienists should work with public health campaigns to raise awareness about tuberculosis, periodontal disease, and the importance of oral hygiene in preventing systemic infections. They can provide educational materials and presentations at community health events, emphasizing the role of oral health in preventing systemic diseases like tuberculosis.

Management of High-Risk Populations

Dentists should prioritize the care of high-risk populations, such as immunocompromised individuals (*e.g.* HIV-positive patients, diabetics) and tuberculosis patients. These groups may require more frequent dental check-ups and early intervention to prevent the progression of periodontitis, which could exacerbate systemic inflammation. Hygienists should provide targeted care for high-risk populations, including personalized oral hygiene regimens and more frequent professional cleanings. Offering tailored advice to these individuals about how their health conditions, such as tuberculosis, can impact their oral health is crucial for long-term disease prevention [14, 16]. Furthermore, with the advancement of technology in recent times, dentists can facilitate the provision of advice [26]. Gaining a deeper understanding of this connection has the potential to revolutionize our approach to treatment and prevention strategies for both tuberculosis and periodontitis [1].

CONCLUSION

The potential association between tuberculosis and periodontitis holds significant public health implications. Both are chronic, infectious conditions that affect millions globally, with tuberculosis being a major public health concern and periodontitis a leading cause of tooth loss. Their link could potentially worsen the overall health burden in affected populations. The inflammation seen in periodontitis may compromise the immune system, possibly increasing susceptibility to tuberculosis or exacerbating its severity. Conversely, tuberculosis's systemic effects might weaken oral health, contributing to periodontal disease progression. This association suggests the need for integrated care models from a public health perspective. Public health strategies should consider joint screening and management of tuberculosis and periodontitis, especially in populations with high tuberculosis prevalence. This could improve early detection, enhance treatment outcomes, and reduce healthcare costs. Raising awareness about oral health's role in systemic diseases like tuberculosis may also encourage preventive measures, promoting better overall health outcomes.

Further research is necessary to solidify the causal links, establish common risk factors, and design effective interventions that address both conditions simultaneously.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

Declared none.

AUTHORS' CONTRIBUTION

Conceptualization- Noor AE.

Writing manuscript- Veseli E, Noor AE.

Data collection, analysis- supervision, review and editing- Veseli E, Noor AE & Ramanarayana B.

All authors read and agreed to the published version of the manuscript.

REFERENCES

1. Swain S, Kumar A, Vishwakarma VK, Aayilliath K A, Mittal A, Wig N. Diagnosis and management of latent tuberculosis infection: updates. Infect Disord Drug Targets 2024; 24(4): 12-9. DOI: https://doi.org/10.2174/0118715265275319231124053615

2. Papapanou PN, Sanz M, Buduneli N, Dietrich T, Feres M, Fine DH, *et al.* Periodontitis: Consensus report of workgroup 2 of the 2017 World Workshop on the classification of periodontal and peri-implant diseases and conditions. J Periodontol 2018; 89: S173-82. DOI: https://doi.org/10.1002/JPER.17-0721
3. Lin P, Liu A, Tsuchiya Y, Noritake K, Ohsugi Y, Toyoshima K, *et al.* Association between periodontal disease and chronic obstructive pulmonary disease. Jpn Dent Sci Rev 2023; 59: 389-402. DOI: https://doi.org/10.1016/j.jdsr.2023.10.004
4. Sharma A, Garg H, Khattri S, Sharma S. Periodontal status of tuberculosis patients–Is there a two-way link? Indian J Tuberc 2016; 63(4): 225-9. DOI: https://doi.org/10.1016/j.ijtb.2016.09.015
5. Schwarz C, Hajdu AI, Dumitrescu R, Sava-Rosianu R, Bolchis V, Anusca D, *et al.* Link between oral health, periodontal disease, smoking, and systemic diseases in Romanian patients. InHealthcare 2023; 11(16): 2354. DOI: https://doi.org/10.3390/healthcare11162354
6. Carabalí-Isajar ML, Rodríguez-Bejarano OH, Amado T, Patarroyo MA, Izquierdo MA, Lutz JR, *et al.* Clinical manifestations and immune response to tuberculosis. World J Microbiol Biotechnol 2023; 39(8): 206. DOI: https://doi.org/10.1007/s11274-023-03636-x
7. Bhuyan R, Bhuyan SK, Mohanty JN, Das S, Juliana N, Abu IF. Periodontitis and its inflammatory changes linked to various systemic diseases: a review of its underlying mechanisms. Biomedicines 2022; 10(10): 2659. DOI: https://doi.org/10.3390/biomedicines10102659
8. Mazurek-Mochol M, Bonsmann T, Mochol M, Poniewierska-Baran A, Pawlik A. The role of interleukin 6 in periodontitis and its complications. Int J Mol Sci 2024; 25(4): 2146. DOI: https://doi.org/10.3390/ijms25042146
9. Javed F, Al-Askar M, Al-Hezaimi K. Cytokine profile in the gingival crevicular fluid of periodontitis patients with and without type 2 diabetes: a literature review. J Periodontol 2012; 83(2): 156-61. DOI: https://doi.org/10.1902/jop.2011.110207
10. Alshiddi IF, AlMubarak AM, Alqutub MN, Alqarawi FK, Alshahrani FA, Javed F, *et al.* Peri-implant sulcular fluid galectin-1, soluble urokinase plasminogen activator receptor and IL-1β levels under peri-implant inflammatory conditions. Oral Health Prev Dent 2021; 19: 503-10. DOI: https://doi.org/10.3290/j.ohpd.b2082081
11. Kumar C, Dhadse PV, Agarwal AA, Kale BV, Sigh BS. Oral and periodontal status in patients with tuberculosis in Vidarbha region of Central India. J Int Clin Dent Res Organ 2018; 10(2): 81-7. DOI: https://doi.org/10.4103/jicdro.jicdro_3_18
12. Yang TW, Park HO, Jang HN, Yang JH, Kim SH, Moon SH, *et al.* Side effects associated with the treatment of multidrug-resistant tuberculosis at a tuberculosis referral hospital in South Korea: A retrospective study. Medicine (Baltimore) 2017; 96(28): e7482. DOI: https://doi.org/10.1097/MD.0000000000007482
13. Albandar JM, Rams TE. Global epidemiology of periodontal diseases: an overview. Periodontol 2002; 29: 7-10. DOI: https://doi.org/10.1034/j.1600-0757.2002.290101.x
14. Giannobile WV. Host-response therapeutics for periodontal diseases. J Periodontol 2008; 79: 1592-600. DOI: https://doi.org/10.1902/jop.2008.080174
15. Veseli E, Noor AE, Veseli K, Tovani-Palone MR. Early childhood caries detection using smartphone artificial intelligence. Eur Arch Paediatr Dent 2024; 25(2): 285. DOI: https://doi.org/10.1007/s40368-024-00871-0
16. Saquib Abullais S, Wykole Y, Abdul Khader M, Mohamed Shamsudeen S, Alanazi S, Ullah Khateeb S, *et al.* Estimation of serum C-reactive protein activity in periodontal health and disease and response to treatment: a clinico-biochemical study. PeerJ 2023; 11: e16495. DOI: https://doi.org/10.7717/peerj.16495
17. Furin J, Cox H, Pai M. Tuberculosis. Lancet 2019; 393(10181): 1642-56. DOI: https://doi.org/10.1016/S0140-6736(19)30308-3
18. Jing, W-D, Jiao J, Xu L, Hou J-X, Li X-T, Wang X-X, *et al.* Periodontal soft- and hard-tissue changes after augmented corticotomy in Chinese adult patients with skeletal Angle Class III malocclusion: a non-randomized controlled trial. J periodontol 2020; 91(11): 1419-28. DOI: https://doi.org/10.1002/JPER.19-0522
19. Kassahun A, Gashe F, Mulisa E, Rike WA. Nonadherence and factors affecting adherence of diabetic patients to anti-diabetic medication in Assela General Hospital, Oromia Region, Ethiopia. J Pharm Bioallied Sci 2016; 8(2): 124-9. DOI: https://doi.org/10.4103/0975-7406.171696
20. Srivastava, K.C. and Shrivastava, D. Analysis of plasma lipid peroxidation and antioxidant enzymes status in patients of oral leukoplakia: a case control study. J Int Soc Prevent Commun Dent 2016; 6(Suppl 3): S213-8. DOI: https://doi.org/10.4103/2231-0762.197195
21. Kohale BR, Agrawal AA, Raut CP. Effect of low-level laser therapy on wound healing and patients' response after scalpel gingivectomy: a randomized clinical split-mouth study. J Indian Soc Periodontol 2018; 22(5): 419-26. DOI: https://doi.org/10.4103/jisp.jisp_239_18
22. Cairo F, Carnevale G, Nieri M, Mervelt J, Cincinelli S, Martinolli C, *et al.* Benefits of fibre retention osseous resective surgery in the treatment of shallow infrabony defects: a double-blind, randomized, clinical trial describing clinical, radiographic and patient-reported outcomes. J Clin Periodontol 2013; 40(2): 163-71. DOI: https://doi.org/10.1111/jcpe.12042
23. Jha V, Garcia-Garcia G, Iseki K, Li Z, Naicker S, Plattner B, *et al.* Chronic kidney disease: global dimension and perspectives. Lancet 2013; 382(9888): 260-72. DOI: https://doi.org/10.1016/S0140-6736(13)60687-X
24. Acunzo, Limiroli E, Pagni G, Dudaite A, Consonni D, Rasperini G. Gingival margin stability after mucogingival plastic surgery. The effect of manual versus powered toothbrushing: a randomized clinical trial. J Periodontol 2016; 87(10): 1186-94. DOI: https://doi.org/10.1902/jop.2016.150528
25. Strom JL Egede LE. The impact of social support on outcomes in adult patients with type 2 diabetes: a systematic review. Current diabetes reports. 2012; 12(6): 769-81. DOI: https://doi.org/10.1007/s11892-012-0317-0
26. Veseli E. Metaverse: a promise avenue for enhancing dental care. Khyber Med Univery J 2024; 16(1): 1-2. DOI: https://doi.org/10.35845/kmuj.2024.23506