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Preface

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RESEARCH ARTICLE

Diagnostic utility of CT Hounsfield unit for accurate classification of ischemic and haemorrhagic stroke

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Abstract:

This study examines the diagnostic value of Hounsfield Unit (HU) measurements on computed tomography (CT) in differentiating ischemic from haemorrhagic stroke, a distinction critical for timely and appropriate clinical intervention. The study aims to quantify HU values for both stroke types and assess their correlation with stroke lesion size and volume. Non-contrast enhanced CT brain images were retrospectively reviewed from the PACS. HU values, demographic characteristics, clinical risk factors, and stroke classifications were analysed quantitatively. The results demonstrated a lower mean HU value in ischemic strokes (24.37 ± 5.85) as compared with haemorrhagic strokes (57.17 ± 20.10). Lesion volume was significantly correlated with haemorrhagic stroke ($r = 0.829$, $p = 0.041$). These findings highlight the utility of HU values as a potential imaging marker for distinguishing ischemic from haemorrhagic stroke. This may improve diagnostic accuracy and support more information in clinical decision-making, hence contributing to better stroke assessment and management.

Keywords: Computed tomography, haemorrhagic stroke, Hounsfield unit (HU), ischemic stroke

1. INTRODUCTION

Stroke is the second leading cause of death globally after heart disease (Gautam & Raman, 2021), with approximately 15 million individuals affected each year (Camporesi et al., 2023). In Malaysia, stroke remains a major public health concern and is the third leading cause of mortality (Hwong et al., 2021). Stroke ranks as the third most common cause of death among men and the second among women, following ischemic heart disease (Ching et al., 2019). The World Health Organization (WHO) reports six new stroke cases every hour in Malaysia, with ischemic strokes accounting for 79.4% and haemorrhagic strokes 18.2% of cases (Danial et al., 2023).

Despite advancements in stroke management, survivors still face high mortality and recurrence rates, and outcomes of long-term research on long-term outcomes remains limited (Hwong et al., 2021). Early diagnosis within the first hour of onset especially is critical for minimizing irreversible neurological damage (Akbarzadeh et al., 2021). CT imaging is widely recommended as the first-line modality for acute stroke evaluation due to its speed, accessibility, and ability to differentiate stroke types (Vincent et al., 2023). HU values that derived from CT imaging may offer additional diagnostic value by providing quantitative information on tissue density, which may improve diagnostic accuracy and support treatment decisions. Quantitative measurement of tissue density on non-contrast CT through HU values can enhance the objectivity and diagnostic yield of acute stroke imaging. HU values reflect the linear attenuation of intracranial tissues and enable differentiation between normal brain parenchyma (e.g., grey and white matter) and pathological states such as ischaemia or haemorrhage (Coskun et al., 2025). Utilization of HU-based assessment thus provides a quantitative, reproducible adjunct to visual interpretation, potentially improving early stroke classification and guiding timely treatment decisions. However, diagnostic utility of HU values in distinguishing ischemic from haemorrhagic stroke in Malaysian population is not well reported. This study aims to evaluate HU values across stroke types and correlation between HU values, lesion size and volume.

2. MATERIALS AND METHODS

2.1 Ethical approval

Ethical approval was granted from the UiTM Research Ethics Committee (FERC/FSK/MR/2024/00080) and Hospital Al-Sultan Abdullah (HASA) UiTM research ethics (500-HUiTM (PJI.18/4/89). As a retrospective study in nature, informed consent was not required.

2.2 Study design

This retrospective single-centre study reviewed stroke patients' data acquired from non-contrast CT scans between December 2022 and December 2023. Non-contrast brain CT scans were acquired with lateral 256 mm topogram, 120 kV and 390 mAs reference, 1.0 mm slice thickness and 0.7 mm reconstruction increment using medium smooth kernel (Siemens SOMATOM Definition AS+128 MDCT, Siemens Healthineers, Germany). Medical records were reviewed using the Picture Archiving and Communication System (PACS) and the Electronic Hospital Record (EHR).

2.3 Sampling and population

A purposive sampling technique was used to select patients who met the inclusion criteria including patients' age more than 18 years and diagnosed with stroke. Patients with incomplete medical records or imaging data were excluded from the study. A total of 79 samples met the inclusion criteria for analysis following the sample size calculation.

2.4 Data collection

Demographic data including patients' age, gender, race, smoking status and clinical risk factors were retrieved from hospital records. Clinical risk factors include hypertension, diabetes mellitus, dyslipidaemia and atrial fibrillation. All data were organised using Microsoft Excel, and anonymisation was ensured by assigning each patient a unique identifier. Following the Malaysian Society of Neurosciences Guidelines, the age was categorised into four groups: 18–39 years, 40–59 years, 60–74 years and ≥ 75 years (Hamidon et al., 2021).

2.5 HU, lesion size and volume measurements

CT images were reviewed using Picture Archiving and Communication System (INFINTI PACS) with a standard brain window (window level; WL = 35 HU; window width; WW = 80 HU). Regions of interest were placed over hypodense (ischemic) or hyperdense (haemorrhagic) areas. HU values were quantified three times to improve the reliability of measurements, and the mean values were recorded.

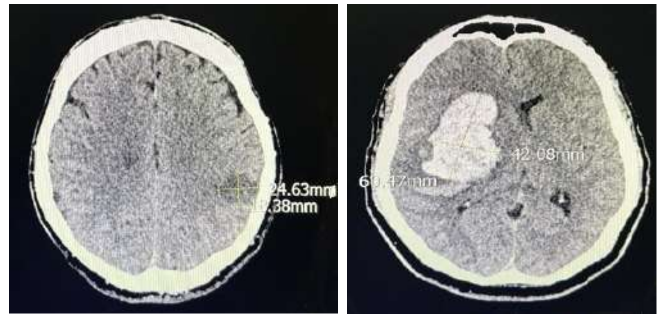
Stroke lesions were identified under supervision of a radiologist. As shown in Figure 1, for ischemic lesions, maximum orthogonal diameters were measured to determine the lesion size using the following formula (Kufner et al., 2020):

$$\text{Area} = A \times B$$

Meanwhile for haemorrhagic lesions, the volume was calculated using the following formula (Annongu et al., 2022):

$$\text{Volume} = (A \times B \times C) / 2$$

where A = transverse diameter, B = vertical diameter, C= total number of slides with the largest hematoma.



(a) (b)

Figure 1. (a) Size measurement of infarcted area in ischemic lesion and (b) haematoma volume in haemorrhagic lesion.

2.6 Statistical analysis

Descriptive statistics, independent t-tests and Pearson's correlation were employed to meet the objectives of the study. A p-value ≤ 0.05 was considered statistically significant. Data analysis was performed using SPSS version 27.

3. RESULTS AND DISCUSSION

3.1 Results

A total of 79 patients who met the inclusion criteria were analysed, comprising 38 males (48.1%) and 41 females (51.9%). The mean age of the study population was 65.27 ± 13.5 years. Females represented a slightly higher proportion (3.8% difference) compared to males. The age distribution showed that the highest incidence of stroke occurred in individuals aged 60 - 74 years (n = 31, 39.2%), followed by patients aged ≥75 years (n = 24, 30.4%). The lowest number of cases was observed in the 18 - 39 age group (n = 6, 7.6%). Malay patients constituted most of the study population (n = 73, 92.4%), followed by Chinese (n = 6, 7.6%), Indian (n = 1, 1.3%), and other ethnicities (n = 1, 1.3%) representing smaller proportions as shown in Table 3.1.

Table 3.1 Distribution of patient demographics in ischemic and haemorrhagic stroke.

	Ischemic n (%)	Haemorrhagic n (%)
Gender		
Male	35 (92.1)	3 (7.9)
Female	38 (92.7)	3 (7.3)
Age		
18 – 39	6 (100)	-
40 – 59	17 (94.4)	1 (5.6)
60 – 74	29 (93.5)	2 (6.5)
≥75	21 (87.5)	3 (12.5)
Ethnicity		
Malay	68 (93.2)	5 (6.8)
Chinese	4 (100)	-
Indian	-	1 (100)
Others	1 (100)	-

Hypertension was the most common clinical risk factor, present in 63 patients (79.7%), followed by diabetes mellitus in 42 patients (53.2%) and dyslipidaemia in 38 patients (48.1%). Smoking (n = 9, 11.4%) and atrial fibrillation (n = 6, 7.6%) were the least common risk factors. Out of the 79 confirmed stroke cases, 73 (92.4%) were ischemic and 6 (7.6%) were haemorrhagic, reflecting the well-established predominance of ischemic stroke in clinical populations.

A significant difference in mean HU values was found between ischemic and haemorrhagic strokes (p = 0.01; 95% CI: –53.74, –11.58). Ischemic lesions demonstrated markedly lower HU values (24.37 ± 5.91) compared to haemorrhagic lesions (57.17 ± 20.10), confirming the expected difference in tissue attenuation on CT imaging (Figure 2).

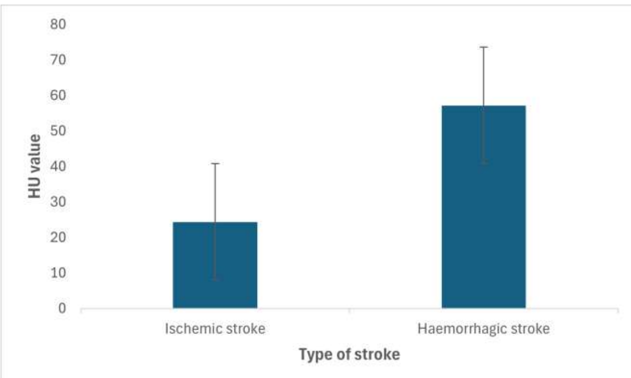


Figure 2. Mean HU values of ischemic stroke and haemorrhagic stroke.

Furthermore, Pearson correlation analysis demonstrated a weak and statistically insignificant correlation between lesion size and HU values (r = – 0.198, p = 0.092) in ischemic stroke. This suggests that HU reduction in ischemia may occur independently of lesion extent during the acute phase. Conversely, haemorrhagic lesions showed a strong and statistically significant positive correlation between HU values and lesion volume (r = 0.829, p = 0.041), indicating that larger haematomas tended to demonstrate higher HU values.

Overall, the findings support the utility and reliability of HU measurements in distinguishing stroke types and offer additional insights into lesion characteristics, particularly in haemorrhagic stroke.

3.2 Discussion

This study demonstrates that HU values obtained from non- contrast CT scans differ significantly between ischemic and haemorrhagic stroke, reinforcing the clinical value of HU quantification in acute stroke diagnosis. The results showed low HU values in ischemic lesions and markedly increased HU values in haemorrhagic lesions, consistent with established CT attenuation principles. Beyond confirming these differences, the study provides insights into the relationship between HU values, lesion characteristics, and patient clinical profiles. The findings of the present study align with previous literature, which reported mean HU values of approximately 18.9 HU in acute ischemic stroke lesions (Peng et al., 2024); 57.5 HU (Jeong et al., 2021) and 66.2–67.6 HU (Chen et al., 2022) in intracerebral haemorrhage; and 60–80 HU in acute haemorrhage (van Poppel, 2022). These established HU differences underpin the diagnostic distinction between haemorrhagic and ischemic stroke on non-contrast CT.

Low HU values in ischemic stroke are primarily attributed to increased water content resulting from cytotoxic and vasogenic oedema (Ajmani et al., 2023). During acute ischemia, failure of ATP-dependent ion pumps causes intracellular sodium and water influx, leading to tissue hypoattenuation (Sims & Muyderman, 2010). Zhu et al. (2021) reported that a 1% increase in water content reduces the HU value by approximately 1.8 HU, indicating a pattern reflected in our findings. Ischemic tissue demonstrates reduced cerebral blood flow, loss of grey–white differentiation and progressive infarction. These mechanisms explain the consistently low HU values observed in ischemic lesions in this study.

The absence of significant correlation between ischemic lesion size and HU values suggests that tissue density changes may occur independently of lesion extent during the acute and early subacute phases. This supports previous findings that early ischemic changes on non-contrast CT may appear subtle regardless of final infarct volume (Ospel et al., 2021), especially within the first 6 hours of onset.

Conversely, haemorrhagic strokes demonstrated significantly higher HU values, reflecting the intrinsic high attenuation of acute blood. HU increases proportionally with red blood cell concentration and haemoglobin content. The variability in HU values (wide SD ± 20.10) may be influenced by hematoma age, clot retraction (contraction), anaemia and serum extravasation, lowering HU values (Unnithan et al., 2023). Jeong et al. (2020) reported that clot contraction in the early hours of haemorrhage increases HU values as red blood cell packing intensifies. This aligns with the strong correlation observed between haemorrhagic lesion volume and HU, indicating that larger haematomas may manifest more extensive clot retraction or contain higher-density blood products. Our findings are consistent with the established radiological characteristics of stroke presenting hypodense and hyperdense on non-contrast CT in ischemic stroke and haemorrhagic stroke, respectively. This agreement strengthens the reliability of HU values as a diagnostic discriminant, particularly in settings lacking advanced imaging such as CT angiography or Magnetic Resonance Imaging (MRI).

The findings highlight several important clinical implications. Firstly, HU value is significant for enhanced diagnostic accuracy for the management of stroke patients. Radiographers and clinicians often rely on visual assessment of non-contrast CT. Quantitative HU measurement improves objectivity and reduces diagnostic uncertainty, especially in early or subtle ischemia. Secondly, the HU value is valuable for rapid triage in emergency stroke pathways. HU-based differentiation is particularly valuable when MRI is unavailable or when CT perfusion is not routinely performed. In resource-limited or high-volume centres, HU quantification can assist in timely thrombolysis decisions. Thirdly, CT-based value is also significant as a prognostic information. Higher HU in haemorrhage has been associated with greater risk of haematoma expansion, increased mortality and poorer functional outcomes. Similarly, extreme low HU values in ischemia may indicate severe cytotoxic oedema and predict malignant infarction.

The demographic findings presenting higher stroke incidence among older adults and prevalence of hypertension and diabetes are consistent with national and global epidemiological patterns. The predominance of ischemic stroke (92.4%) aligns with the statistics by the Malaysian Society of Neurosciences, which has reported ischemic stroke as the most common subtype (Clinical Practice Guidelines: Management of Ischaemic Stroke, 2020). This study contributes to the growing literature on HU-based stroke evaluation. The findings provide local single centre-based Malaysian data on HU distributions in stroke patients and enhance the understanding of lesion density changes across stroke types.

There are several key limitations in this study. Firstly, the study was limited with small sample size for haemorrhagic stroke which restricting generalisation of the study population. The limited sample size restricts the stability of threshold-based analyses. Secondly, the single-centre design may not represent broader populations. Thirdly, there was absence of histopathology during data collection, which could improve biological interpretation. Future studies with larger and multi-centre stroke cohorts could be improved by several considerations which includes evaluating serial HU changes over time (e.g., hours to days), exploring HU thresholds predictive of clinical outcomes, combining imaging biomarkers with blood-based biomarkers and incorporating automated HU mapping software.

4. CONCLUSION

Haemorrhagic stroke presents significantly higher HU values than ischaemic stroke and correlated with the lesion volume. CT HU value is a potential imaging marker in differentiating ischemic from haemorrhagic stroke. This quantitative parameter may enhance diagnostic accuracy, especially in emergency settings where rapid decision-making is essential. Correlations between HU values and lesion volume further support their clinical utility.

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REFERENCES

Ajmani, S., Bruce, E., Suresh, S., & Wintermark, M. (2023). Pathophysiology of ischemic stroke: Imaging perspectives and implications for clinical management. *Neuroimaging Clinics of North America, 33*(1), 1–15. https://doi.org/10.1016/j.nic.2022.09.001

Akbarzadeh, M. A., Sanaie, S., Kuchaki Rafsanjani, M., & Hosseini, M.-S. (2021). Role of imaging in early diagnosis of acute ischemic stroke: a literature review. *The Egyptian Journal of Neurology, Psychiatry and Neurosurgery*, *57*(1). https://doi.org/10.1186/s41983-021-00432-y

Annongu, I. T., Iwuozo, E. U., Hameed, M. O., Chia, D. M., Mohammed, S. S., & Mbahon, F. A. (2022). Clinical and brain computed tomographic profile of stroke patients in a tertiary hospital, North Central Nigeria. *World Journal of Neuroscience*, 12(4), 187–202. https://doi.org/10.4236/wjns.2022.124020

Camporesi J., Strumia, S., Andrea Di Pilla, Paolucci, M., Orsini, D., Chiara Assorgi, Maria Gabriella Cacciuttolo, & Maria Lucia Specchia. (2023). Stroke pathway performance assessment: a retrospective observational study. *BMC Health Services Research*, *23*(1). https://doi.org/10.1186/s12913-023-10343-8

Chen, Y., Cao, D., Guo, Z. Q., Ma, X. L., Ou, Y. B., He, Y., Chen, X., & Chen, J. (2022). The Attenuation value within the non-hypodense region on non-contrast computed tomography of spontaneous cerebral hemorrhage: a long-neglected predictor of hematoma expansion. *Frontiers in Neurology*, *13*, 785670. https://doi.org/10.3389/fneur.2022.785670

Ching, S., Chia, Y. C., Chew, B. N., Soo, M. J., Lim, H. M., Sulaiman, W. A. W., Hoo, F. K., Saw, M. L., Ishak, A., Palanivelu, T., Caruppaiya, N., & Devaraj, N. K. (2019). Knowledge on the action to be taken and recognition of symptoms of stroke in a community: findings from the May Measurement Month 2017 blood pressure screening Programme in Malaysia. *BMC Public Health*, *19*(1). https://doi.org/10.1186/s12889-019-7922-7

Clinical Practice Guidelines: Management of Ischaemic Stroke. (2020). https://www.moh.gov.my/moh/resources/Penerbitan/CPG/CARDIOVASCULAR/CPG_Management_of_Ischaemic_Stroke_3rd_Edition_2020_28.02_.2021_.pdf

Coskun, S., Demircan, S., Gunaydin, G. P., & Ercan, K. (2025). Hounsfield unit comparison of opposite hemispheres in computed tomography for early diagnosis of ischemic stroke. *The Tohoku Journal of Experimental Medicine*, *266*(4), 305–309. https://doi.org/10.1620/tjem.2025.J017

Danial, M., Mohd Radzi N.S.I., Khan, A.H., Swee, A., & Irene, L. (2023). Survivability of patients admitted for stroke in a primary stroke center, Penang, Malaysia: a retrospective 5-year study. *BMC Pharmacology & Toxicology*, *24*(1). https://doi.org/10.1186/s40360-023-00669-8

Gautam, A., & Raman, B. (2021). Towards effective classification of brain hemorrhagic and ischemic stroke using CNN. *Biomedical Signal Processing and Control*, *63*, 102178–102178. https://doi.org/10.1016/j.bspc.2020.102178

Hamidon, B. B., Hoo, F. K., Law, W. C., & Albart, S. A. (2021). Clinical Practice Guidelines Management of Ischaemic Stroke 3rd ed. Malaysian Society of Neurosciences.

Hwong, W. Y., Ang, S. H., Bots, M. L., Sivasampu, S., Selvarajah, S., Law, W. C., Latif, L. A., & Vaartjes, I. (2021). Trends of Stroke Incidence and 28-Day All-Cause Mortality after a Stroke in Malaysia: A Linkage of National Data Sources. *Global Heart*, *16*(1). https://doi.org/10.5334/gh.791

Jeong, H.-G., Jae Seung Bang, Beom Joon Kim, Bae, H.-J., & Han, M.-K. (2021). Hematoma Hounsfield units and expansion of intracerebral haemorrhage: A potential marker of haemostatic clot contraction. *International Journal of Stroke*, 16(2), 163–171. https://doi.org/10.1177/1747493019895703

Unnithan, A. K. A., Mehta, P., & Das, J. M. (2023, May 8). Hemorrhagic Stroke. National Library of Medicine; StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK559173/

Kufner, A., Stief, J., Siegerink, B., Nolte, C., Endres, M., & Fiebach, J. B. (2020). Two simple and rapid methods based on maximum diameter accurately estimate large lesion volumes in acute stroke. Brain and Behavior, 10(11). https://doi.org/10.1002/brb3.1828

Van Poppel, L. M., Majoie, C. B. L. M., Marquering, H. A., & Emmer, B. J. (2022). Associations between early ischemic signs on non-contrast CT and time since acute ischemic stroke onset: A scoping review. *European Journal of Radiology*, 155, 110455. https://doi.org/10.1016/j.ejrad.2022.110455

Ospel, J. M., Hill, M. D., Menon, B. K., Demchuk, A. M., McTaggart, R. A., Nogueira, R. N., Poppe, A. R., Haussen, D. C., Qiu, W., Arnuv Mayank, Almekhlafi, M. A., Zerna, C., Joshi, M. J., Jayaraman, M., Roy, D., Rempel, J., Buck, B., Tymianski, M., & Goyal, M. (2021). Strength of association between infarct volume and clinical outcome depends on the magnitude of infarct size: results from the ESCAPE-NA1 trial. 42(8), 1375–1379. https://doi.org/10.3174/ajnr.a7183

Peng, Y., Luo, C., Wang, H., Sun, K., Lin, F., Wang, J., Rao, Y., Fan, R., Gong, L., & Sun, X. (2024). Feasibility of CT attenuation values in distinguishing acute ischemic stroke, old cerebral infarction and leukoaraiosis. *BMC Medical Imaging*, *24*(1), 160. https://doi.org/10.1186/s12880-024-01340-2.

Sims, N. R., & Muyderman, H. (2010). Mitochondrial dysfunction in stroke**.** *Biochimica et Biophysica Acta (BBA) – Molecular Basis of Disease, 1802*(1), 80–91. https://doi.org/10.1016/j.bbadis.2009.09.012

Unnithan, A. K. A., Mehta, P., & Das, J. M. (2023, May 8). Hemorrhagic stroke. National Library of Medicine; StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK559173/

Vincent, M., Senai Goitom Sereke, Nassanga, R., Robert, M., & Ameda, F. (2023). Correlation of neurological clinical and brain computed tomography findings of stroke patients – a multicenter study from a low-income setting. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-2219254/v1

Zhu, Z., Zhang, R., Ren, K., Cong, R., Zhu, X., Zhu, L., & Wang, T. (2021). The prognosis prediction significance of Hounsfield unit value for stroke patients treated by intravenous thrombolysis. *BMC Medical Imaging*, *21*(1). https://doi.org/10.1186/s12880-021-00592-6

RESEARCH ARTICLE

Prevalence Of Pulmonary Embolism (Pe) Among Cancer Patients As Incidental Finding Using Computed Tomography (CT): A Single Centre Retrospective Study

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Abstract:

Incidental pulmonary embolisms (PE) are defined as an unsuspected filling defect of the pulmonary arteries identified on the computed tomography (CT) images. Due to its nature as non-specific symptoms and some patients may even asymptomatic, PE was knowns as the most common cause of death for patients who are bedridden and the second most common cause of death for cancer patients. This study aimed to assess the prevalence of incidental PE in cancer patients undergoing routine CT scans at a single institution. This study seeks to categorize primary cancer types, assess the prevalence of incidental PE, and identify the typical locations of emboli within the branches of the pulmonary artery. The relationship between risk factors and the occurrence of PE was subsequently assessed. 534 cancer patients' data who underwent CT scans from January to June 2023 were reviewed. The results indicated that accidental PE was most prevalent in lung cancer (25.6%), followed by gastrointestinal tract cancer (21%) and breast cancer (16.3%). The right lower pulmonary artery was the most frequently affected arterial site, accounting for 25.6%. The findings underscored the importance of thorough physical examination screening for cancer patients to facilitate early detection and intervention of incidental PE.

Keywords: computed tomography (CT), incidental findings, oncology patients, pulmonary embolism

1. INTRODUCTION

Over the years, Computed Tomography (CT) scanning has become a standard procedure for many patients, particularly those with cancer, for purposes including diagnosis, staging, or treatment evaluation. CT examinations are commonly conducted for oncology patients for various purposes, including staging the disease by evaluating its extent, monitoring treatment response, and conducting regular follow-ups to detect recurrence or metastasis. Incidental pulmonary embolism (PE) frequently emerged as a finding during examinations, particularly in cancer patients who exhibit an elevated risk of venous thromboembolism. This increased risk is attributed to factors such as cancer-related hypercoagulability, immobility, and the effects of treatment (Poenou et al., 2022)

Incidental PE refer to an unexpected filling defect in the pulmonary arteries detected on a CT scan (Ahuja et al.2020). In adults, PE account for 10-15% of deaths (Deniz et al., 2017). It ranks as the second leading cause of mortality among hospitalized cancer patients and is the primary cause of death for individuals who are bedridden. Furthermore, following coronary artery disease and stroke, it ranks third in terms of the frequency of cardiovascular disease-related deaths. Samra et al. (2022) reported an estimated incidence of PE at 4.4% among 540 patients suffering from various cancer types.

Moreover, the incidence of thromboembolic disease among cancer patients ranges from 4% to 28%, depending on the specific types and stages of cancer (Luo et al, 2023). Cancer patients are at an increased risk of pulmonary thromboembolism, particularly due to factors such as chemotherapy, surgery, radiotherapy, or the ongoing progression of the disease. These embolic events are clinically asymptomatic, yet they result in significant morbidity and mortality in untreated patients. Identifying and addressing risk factors in cancer patients is essential for implementing preventive measures to decrease the incidence of PE and enhance patient outcomes. The mortality rate in untreated PE is significant, which is at 30%; however, with effective treatment, it can reduce this rate to between 2% and 18% (Bach et al., 2015).

This single-centre study provides insights into the prevalence of PE as an incidental finding in cancer patients, with potential implications for improving oncology patient outcomes and treatment. The researcher hypothesized that the study's outcomes could improve the understanding of the relationship between cancer and PE, therefore optimizing the management of this significant comorbid condition in cancer treatment.

2. MATERIALS AND METHODS

From January to June 2023, 534 cancer patients underwent CT scans. The study utilized specific exclusion and inclusion criteria. The data were retrieved from the Radiology Information System (RIS). The original radiological reports for the CT scan of the thorax from January until June 2023 reported by the radiologists that were stationed at the CT suite (for the stipulated time frame) were retrieved and reviewed by the 1st author. The review process was to filter all CT thorax result with the confirmation of PE, identify the primary cancer types, determine the common locations of emboli in pulmonary artery branches, and assess the association between risk factors and pulmonary embolism. Statistical analysis was performed utilizing SPSS 27.0 to obtain statistical insights. Descriptive statistics consists of the computation of means and standard deviations (SD) for various key variables. The Chi-Square test assessed the relationship between various risk factors and the incidence of PE across different cancer types. The variables contained the items pertinent to the study, including patient age, gender, and the type of cancer diagnosed in the individuals being examined. The methodological framework used in this study is based on earlier research by Deniz et al. (2017) and Samra et al. (2022), which is cited in the current study.

2.1 Inclusion criteria

Oncology patients who had tissue biopsies with easily accessible biopsy results are included in the sample group. The samples must also have received continuous treatment over the six months during the data collecting period, and they must have had routine CT scans of the thorax with contrast.

2.2 Exclusion Criteria

Oncology patients with a prior history of pulmonary embolism (PE) or deep vein thrombosis (DVT), those exhibiting dense scanning artefacts, and cases where pulmonary arteries could not be traced due to conditions such as pleural effusion or large masses, and who underwent CTPA examination, were excluded from this study**.** CT thorax images that were degraded by artefacts due to the treatment received for more than six months by the oncology patients during the data collection period, the images were then excluded from the study.

Ethical approval for this study was acquired from the Universiti Teknologi MARA (UiTM) ethics committee, with reference number FERC/FSK/MR/2024/00145. Ethical approval was also obtained from the Medical Research and Ethics Committee (MREC), with the reference number NMRR ID-24-01411-NH1 (IIR). The data from this study was not manipulated for other non-related purposes and patients' identities were kept safe and confidential.

3. RESULTS AND DISCUSSION

3.1 Demographic data and samples distribution by types of cancer

Out of the 534 patients that participated in the study, 327 (61.2%) were female and 207 (38.8%) were male. This study indicates that female patients had a higher cancer prevalence than male patients, as demonstrated by a gender ratio of 1.58:1, consistent with various findings in the literature. A primary factor contributing to the rise in female patients is breast cancer. The overall number of female cancer patients includes additional illnesses exclusive to women, such as ovarian and cervical cancers within the reproductive cancer category. The patients' age range was 12 to 87 years, with a mean age of 56 ± 13.6 years. Figure 1 below illustrates the distribution of subjects categorized by primary cancer types. The majority of the subjects consist of primary cancers originating from the breast (26.8%), followed by gastrointestinal tract (GIT) cancer (20.2%), lung cancer (19.7%), reproductive system cancers (17.4%), bone-soft tissue cancers (4.9%), nasopharyngeal carcinoma (NPC) (4%), kidney cancer (3.2%), biliary system cancers (1.7%), thyroid cancer (1%), germ cell tumors (0.7%), and lymphatic system cancers (0.4%).

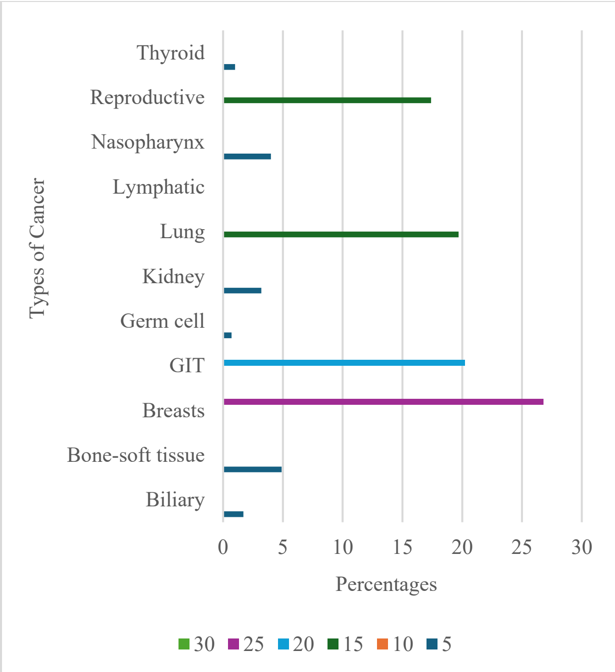

Figure 1. Subject Distribution by Types of cancer

3.2 Prevalence of patients with incidentally detected PE by cancer type

Table 1 below showed that lung cancer patients exhibited the highest prevalence of incidental PE (25.60%), with 11 cases found within the research cohort. This result supported by case study conducted by Dong, H. Y.,(2023) where they suggested the risk of getting PE in lung cancer patients will increase when the patient was known to have deep venous thrombosis. The incidence rate of gastrointestinal tract (GIT) cancer among patients was 21%, accompanied by 9 cases of incidental PE. The reproductive system and breast malignancies, which collectively represented 7 cases in the study, exhibited incidental PE rates of 16.30%. Basaran et al (2021) did relate the ovarian cancer patients that received neoadjuvant chemotherapy treatment in the risk of getting venous thromboembolism which could possibly lead to PE. In contrast, patients with bone-soft tissue cancer exhibited an incidence rate of 9.30%, with 4 instances of incidental PE identified. The prevalence of incident PE in patients with renal cancer progressively declined; the study group reported 2 cases, constituting 4.70%. The results indicated a consistent link yielding a singular outcome for the frequencies of incidental PE for biliary system, thyroid, and nasopharyngeal malignancies, totaling 2.30%. No predominance was identified in the lymphatic and germ cell types. The findings of this research contradicted those of other studies. Sinclair De Frías et al. (2022) found that the gastrointestinal cancer cohort of oncology patients exhibited the highest incidence of incidental PE (6.9%), with 15 out of 46 patients affected. This suggests variability in PE rates among diverse populations, potentially attributable to differences in clinical practices or patient demographics. In a separate article by Samra et al. (2022), unintentional PE was predominantly observed in persons with lung, uterus, and pancreatic malignancies.

Table 1. The rates of patients with incidentally detected pulmonary embolism (PE) by cancer type.

Primary cancer types	Number of patients	Number of patients with detected incidental PE	Incidental PE according to primary cancer	The rates of patients with incidentally detected PE according to cancer type
Breast	143	7	4.90%	16.30%
Gastrointestinal Tract (GIT)	108	9	8.30%	21%
Lung	**105**	**11**	**10.50%**	**25.60%**
Reproductive system	93	7	7.50%	16.30%
Bone-soft tissue	26	4	15.40%	9.30%
Nasopharyngeal (NPC)	21	1	4.80%	2.30%
Kidney	17	2	11.80%	4.70%
Biliary system	9	1	11.10%	2.30%
Thyroid	6	1	16.70%	2.30%
Germ cell	4	0	0%	0%
Lymphatic	2	0	0%	0%
	534	43		100

3.3 Incidence Distribution in Relation to Pulmonary Arterial Branches

An additional part of the study was the assessment of the incidence of distribution about the involvement of the pulmonary arterial section. This study offers insights into the structural patterns of PE inside the arterial branches. Referring to Table 2, the findings revealed that patients with identified PE involved the right upper branch including 10 patients, or 23.3% of the total cases. PE found at the right middle branch in 10 patients, representing 23.3% of the cases, whereas PE occurred at the right lower branch involved 11 patients, constituting 25.6% of the instances. 5 patients (11.6%)

exhibited detectable PE in the upper left pulmonary artery section, whereas 13 patients (30.2%) were identified in the lower left segment. Emboli were predominantly identified in the right upper branches of the right pulmonary artery, whereas they were least frequently observed in the left upper branch of the pulmonary artery. This was determined based on the engagement of the pulmonary artery segment. The results align with the data by Deniz et al., (2017) which indicated that the left lower pulmonary artery branch had the highest incidence, succeeded by the right upper and middle branches.

Table 2. Incidence Distribution in Relation to Pulmonary Arterial Branches

Pulmonary artery branches	Number of patients with detected PE	Incidence (%)
Right upper	10	23.3
Right middle	10	23.3
Right lower	11	25.6
Left upper	5	11.6
Left lower	13	30.2

3.4 Distribution of Patients with Incidental Pulmonary Embolism (PE) Diagnoses by Different Risk Factors

The data in Table 3 highlighted 4 most prevalence cancer and risk factors involved. indicates that chemotherapy administered over the past six months is prevalent, PE was detected present in 2.8% of breasts cancer patients 6.5% GIT cancer patients, 4.8% lung cancer patients and 4.3% with reproductive cancer. Chemotherapy is frequently offered to these patients due to the high occurrence. In the research conducted by Chlapoutakis., et al. (2022), the predominant risk factor for PE among cancer patients was recent chemotherapy, with 60% of patients having undergone this treatment in the preceding six months. Simultaneously, 1.4% of breast cancer patients, 1.9% GIT and lung cancer patients with PE exhibited metastases. The proportion of PE patients is marginally elevated, although it is not statistically distinct from the overall population. 0.7% of patients with breast cancer and 2.2% with reproductive cancer with PE had undergone surgery, in contrast to 43.2% of those without PE, underscoring a notable trend in post-surgical outcomes. This suggests that other factors may exert a more significant influence on the incidence of PE than surgical operations. Another factor to examine is the incidence of recent hospitalizations; 2.5% of patients with PE and 25.4% of individuals without PE had recent hospitalizations, respectively. This indicates that a recent hospitalization does not substantially influence the likelihood of developing PE. Finally, only 1.9% of patients with PE and 22.5% of patients without PE had radiation in the preceding six months. In a comparable scenario, radiation did not markedly distinguish those with PE from those without PE, based on nearly identical percentages.

Table 3. Distribution of Patients with Incidental PE diagnoses with different risk factors (*p*-value, *p*>0.05)

Type of primary cancer & total number of patients (N)	Various risk factors						Fisher Exact Tests (p-value, p>0.05)
	Yes/ No PE	Chemo within 6 mths = N (%)	Mets= N (%)	Post surgery = N (%)	Hosp stayed recently = N (%)	Radio within 6 mths = N (%)	
Breasts (135)	Yes	4(3)	2(1.5)	1(0.7%)	0(0)	0(0)	.886
	No	67(49.6)	18(13)	21(15.6)	13(9.6)	9(6.7)	
GIT (108)	Yes	7 (6.5)	2(1.9)	0(0)	0(0)	0(0)	.749
	No	62(57.4)	12(11)	13(12)	4(3.7)	6(5.6)	
Lung (105)	Yes	5(4.8)	2(1.9)	0(0)	1(0.95)	2(1.9)	.358
	No	58(55)	19(18)	4(3.8)	7(6.7)	5(4.8)	
Reproductive (93)	Yes	4(4.3)	0(0)	2(2.2)	1(1.1)	0(0)	.470
	No	50(54)	11(11)	11(11.8)	5(5.4)	5(5.4)	

Additionally, aside from the primary cancer types and associated risk factors outlined in the context, a significant risk factor associated with PE in oncology patients is the presence of central venous catheters (CVCs). CVCs are frequently employed in oncology patients for several functions, such as the delivery of chemotherapy, intravenous medications, and blood sampling. Nonetheless, the utilization of CVCs can increase the risk of thromboembolism, including pulmonary embolism (Qdaisat et al., 2020) (Jones.,2017).

Table 3 also shows the *p*-value for each of the four cancer types, the p-value is greater than 0.05 (p>0.05), hence the null hypothesis cannot be rejected. The examination of cancer type prevalence and related risk variables reveals no statistically significant association was found due to the limited population size. A bigger population size may lead to the acceptance of the proposed hypotheses in the study. In the article written in Fujieda et al., (2021), they stated that numerous clinical research and epidemiological studies had consistently established a strong association between these types of tumours and the occurrence of PE. Breast cancer, gastric cancer, hepatocellular carcinoma, esophageal squamous cell carcinoma, lung cancer, urothelial carcinoma, and pancreatic adenocarcinoma were prominent cancer types frequently linked to PE (He et al., 2021). These risk variables are prevalent among patients. However, their similar prevalence in both groups indicates that none can independently predict the incidence of pulmonary embolism. The emergence of PE in these individuals may instead result from other or unexamined reasons, or a confluence of multiple ones.

4. CONCLUSION

This research highlights the necessity of identifying and mitigating risk factors in clinical practice to reduce the occurrence and consequences of PE. Although this study found no statistically significant association between the examined risk factors and incidental PE, maintaining awareness of PE as a potential complication remains essential. Healthcare providers should continue to implement comprehensive preventive measures and early detection protocols for at-risk populations to improve patient outcomes and reduce the burden of this life-threatening condition. The analysis revealed no statistically significant relationship between cancer types and associated risk factors, which may be attributable to the relatively small sample size. A larger cohort could potentially yield sufficient power to detect significant associations and support the hypotheses proposed. Future studies should also incorporate cancer staging as an additional variable, given its potential influence on risk factor associations.

Moreover, the development of PE in these individuals may be driven by other unmeasured or multifactorial contributors, underscoring the need for comprehensive investigations into alternative mechanisms.Future research with prospective studies is necessary to confirm and enhance the findings of this investigation. The findings from this study may inform evidence-based practices, guide decision-making in patient care, and advance knowledge in PE research. Proactively addressing risk factors and tailoring interventions to individualized risk profiles can lead to improved outcomes and enhanced quality of care for patients at risk of PE.

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REFERENCES

Ahuja, J., Shroff, G. S., Benveniste, M. F., Marom, E. M., Truong, M. T., & Wu, C. C. (2020). In situ pulmonary artery thrombosis: unrecognized complication of radiation therapy. *American Journal of Roentgenology*, *215*(6), 1329-1334.

Bach, A. G., Taute, B. M., Baasai, N., Wienke, A., Meyer, H. J., Schramm, D., & Surov, A. (2016). 30-day mortality in acute pulmonary embolism: prognostic value of clinical scores and anamnestic features. *PloS one*, *11*(2), e0148728.

Basaran, D., Boerner, T., Suhner, J., Sassine, D., Liu, Y., Grisham, R. N., ... & Jewell, E. L. (2021). Risk of venous thromboembolism in ovarian cancer patients receiving neoadjuvant chemotherapy. *Gynecologic oncology*, *163*(1), 36-40.

Chlapoutakis, S., Georgakopoulou, V., Trakas, N., Kouvelos, G., Papalexis, P., Damaskos, C., Sklapani, P., Grivas, A., Gouveris, P., Tryfonopoulos, D., Tzovaras, A., Ardavanis-Loukeris, G., Grouzi, E., Spandidos, D. and Matsagkas, M. (2022). Characteristics and outcomes of cancer patients who develop pulmonary embolism: A cross-sectional study. *Oncology Letters*, 23(5). doi:https://doi.org/10.3892/ol.2022.13288.

Deniz, M. A., Deniz, Z. T., Adin, M. E., Akıl, F., Turmak, M., Urakcı, Z., ... & Goya, C. (2017). Detection of incidental pulmonary embolism with multi-slice computed tomography in cancer patients. *Clinical Imaging*, *41*, 106-111.

Dong, H. Y., Tong, M. S., Wang, J., Liu, Y., Tao, G. Y., Petersen, R. H., ... & Chen, J. (2023). Risk factors for pulmonary embolism in lung cancer patients with lower limb deep venous thrombosis: a case-control study. *Translational lung cancer research*, *12*(7), 1539.

Fujieda, K., Nozue, A., Watanabe, A., Shi, K., Itagaki, H., Hosokawa, Y., ... & Nishide, K. (2021). Malignant tumor is the greatest risk factor for pulmonary embolism in hospitalized patients: a single-center study. *Thrombosis journal*, *19*(1), 77.

He, X., Anthony, D. C., Catoni, Z., & Cao, W. (2021). Pulmonary tumor embolism: A retrospective study over a 30-year period. *PLOS ONE*, *16*(8), e0255917. https://doi.org/10.1371/journal.pone.0255917

Jones, D., Wismayer, K., Bozas, G., Palmer, J., Elliott, M., & Maraveyas, A. (2017). The risk of venous thromboembolism associated with peripherally inserted central catheters in ambulant cancer patients. *Thrombosis journal*, *15*(1), 25.

Luo, Z., Ma, G., Lu, Y., Yao, J., Xu, N., Cao, C. and Ying, K. (2023). Characteristics and 6-Month Mortality of Medical Oncology Patients With Incidental and Symptomatic Pulmonary Embolism: A Single-Institutional Retrospective Longitudinal Analysis. *Clinical and applied thrombosis/hemostasis*, 29, p.107602962311551-107602962311551. doi: https://doi.org/10.1177/10760296231155177

Qdaisat, A., Kamal, M., Al-Breiki, A., Goswami, B., Wu, C.C., Zhou, S., Rice, T.W., Alagappan, K. and Yeung, S.-C.J. (2020). Clinical characteristics, management, and outcome of incidental pulmonary embolism in cancer patients. *Blood Advances*, 4(8), pp.1606–1614. doi: https://doi.org/10.1182/bloodadvances.2020001501

Poenou, G., Dumitru Dumitru, T., Lafaie, L., Mismetti, V., Ayoub, E., Duvillard, C., Accassat, S., Mismetti, P., Heestermans, M., & Bertoletti, L. (2022). Pulmonary Embolism in the Cancer Associated Thrombosis Landscape. *Journal of Clinical Medicine*, *11*(19), 5650. https://doi.org/10.3390/jcm11195650

Samra, S. R., Said, A. M., Elsayed, D. H., Elhamed, M. E. A., & HAbeb, M. A. (2022). The incidence and clinical characteristics of pulmonary embolism in oncologic patients. *The Egyptian Journal of Bronchology*, *16*(1), 64.

Sinclair De Frías, J., Cukier, M., Olivero, L., Vazquez, D. and Tapia, H. (2022). Incidental Pulmonary Embolism in Cancer Patients: A Single-Institution Analysis in Panama. *Multidisciplinary Cancer Investigation*, 6(1), pp.1–7. doi: https://doi.org/10.30699/mci.6.1.559-1

RESEARCH ARTICLE

Comparative evaluation of soft-tissue foreign body detection using ultrasound and radiography: A phantom study

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Abstract:

Soft-tissue foreign bodies (STFBs) are common clinical presentations requiring accurate imaging for effective diagnosis and management. This experimental phantom study compared the performance of ultrasound and general radiography in detecting STFBs of various materials and depths using anatomically relevant cow-foreleg models. Eight foreign bodies; metallic, organic, and inorganic were inserted at depths of 1, 3, and 5 cm. Image visibility was assessed by two radiologists using standardized scoring criteria, with substantial inter-rater agreement (weighted Cohen's $\kappa = 0.74$). Ultrasound yielded significantly higher visibility scores than radiography, as confirmed by a Wilcoxon signed-rank test ($Z = -2.82$, $p = .01$). A Friedman test showed no significant depth-related differences in ultrasound image quality (χ^2 (2) = 0.57, $p = .75$). Radiographic detection also remained consistent across depths (χ^2 (2) = 4.00, $p = .14$), although it was notably influenced by the radiopacity of the foreign body materials. Overall, the findings support existing evidence that ultrasound provides superior diagnostic performance, particularly when the composition of the suspected foreign body is unknown. This study reinforces the potential role of ultrasound as a first-line imaging modality for suspected STFBs.

Keywords: Phantom study, radiography, soft-tissue foreign bodies, ultrasound

1. INTRODUCTION

Soft-tissue foreign bodies (STFBs), whether introduced intentionally or accidentally, represent a common cause of emergency and outpatient visits, requiring prompt evaluation and intervention (Campbell & Wilbert, 2023). This foreign bodies are categorised by composition; metallic, organic, or inorganic materials and most injuries result from abrasive, blunt, or penetrating trauma (Skinner & Morrison, 2023). STFBs can lead to acute pain, functional impairment, and complications such as inflammation, infection, or allergic reactions (Del Cura et al., 2020). Organic materials, particularly wood, pose significant challenges due to severe inflammatory responses and persistent infections that often resist antibiotic therapy, necessitating timely removal (Campbell & Wilbert, 2023). Accurate detection and extraction are therefore critical to prevent morbidity and avoid further complications.

While superficial STFBs may be removed during routine examination, imaging becomes essential when palpation fails to confirm their presence (Campbell & Wilbert, 2023; Del Cura et al., 2020). Common modalities include general radiography, ultrasound, computed tomography (CT) and magnetic resonance imaging (MRI), which aid in detection and surgical planning by localizing foreign bodies relative to surrounding structures (Voss et al., 2020). General radiography is often the first-line technique due to accessibility and cost-effectiveness, but its utility is limited to radiopaque materials such as glass, metal and stone whereas radiolucent objects like wood and certain plastics remain poorly visualized (Carneiro et al., 2020; Grocutt et al., 2023; Rupert et al., 2020; Voss et al., 2021). Ultrasound complements general radiography by detecting both radiopaque and radiolucent objects, particularly in superficial regions such as the hand and wrist (Grogan & Mount, 2023). Although several studies have assessed ultrasound for STFB detection, methodological limitations including non-representative phantom models and controlled foreign body orientations restrict the generalizability of findings (Alfuraih et al., 2021; Grocutt et al., 2023; Tok & Kadioglu, 2021).

However, critical gaps remain. First, most studies evaluated detection at a single depth, overlooking how varying depths influence diagnostic accuracy, especially for ultrasound. Second, phantom models often lacked anatomical realism, using homogeneous materials that fail to replicate musculoskeletal heterogeneity and bone presence. Third, foreign bodies were frequently aligned parallel to the ultrasound beam, artificially enhancing echogenicity and detectability (Kawalec, 2023). These limitations reduce clinical applicability, as real-world scenarios involve variable depths, heterogeneous tissue structures, and diverse orientations. To address these gaps, this study employs anatomically relevant phantoms incorporating bone tissue and assesses detection of metallic, organic, and inorganic STFBs at multiple depths (1 cm, 3 cm, and 5 cm) using linear ultrasound and radiography. Diagnostic accuracy of both modalities is compared across foreign body types and depths, providing a more realistic and clinically relevant evaluation of imaging performance in STFB detection.

2. MATERIALS AND METHODS

Three cow-foreleg phantoms were used, each embedded with eight soft-tissue foreign bodies (STFBs): two metallic (office pin, aluminium shard), two organic (cactus spine, wooden splinter), and four inorganics (glass shard, small stone, pencil lead, plastic fragment). These materials were selected based on commonly reported STFB injuries. Foreign bodies were inserted at depths of 1, 3, and 5 cm, with each foreleg representing a single depth. Both ultrasound and general radiography were performed on all phantoms, yielding 24 images were independently assessed by two radiologists using a validated scoring system adapted from Alfuraih et al. (2021).

Fresh cow-forelegs were obtained from a local slaughterhouse, transported on ice, and stored frozen until imaging. Three forelegs (Leg A, B, C) were incised to depth of 1, 3, and 5 cm, respectively, following the method described by Tok & Kadioglu (2021). Incision depths were determined using pre-marked indicators on the knife and forceps, to ensure consistent depth during foreign body inserting. Each foreign body was inserted individually using forceps, and orientation were randomised to simulate clinical variability. All insertions were performed by a co-researcher to ensure blinding of the sonographer, radiographer and primary researcherr. Prior to ultrasound and general radiographic image acquisition, the cow-forelegs were thawed at room temperature for approximately 12 hours to preserve soft-tissue characteristic similar to in vivo condition, as recommended by USDA FSIS (2023).

All materials measured ≤3 cm, reflecting commonly encountered STFB sizes (2 - 4 cm). Selected materials were able to penetrate soft tissue and represented the major clinical categories of metallic, organic, and inorganic foreign bodies (Table 1).

Table 1. Classification of soft-tissue foreign body materials

Classification	Type	Material	Radiographic property
Metallic	Metal	Office pin	Radiopaque
	Metal	Aluminium shard	Low radiopacity
Organic	Wood	Cactus spine	Radiolucent
	Wood	Splinters	Radiolucent
Inorganic	Glass	Glass shard	Radiopaque
	Stone	Small stone	Radiopaque
	Graphite	Pencil lead	Radiopaque
	Plastic	Plastic fragment	Radiolucent

Note: Classification based on material composition and radiographic visibility.

Ultrasound was performed by a sonographer with more than 15 years of clinical experience, to ensure consistent image acquisition, using a Samsung RS85 Prestige system with a 3–12 MHz linear transducer. Depth was adjusted manually. Each phantom was scanned in longitudinal and transverse planes to optimize visualisation, following recommendations by Grocutt et al. (2023) and Tok & Kadioglu (2021). Images were exported directly from the system.

General radiography was performed using a Carestream ceiling-suspended X-ray system with a Fuji Computed Radiography (FCR) imaging plate. The imaging plate surface and housing were inspected for physical damage, scratches, or debris, and was erased prior to image acquisition to remove any residual latent image from previous exposures. Anteroposterior (AP) and lateral projections were acquired in a single imaging plate, at a source-to-image distance (SID) of 100 cm. The initial exposure was set at 63 kVp and 4.0 mAs, followed by two reduced-kVp settings (53 kVp and 45 kVp) to enhance contrast for low-density materials (Sy et al., 2022). Metallic foreign bodies, high density material, required a higher kVp (63 kVp) for adequate penetration. While the organic materials such as wood, which are low-density, required a lower kVp (45 kVp) to improve contrast between the material and surrounding soft tissue. Inorganic materials, with intermediate in density, were imaged at medium kVp (53 kVp) to achieve balanced penetration and contrast. As each phantom contained various foreign body types and materials, the same imaging protocol was applied to all phantoms for consistency.

Two radiologists, each with more than 15 years of clinical and ultrasound imaging experience, independently scored all images while being blinded to the foreign body type and depth. The separation of roles between the sonographer and radiologists was implemented to minimise bias and ensure an objective evaluation of modality's performance. Images were provided in JPEG format via Google Forms, and scoring was conducted using the foreign bodies visibility criteria, ranging from 0 (no foreign body detected) to 5 (excellent visibility), adapted from Alfuraih et al. (2021; see Table 2).

Table 2. Scoring criteria (Adapted from Alfuraih et al., 2021)

Score	Quality	Description
4	Excellent	Excellent visibility with clear detail resolution and good demarcation from surrounding tissues.
3	Good	Clear visibility with good detail resolution and adequate demarcation from surrounding tissues.
2	Fair	Limited visibility with insufficient detail resolution and poor demarcation.
1	Poor	Poor visibility with no meaningful detail resolution and unclear demarcation from surrounding tissues.
0	Invisible	No foreign body detected.

All analyses were performed using IBM SPSS Statistics version 29. Inter-rater reliability between the two radiologists was assessed using Cohen's Kappa, with interpretation as follows: ≤0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (moderate), 0.61–0.80 (substantial), and ≥0.81 (excellent). Substantial agreement or higher permitted averaging of the raters' scores.

The Friedman test, a non-parametric alternative to repeated-measures ANOVA, was used to compare visibility scores across the three depths for each imaging modality. Statistical significance was set at $p < 0.05$. The Wilcoxon signed-rank test, the non-parametric equivalent of the paired t-test, was used to compare ultrasound and radiography scores, with significance similarly defined as $p < 0.05$.

This study received approval from the Universiti Teknologi MARA (UiTM) Ethics Committee (Reference: FERC/FSK/MR/2025/00013) and was conducted in accordance with institutional and research ethics guidelines.

3. RESULTS AND DISCUSSION

Inter-rater reliability for image quality scores was assessed using weighted Cohen's Kappa (Table 3). The two radiologists demonstrated substantial agreement, κ = .74, 95% CI [0.59, 0.89, p<.001. Modality-specific analyses also indicated substantial agreement for ultrasound (κ = .75, 95% CI [0.53, 0.96], p<.001) and radiography (κ = .70, 95% CI [0.49, 0.92], p<.001). Because the agreement met the recommended threshold, scores from both raters were averaged for subsequent analyses (Ranganathan et al., 2017). Both raters, with more than 15 years of clinical experience, were aware of the presence of foreign bodies but blinded to material types. High agreement is likely attributable to their comparable experience and the use of a standardized scoring framework, which enhances reliability (Alfuraih et al., 2021; Luiz et al., 2021; Neto et al., 2022).

Table 3. Inter-rater reliability between Radiologist 1 and Radiologist 2

Measure of Agreement	Value	Asymptotic Standard Error	Approximate T	Approximate Significance
Kappa	0.74	0.08	7.29	< .001

Interpretation: Agreement is substantial according to Landis & Koch criteria (κ = 0.61–0.80).

A Friedman test was conducted to examine the effect of foreign body depth (1 cm, 3 cm, and 5 cm) on ultrasound image quality scores (Table 4). Results indicated no statistically significant differences across depths, $\chi^2(2) = 0.57$, $p = .75$. Median scores were highest at 1 cm and 3 cm (Mdn = 4.00) and slightly lower at 5 cm (Mdn = 3.88), suggesting a minor decline with increased depth that did not reach statistical significance. Therefore, the null hypothesis was retained, indicating that depth had no significant effect on ultrasound image quality.

The slight decline in image quality with depth aligns with established principles; high-frequency linear probes provide excellent resolution but reduced penetration, and objects deeper than 2 cm are more challenging to visualize due to attenuation (Grogan & Mount, 2023; Campbell & Wilbert, 2023). Sample size may also have contributed to the non-significant results. Three cow-forelegs (n=3) were used in this study, limiting statistical power. Larger studies, such as Voss et al. (2021) with n = 34, offer greater generalizability, though the current sample aligns with prior phantom studies (Grocutt et al., 2023; Tok & Kadioglu, 2021).

Additionally, the use of a high-end ultrasound system (Samsung RS85 Prestige) may have reduced depth-related degradation. Its advanced beam-forming technology, attenuation compensation, and AI-assisted optimisation likely enhanced visibility at deeper levels. Emerging AI tools that assist in structural detection and noise reduction may also contribute to more stable performance across depths, thereby diminishing detectable differences (Shin et al., 2020). These technological features help improve shadowed regions, where attenuation and posterior acoustic shadowing are commonly produced by foreign bodies (Carneiro et al., 2020). Proper optimisation of imaging parameters further enhances penetration and image quality, potentially minimising depth-driven variability (Zander et al., 2020). Overall, while depth-related attenuation trends were present, they did not significantly influence ultrasound detection performance within the tested depth range.

A Friedman test also evaluated the effect of foreign body depth on radiography image quality (Table 4). Results showed no statistically significant differences across the three depths, χ^2 (2) = 4.00, p = .14. Median scores were identical at all depths (Mdn = 0.00), indicating no effect of depth on radiographic visibility. The null hypothesis was therefore rejected.

This aligns with radiography's principle of detecting foreign bodies primarily based on radiopacity rather than depth. Radiopaque materials absorb more X-ray photons and are easily visualized regardless of insertion depth, whereas radiolucent materials remain difficult to detect (Mowery & Singh, 2022). Exposure parameters such as kVp and mAs influence image contrast; in this study, a 15% kVp reduction enhanced contrast for low-density foreign bodies (Sy et al., 2022). Despite this adjustment, the number of detectable foreign bodies remained unchanged, supporting the conclusion that depth alone does not substantially affect general radiography detection. These findings align with previous observations suggesting that radiography's effectiveness is largely determined by material density rather than depth, emphasizing the modality's limitation in detecting radiolucent objects regardless of insertion depth (Hammoud et al., 2024).

Table 4. Friedman Test for ultrasound and general radiography image scores across varying depths

Imaging Modality	N	Chi-Square	df	Asymptotic Significance
Ultrasound	8	0.57	2	0.75
General Radiography	8	4.00	2	0.14

Note: Friedman test was used to compare image visibility scores across three depths (1 cm, 3 cm, and 5 cm). Statistical significance was set at p < 0.05.

A Wilcoxon signed-rank test (Table 5) was used to compare ultrasound and general radiography scores, as the ordinal data did not meet the assumptions required for a parametric paired t-test. Ultrasound demonstrated higher median scores (Mdn = 3.25, IQR = 4.00) compared with general radiography (Mdn = 0.00, IQR = 3.00). The difference between the two modalities was statistically significant, Z = −2.82, N = 24, p = .01, indicating superior diagnostic performance of ultrasound for detecting soft-tissue foreign bodies. Accordingly, the null hypothesis was rejected.

Table 5. Wilcoxon signed-rank test for averaged ultrasound and general radiography scores

Variable	Ultrasound median (IQR)	Radiography median (IQR)	Z	p-value
Soft tissue foreign body detection score	3.25 (4.00)	0.00 (3.00)	-2.82	0.01*

*Wilcoxon signed-rank test; p < 0.05 indicates statistical significance.

Ultrasound demonstrated superior performance compared to radiography, which can be attributed to its enhanced soft tissue visualisation, multiplanar imaging capabilities, and ability to detect both radiopaque and radiolucent foreign bodies, particularly those located superficially (Carneiro et al., 2020; Vishwanath et al., 2020; Voss et al., 2021). The presence of posterior acoustic shadowing further improves identification by increasing diagnostic confidence and sensitivity (Del Cura et al., 2020; Grocutt et al., 2023). In contrast, radiography relies primarily on the radiopacity of materials. Dense foreign bodies such as metal, glass, and stone demonstrate high X-ray attenuation and are readily detected, whereas radiolucent materials including wood and many plastics, are frequently missed, resulting in lower visibility scores and a higher likelihood of undetected foreign bodies (Voss et al., 2021).

The findings of this study are consistent with Voss et al. (2021), particularly regarding the material-dependent nature of detectability. Consistent with their observations, ultrasound displayed superior performance for radiolucent materials and maintained high detection rates for foreign bodies located within the first 4–6 cm, a depth range previously identified as optimal for high-frequency linear transducers (Lee et al., 2025). The studies support the conclusion that ultrasound's diagnostic value is influenced more by material composition than by depth, provided the object remains within the effective penetration range of the transducer.

Earlier research by Manthey et al. (1996) reported poor ultrasound sensitivity and considerable difficulty in detecting radiolucent materials, while radiography showed excellent detection of radiopaque objects but failed entirely to identify radiolucent foreign bodies such as wood, plastic, and cactus spines. The authors attributed ultrasound's limited performance to the technological constraints of earlier-generation systems, including inadequate management of acoustic shadowing, heterogeneous tissue backgrounds, and attenuation.

The improved outcomes observed in this study compared to Manthey et al. (1996) likely reflects major advancements in ultrasound technology over the past three decades. The Samsung RS85 Prestige system used in this study incorporates advanced beam-forming, attenuation compensation, speckle-reduction algorithms, and AI-assisted optimisation. These features appear to mitigate the confounding effects of soft-tissue interfaces and acoustic artefacts, contributing to more consistent detection across depths and reinforcing ultrasound's role as a highly effective modality for foreign-body identification.

This technological contrast is further highlighted by the performance of general radiography in the present study. Radiography detected fewer foreign bodies (N = 9) than ultrasound (N = 15), despite the application of three different exposure settings. Adjustments to exposure parameters influenced only visibility scores rather than the number of foreign bodies detected, supporting previous findings that detectability is driven primarily by material composition rather than radiographic exposure selection (Carneiro et al., 2020; Mowery & Singh, 2022). Only three radiopaque foreign bodies; an office pin, a glass shard, and a small stone were consistently visualised across all kVp and mAs combinations and at varying depths, although visibility diminished as kVp and depth increased. Conversely, radiolucent soft-tissue foreign bodies were undetectable regardless of exposure settings or depth, as shown in Figure 1.

These findings support ultrasound as the preferred first-line imaging modality for STFB detection, particularly when the composition of the foreign body is unknown or radiolucent. As shown in Figure 2, ultrasound reliably demonstrate various range of STFB, including radioapaque and radiolucent materials, with high sensitivity. Ultrasound offers real-time, non-invasive imaging and non-ionising radiation, making it particularly suitable for evaluating musculoskeletal injuries of the hands, wrists, and other soft tissues (Alfuraih et al., 2021; Grogan & Mount, 2023; Tok & Kadioglu, 2021). Overall, the results of this study reinforce the clinical value of ultrasound over general radiography for comprehensive detection of soft-tissue foreign bodies.

Figure 1. Anteroposterior (AP) and lateral projections of the cow foreleg phantom acquired with 45 kVp/4.0 mAs (A), 53 kVp/4.0 mAs (B), and 63 kVp/4.0 mAs (C), demonstrating three radiopaque foreign bodies; an office pin, a glass shard, and a small stone (arrow from top to bottom).

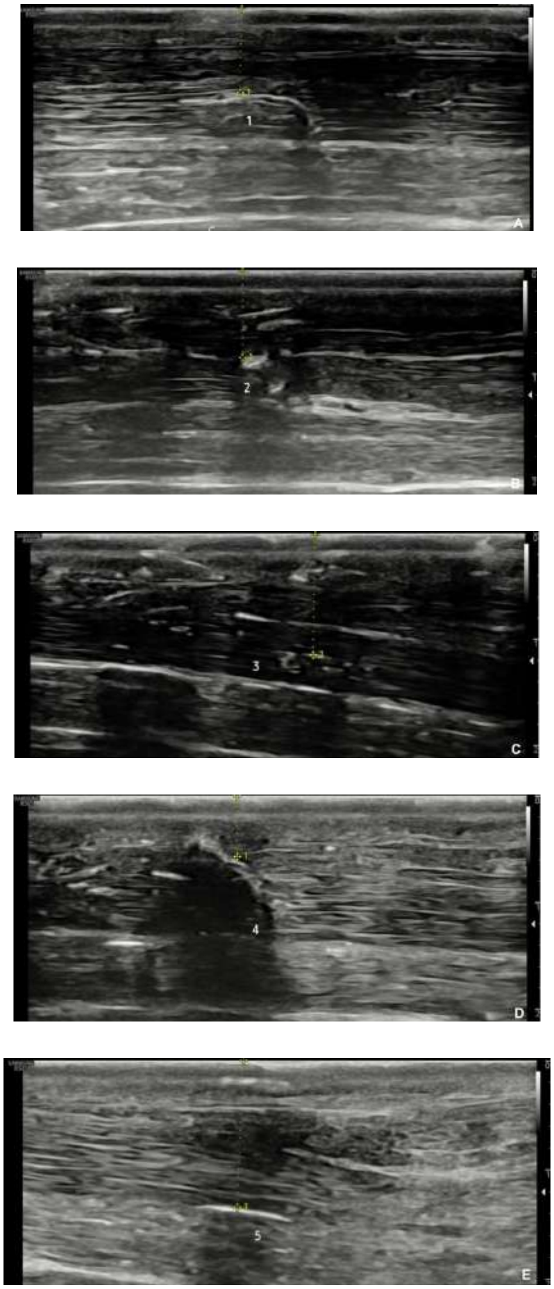

Figure 2. Ultrasound images (A-E) demonstrating the detection of various soft-tissue foreign bodies (STFBs) embedded within the foreleg phantom. Each image shows the foreign body as a hyperechoic structure with posterior acoustic shadowing or artefacts, aiding identification.

Although this study provides valuable insights into the effectiveness of ultrasound and general radiography for detecting STFB of varying depths and materials, several limitations should be acknowledged. First, the sample size was small (n = 3), which may have reduced the statistical power of the findings. Additionally, although eight foreign body types were included, they do not represent the diversity of STFB materials encountered in real clinical settings. Clinically, STFBs may involve a much broader range of radiolucent, radiopaque, and specialised materials, such as carbon-fibre fragments, depending on the mechanism of injury. Consequently, while the findings offer meaningful insight into STFB imaging and detectability, their generalisability to all clinical scenarios is limited. Second, the study utilized cow-foreleg phantom models. Although these phantoms approximate human forearm anatomy, they do not replicate the dynamic characteristics of live tissue, such as patient motion, pain response, and swelling. Unlike clinical settings, phantoms are static and free from motion artefacts which may limit the applicability of results to real-world conditions. Third, the absence of clinical validation represents another constraint. Controlled phantom environments do not account for practical challenges such as patient movement or incorrect positioning, both of which are critical in musculoskeletal imaging and can lead to diagnostic errors. Additionally, variability in image review conditions may have influenced interpretation. Image scoring was performed at different times, locations, and on different display screens, introducing potential inconsistencies due to variations in resolution, brightness, and ambient lighting. Lastly, the incision depth was estimated by marking the knife and forceps with a marker to indicate the level of penetration. Although this method provided a practical reference, it lacked the precision of direct measurement. Future studies should consider using a calibrated digital calliper or depth gauge to obtain accurate measurements from the surface to the deepest point, thereby enhancing the consistency and reproducibility of the results.

4. CONCLUSION

As a conclusion, ultrasound demonstrated superior performance over general radiography in detecting soft tissue foreign bodies (STFB). Although ultrasound image quality decline slightly with increasing depth, this difference was not statistically significant. In contrast, radiographic detection remained consistent across depths but was strongly influenced by material radiopacity, highlighting its limitations for identifying radiolucent foreign bodies. These findings support ultrasound as a more reliable modality for STFB detection, particularly when foreign body composition is unknown. Despite limitations such as small sample size and limited clinical variability, this study reinforces the potential of ultrasound as a first-line imaging technique in suspected STFB cases.

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REFERENCES

Alfuraih, A. M., Almutairi, F. N., Alotaibi, S. B., & Alshmrani, A. A. (2021). Semi-quantitative scoring of imaging modalities in detecting soft tissue foreign bodies: an in vitro study. *Acta Radiologica*, *63*(4), 474–480. https://doi.org/10.1177/0284185121999654

Campbell, E. A., & Wilbert, C. D. (2023, July 30). *Foreign body imaging*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK470294/

Carneiro, B. C., Cruz, I. a. N., Chemin, R. N., Rizzetto, T. A., Guimarães, J. B., Silva, F. D., Yoshida, C., Junior, Pastore, D., Filho, A. G. O., & Nico, M. a. C. (2020). Multimodality Imaging of Foreign Bodies: New Insights into Old Challenges. *Radiographics*, *40*(7), 1965–1986. https://doi.org/10.1148/rg.2020200061

Del Cura, J. L., Aza, I., Zabala, R. M., Sarabia, M., & Korta, I. (2020). US-guided localization and removal of Soft-Tissue foreign bodies. *Radiographics*, *40*(4), 1188–1195. https://doi.org/10.1148/rg.2020200001

Grocutt, H., Davies, R., & Heales, C. (2023). Ultrasound compared with projection radiography for the detection of soft tissue foreign bodies – A technical note. *Radiography*, *29*(6), 1007–1010. https://doi.org/10.1016/j.radi.2023.08.005

Grogan, S. P., & Mount, C. A. (2023, March 27). *Ultrasound Physics and instrumentation*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK570593/

Hammoud, S., Tishkowski, K., Hammad, A., Barbat, J., Cohen, A., & Brenner, B. (2024). Identifying glass foreign bodies using conventional X-ray in a gelatinous model. *World Journal of Emergency Medicine*, *16*(1), 71. https://doi.org/10.5847/wjem.j.1920-8642.2025.002

Kawalec, A. (2023). Use of ultrasound in differential diagnosis of soft tissue foreign bodies in children – a case series. *Pediatria Polska*, *98*(2), 180–184. https://doi.org/10.5114/polp.2023.128061

Lee, W. A., Nelson, G., Lala, V., & Grogan, S. P. (2025, March 20). *Sonography 1st trimester assessment, protocols, and interpretation*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK573070/

Luiz, L., Marques, I., Folador, J., & Andrade, A. (2021). Intra and inter-rater remote assessment of bradykinesia in Parkinson's disease. *Neurología*, *39*(4), 345–352. https://doi.org/10.1016/j.nrl.2021.08.005

Manthey, D. E., Storrow, A. B., Milbourn, J., & Wagner, B. J. (1996). Ultrasound versus Radiography in the detection of Soft-Tissue foreign bodies. *Annals of Emergency Medicine*, *28*(1), 7–9. https://doi.org/10.1016/s0196-0644(96)70130-0

Mowery, M. L., & Singh, V. (2022, October 17). *X-ray production technical evaluation*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK564332/

Neto, H. G. R., Sinem, T. B., Koiller, L. M., Pereira, A. M., De Souza Gomes, B. M., Filho, C. L. V., Cavalcanti, M. T., & Telles-Correia, D. (2022). Intra-rater Kappa Accuracy of Prototype and ICD-10 Operational Criteria-Based Diagnoses for Mental Disorders: A Brief Report of a Cross-Sectional Study in an outpatient setting. *Frontiers in Psychiatry*, *13*, 793743. https://doi.org/10.3389/fpsyt.2022.793743

Ranganathan, P., Pramesh, C., & Aggarwal, R. (2017). Common pitfalls in statistical analysis: Measures of agreement. *Perspectives in Clinical Research*, *8*(4), 187–191. https://doi.org/10.4103/picr.picr_123_17

Rupert, J., Honeycutt, J. D., & Odom, M. R. (2020). Foreign bodies in the skin: Evaluation and Management. *PubMed*, *101*(12), 740–747. https://pubmed.ncbi.nlm.nih.gov/32538598

Shin, Y., Yang, J., Lee, Y. H., & Kim, S. (2020). Artificial intelligence in musculoskeletal ultrasound imaging. *Ultrasonography,* *40*(1), 30–44. https://doi.org/10.14366/usg.20080

Skinner, E. J., & Morrison, C. A. (2023, May 1). *Wound foreign body removal*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK554447/

Sy, E., Samboju, V., & Mukhdomi, T. (2022, October 17). *X-ray image production Procedures*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK564352

The big thaw — safe defrosting methods. (n.d.). .S. Department Of Agriculture, Food Safety and Inspection Service. https://www.fsis.usda.gov/food-safety/safe-food-handling-and-preparation/food-safety-basics/big-thaw-safe-defrosting-methods

Tok, S., & Kadioglu, E. (2021). Ultrasonography in soft-tissue foreign-body detection: a phantom study. *Polish Journal of Radiology*, *86*, 496–499. https://doi.org/10.5114/pjr.2021.108879

Vishwanath, V., Jafarieh, S., & Rembielak, A. (2020). The role of imaging in head and neck cancer:An overview of different imaging modalitiesin primary diagnosis and staging of the disease. *Journal of Contemporary Brachytherapy*, *12*(5), 512–518. https://doi.org/10.5114/jcb.2020.100386

Voss, J. O., Doll, C., Raguse, J. D., Beck-Broichsitter, B., Walter-Rittel, T., Kahn, J., Böning, G., Maier, C., & Thieme, N. (2020). Detectability of foreign body materials using X-ray, computed tomography and magnetic resonance imaging: A phantom study. *European Journal of Radiology*, *135*, 109505. https://doi.org/10.1016/j.ejrad.2020.109505

Voss, J. O., Maier, C., Jonas Wüster, Benedicta Beck-Broichsitter, Tobias Ebker, Jana Vater, Steffen Dommerich, Raguse, J. D., Georg Böning, & Nadine Thieme. (2021). Imaging foreign bodies in head and neck trauma: a pictorial review. In *Insights Imaging* (Vol. 12, p. 20). https://doi.org/10.1186/s13244-021-00969-9

Zander, D., Hüske, S., Hoffmann, B., Cui, X., Dong, Y., Lim, A., Jenssen, C., Löwe, A., Koch, J. B., & Dietrich, C. F. (2020). Ultrasound Image Optimization ("Knobology"): B-Mode. *Ultrasound International Open*, *06*(01), E14–E24. https://doi.org/10.1055/a-1223-1134

RESEARCH ARTICLE

The effectiveness of coconut-dreg-based mudballs in kitchen wastewater treatment from restaurants and poultry shops

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Abstract:

This study investigates the effectiveness of coconut-dreg-based mudballs as a sustainable and cost-effective solution for treating kitchen wastewater from restaurant and poultry shop sources. Kitchen wastewater, characterized by its high organic load and potential pathogen content, poses significant environmental and public health risks if not adequately treated. Leveraging the principles of circular economy and sustainable waste management, coconut dregs, a by-product of the food industry, are harnessed for their potential in bioaugmentation to develop mudballs for wastewater treatment. Mudballs is a well-known biological treatment method for wastewater. Laboratory experiments were conducted to assess the removal efficiency of pollutants, including pH, dissolved oxygen (DO), turbidity, chemical oxygen demand (COD), and ammoniacal nitrogen, comparing the performance of coconut-dreg-based mudballs with conventional mudballs. Coconut- dreg-based mudballs demonstrated significant turbidity reduction (91.33%), COD reduction (84.84%), and effective ammoniacal nitrogen reduction (89.13%), particularly in kitchen wastewater from restaurants. The alkaline and fibrous nature of coconut dregs were identified as the key factors contributing to these favourable results. The enhanced effectiveness of coconut-dreg-based mudballs highlights their viability as a cost-effective and environmentally friendly alternative for kitchen wastewater treatment.

Keywords: circular economy, adsorbent, kitchen, bioaugmentation

1. INTRODUCTION

As defined in Malaysia Food Hygiene Regulations (2009), “food premises” is a term that defines premises employed for or to any of the following: food preparation, preservation, packaging, storage, transportation, distribution, or sale; or food relabelling, reprocessing, or reconditioning. Food premises, and food facilities, also known as; Food Service Establishment (FSE), play a vital role in meeting the growing demand for food products. However, these facilities generate substantial amounts of wastewater that contains high levels of pollutants, such as organic matter, nutrients, and suspended solids (Nayyar et al., 2021). Improper management and inadequate treatment of this wastewater can lead to adverse environmental impacts, including water pollution, eutrophication, and contamination of aquatic ecosystems (Ahmad et al., 2023). Therefore, there is a pressing need to develop effective and sustainable wastewater treatment methods specifically tailored to the characteristics of food processing wastewater.

Mudballs have gained attention as a low-cost and eco-friendly technology for water purification and environmental remediation (Maharjan & Ghimere, 2021; Ahmad Nazri & Ghazali, 2017). Mudballs are small spherical structures composed of bokashi – a mixture of clay, organic materials, microorganisms, and bran (EM Research Organization Inc., 2016). They have demonstrated promising results in various applications, such as soil restoration, river rehabilitation, and wastewater treatment (Park et al., 2016; Nayyar et., 2021). Mudballs act as natural filtration devices, absorbing pollutants and facilitating biological processes that aid in the degradation of organic matter and the removal of contaminants (Gumogda, 2022; Maharjan & Ghimere, 2021).

Coconut dregs, by-products of the coconut industry, have gained attention due to their high carbon content and fibrous nature (Madawala et al., 2023; Mohd Zin et al., 2017). These characteristics suggest that coconut dregs have adsorbent properties and can act as a filtration material for pollutant removal in wastewater treatment. Coconut dregs are abundantly available in tropical countries like Malaysia and are also known as a low-cost material, making them an attractive option for sustainable wastewater treatment applications (Rosni et al., 2020). However, its potential in treating kitchen wastewater is still underexplored. Untreated kitchen wastewater presents a serious environmental risk especially when the kitchen wastewater is discharged straight into the sewers and into water bodies. This is due to its properties that are laden with high organic matter, fats, oils, and grease (Nayyar et al, 2021; Tan & Wong, 2019). Additionally, wastewater characteristics from a particular kitchen from food premises vary significantly and determine the type of treatment it requires. Diverse methodologies were used to address the issues that can be found in previous studies, with an emphasis on protecting water quality and eliminating pollutants (Nayyar et al., 2021; Al-Gheethi, 2019; Mihelcic et al., 2014).

2. MATERIALS AND METHODS

Laboratory-based experiments were conducted to evaluate the performance of coconut- dreg-based mudballs in treating kitchen wastewater obtained from a restaurant and a poultry shop in Bandar Puncak Alam. Physico-chemical parameters, including pH, DO, turbidity, COD, and ammoniacal nitrogen, were measured to assess removal efficiency percentage. A comparative analysis was conducted between coconut-dreg-based and conventional mudballs to determine their respective effectiveness in wastewater treatment.

Mudballs preparation

Both types of mudballs – conventional and coconut-dreg-based mudballs were prepared before collecting the kitchen wastewater samples. The steps in preparing the mudballs were described in Figure 1.

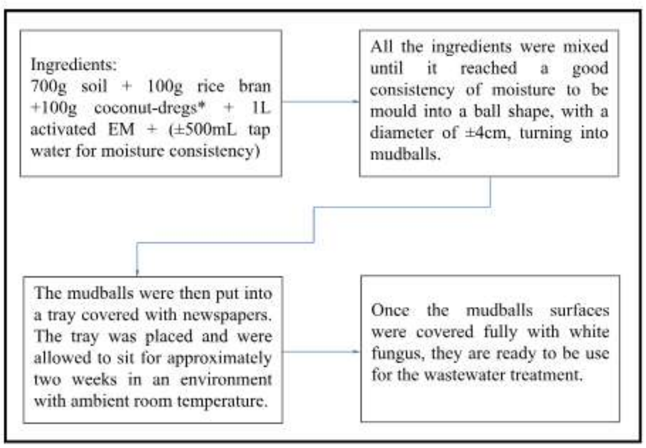

Figure 1. Mudball preparation

The mudball formulations were tested in three batches as part of a pilot study, and the final formulations that came from the preliminary investigation were used in the later stages of the research.

Samples collection and experimental setup

Kitchen wastewater samples were obtained from a restaurant and a poultry shop located in Bandar Puncak Alam, Selangor. Designated as sampling points A and B, respectively, the collection involved using a grab sample technique, extracting 4 litres of kitchen wastewater from each location. Then, the wastewater samples are categorized as follows:

A1 = Kitchen wastewater from restaurants treated with conventional mudballs

A2 = Kitchen wastewater from restaurants treated with coconut-dreg-based mudballs B1 = Kitchen wastewater from poultry shops treated with conventional mudballs

B2 = Kitchen wastewater from poultry shops treated with coconut-dreg-based mudballs. Daily observations and data collection were conducted for 22 days to ensure a comprehensive assessment of the kitchen wastewater treatment. The characterisation of both types of kitchen wastewater samples was initiated on the first day of the experiment through comprehensive laboratory analysis.

Figure 2 shows the experimental setup for kitchen wastewater from restaurant and poultry shop, together with the application of conventional and coconut-dreg-based mudballs.

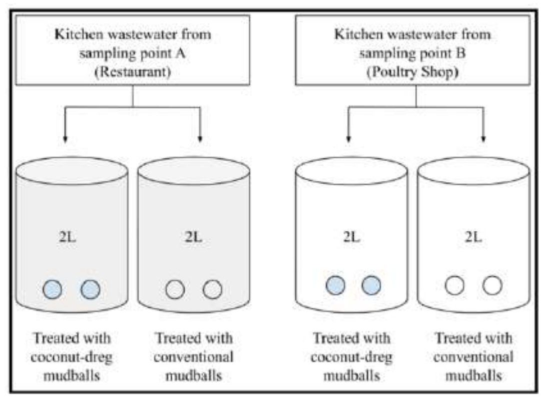

Figure 2. Experimental Setup

Data collection and analysis

Throughout the study, various instruments were employed to gather data and insights. These instruments include a pH meter for measuring pH and temperature in degrees Celsius (°C), a turbidity meter for assessing turbidity in Nephelometric Turbidity Units (NTU), a DO meter for determining dissolved oxygen (DO) levels in parts per million (ppm), a COD reactor for analysing Chemical Oxygen Demand (COD) in milligrams per litre (mg/L), and a DR2800 device for quantifying ammoniacal nitrogen concentration, also in milligrams per litre (mg/L).

Daily readings were taken for in-situ parameters; pH, temperature, turbidity, and DO. Meanwhile, for ex-situ parameters; ammoniacal nitrogen and COD were analysed using initial and final readings only, where the readings were taken before (initial) and after (final) the mudballs were added to the wastewater. Hence, the effectiveness of the treatment can be measured effectively through the removal percentage calculation.

Descriptive analysis and statistical testing, specifically the Independent T-test, were employed to assess the variations and significance difference in these parameters. This structured approach allows for a thorough examination of water quality dynamics, providing insights into key environmental indicators through a combination of daily and point-specific measurements.

3. RESULTS AND DISCUSSION

3.1 Characterisation of kitchen wastewater from Restaurant and Poultry Shop

The initial value of kitchen wastewater from the restaurant and poultry shop upon sampling and before adding the mudballs are shown in Table 1. The table provides insights into the general characteristics of the influent from both kitchen wastewater sources.

There is a difference in pH levels between the two types of kitchen wastewater. The restaurant wastewater is more acidic (pH 4.01), while the poultry shop wastewater is relatively neutral (pH 5.41). This difference may be attributed to the nature of food preparation and cleaning practices in each setting. Restaurants often use acidic ingredients or produce acidic by-products, influencing the pH of their wastewater (Parwin & Paul, 2020). Thus, the lower pH value in the restaurant may be attributed to acidic substances commonly found and used in the restaurant's kitchen, such as organic acids from food residues (Nasaruddin & Radin, 2021). In contrast, the poultry shop, dealing with raw poultry and associated organic matter, tends to yield a more neutral pH. Additionally, the higher pH in the poultry shop might be linked to the presence of alkaline substances associated with meat processing facilities. Consequently, temperature readings were relatively consistent between the two sampling points, with values of 24.6°C and 24.7°C, respectively, suggesting a comparable thermal environment was taken care of upon sampling. It is relevant to include temperature as a parameter when determining the removal rate in kitchen wastewater treatment, due to the fact, that it may affect the effectiveness of the treatment processes or influence the behaviour of pollutants in the wastewater. Temperature can also affect the rates of chemical reactions and microbial activities, which are crucial factors in wastewater treatment (Nasaruddin & Radin, 2021; Gurd et al, 2019).

However, substantial variations were noted in turbidity, DO, ammoniacal nitrogen, and COD. The higher turbidity level in the restaurant (303.1 NTU) compared to the poultry shop (134.87 NTU) could be indicative of increased suspended particles and solids, possibly originating from specific food preparation activities and washing processes in the restaurant. On the other hand, dissolved oxygen results revealed minimal differences, with both sampling points registering low dissolved oxygen concentrations (0.28 ppm for the restaurant, and 0.20 ppm for the poultry shop). This suggests that both sources of wastewater have limited oxygen content, potentially due to organic matter decomposition (19). Whereas, ammoniacal nitrogen levels are higher in the poultry shop wastewater (9.1 mg/L) compared to the restaurant wastewater (4.6 mg/L). The elevated ammoniacal nitrogen in the poultry shop influents may arise from the breakdown of nitrogen-containing compounds present in meat products (Uhlig et al., 2024; Zakri Ahmad et al., 2019).

Furthermore, the COD values demonstrate notable differences, with the restaurant wastewater having a considerably higher initial COD (4974 mg/L) than the poultry shop wastewater (1894 mg/L). This variation in COD concentration reflects the diverse composition of organic and inorganic substances in the wastewater, influenced by the types of food processed and cleaning agents used in these establishments. These results demonstrate the differing characteristics of kitchen wastewater and highlight the need for tailored treatment strategies based on the specific characteristics of influents from different food service establishments.

3.2 Effectiveness of coconut-dreg-based mudballs in treating kitchen wastewater from restaurant

Based on the average parameter results obtained from the restaurant, it is evident that coconut-dreg-based mudballs exhibit better performance in treating kitchen wastewater from restaurant compared to conventional mudballs as shown in Table 2.

For pH levels, both types of mudballs demonstrated an improvement from their initial value. Coconut-dreg-based mudballs achieved a higher final pH value of 8.29 compared to 6.8 for conventional mudballs. This suggests the alkaline nature of coconut dregs, contributing to a more pronounced pH adjustment during treatment. Moreover, temperature readings indicate the minimal variation between conventional mudballs and coconut-dreg-based mudball treatments, with averages of 23.65°C and 23.60°C, respectively. This consistency implies that both mudballs maintain similar thermal conditions during the treatment process.

Table 1. Summary of restaurant's and poultry shop's kitchen wastewater characteristics upon sampling.

Kitchen Wastewater	pH	Temp (°C)	Turbidity (NTU)	DO (ppm)	NH_3-N (mg/L)	COD (mg/L)
Restaurant	4.01	24.6	303.1	0.28	4.6	4974
Poultry Shop	5.41	24.7	134.87	0.20	9.1	1894

Table 2. Effectiveness of coconut-dreg-based mudballs in treating kitchen wastewater from restaurants

Types of Mudballs	Parameters	Unit	Results			Removal Efficiency
			Initial	Final	Average	
Conventional mudballs	pH	-	4.01	6.8	5.41	N.A.
	Temperature	°C	24.6	22.7	23.65	N.A.
	Turbidity	NTU	303.1	161.6	232.35	46.68
	DO	ppm	0.28	0.12	0.20	57.14*
	COD	mg/L	4974	2031.5	3502.75	59.16
	NH3-N	mg/L	4.6	2.12	3.36	53.91
Coconut-dreg-based mudballs	pH	-	4.01	8.29*	6.15	N.A.
		°C	24.6	22.6	23.60	N.A.
	Turbidity	NTU	303.1	26.29	164.70	91.33*
	DO	Ppm	0.28	0.13	0.21	53.57
	COD	mg/L	4974	754	2864	84.84*
	NH3-N	mg/L	4.6	0.5	2.55	89.13*

Note:
N.A. – Not Applicable for removal efficiency percentage
* – Highest reading for removal percentage
NH3-N – Ammoniacal Nitrogen, COD – Chemical Oxygen Demand, DO – Dissolved Oxygen

Meanwhile, DO concentrations in conventional mudballs-treated wastewater average at 0.20 ppm, while coconut-dreg-based mudballs exhibit a slightly higher average DO value of 0.21 ppm. This minor difference suggests that both mudball types contribute similarly in maintaining oxygen levels in the treated influent. Consequently, the removal efficiency for DO indicates a more substantial decrease for coconut-dreg-based mudballs, emphasising their potential to deplete oxygen content in wastewater, a crucial aspect of treating organic pollutants. More importantly, turbidity removal is notable, especially for coconut-dreg-based mudballs, with a significant reduction from 303.1 NTU to 26.29 NTU. This can be associated with the fibrous composition of coconut dregs, which acts as an effective filter, significantly decreasing suspended particles (Rosni et al., 2020).

As for chemical parameters, the average (and removal efficiency percentage) COD in the treated kitchen wastewater from restaurant with conventional mudballs is notably higher at 3502.75 mg/L (59.16%) compared to the treated kitchen wastewater from restaurant with coconut-dreg-based mudballs-treated wastewater with an average COD of 2864 mg/L (84.84%). This outcome indicates that the coconut-dreg-based mudballs are more effective in reducing COD, reflecting their enhanced capacity for organic matter removal (Bahri et al., 2020). Conversely, the concentration of ammoniacal nitrogen in wastewater treated with conventional mudballs averages at 3.36 mg/L, while coconut-dreg-based mudballs-treated wastewater records a lower average ammoniacal nitrogen concentration of 2.55 mg/L. The coconut-dreg-based mudball's capacity to achieve a lower ammoniacal nitrogen level concentration after the treatment underscores its effectiveness in nitrogen removal from kitchen wastewater. Thus, coconut-dreg-based mudballs have higher removal efficiencies for COD and ammoniacal nitrogen (84.84% and 89.13%, respectively), indicating that they are more effective at reducing organic and nitrogenous pollutant concentrations.

The comparative analysis between the conventional and coconut-dreg-based mudballs in treating kitchen wastewater from the restaurant reveals significant differences in key parameters of this research. For restaraunt wastewater, coconut-dreg-based mudballs significantly improved pH ($t(42) = -2.58$, $p = 0.013$) and turbidity ($t(42) = 5.59$, $p < 0.001$) compared to conventional mudballs, indicating better clarification of kitchen wastewater. Other parameters, including temperature, DO, COD, and AN, showed no significant differences (all $p > 0.05$).

After the treatment, the wastewater treated with coconut-dreg-based mudballs appeared to be clearer compared to the wastewater treated with conventional mudballs. Interestingly, the treated kitchen wastewater from restaurant with coconut-dreg-based mudballs develops a layer of fats, oil, and grease (FOG)– which shows the capabilities of coconut dregs to filter FOG compared to the wastewater treated with conventional mudballs that seems to be more concentrated and did not develop any noticeable layers of surfactants through the period.

3.3 Effectiveness of coconut-dreg-based mudballs in treating kitchen wastewater from poultry shop

Meanwhile, according to the average reading results from the poultry shop, the data comparison shows that coconut-dreg-based mudballs are also slightly more effective than conventional mudballs in treating kitchen wastewater from poultry shop.

In the poultry shop's kitchen wastewater treatment, the pH value of the coconut-dreg-based mudballs increased more from the initial to final readings, reaching an average of 7.03 compared to 6.91 for conventional mudballs. Consequently, turbidity was significantly reduced in coconut-dreg-based mudballs, reaching an average (and removal efficiency percentage) of 78.97 NTU (82.90%) compared to 86.79 NTU (71.30%) in conventional mudballs. Recognising the porous nature of coconut dregs, effective adsorption and filtration of suspended particles occurred, resulting in clearer and cleaner treated water. Additionally, both DO and COD levels improved progressively in coconut-dreg-based mudballs treatment, with the final DO value decreasing from 0.20 to 0.11 ppm and COD decreasing from 1894 mg/L to 810.5 mg/L. The declination of DO reading proves the treatment to be effective as biological processes are active in the water (Brown et al., 2025; Dharmarathne et al., 2013). Furthermore, ammoniacal nitrogen levels decreased from 9.1 mg/L to 5.45 mg/L. These findings suggest that using coconut-dreg-based mudballs improves a slightly better performance in terms of oxygenation, organic pollutant removal, and nitrogen removal efficiency, though it was not that significant.

Independent t-tests for poultry shop kitchen wastewater showed no significant differences between conventional and coconut-dreg mudballs for all parameters—including pH, temperature, turbidity, DO, COD, and AN (all $p > 0.05$). This indicates that both mudball types performed similarly in treating poultry shop wastewater.

Additionally, the findings from the comparison of removal efficiency percentage between conventional mudballs and coconut-dreg-based mudballs in treating kitchen wastewater from poultry shops reveal distinct patterns. In terms of pH, coconut-dreg-based mudballs suggest a more pronounced alkalizing effect, aligning with the alkaline characteristics of coconut dregs (Madawala et al., 2023). For turbidity reduction, coconut-dreg-based mudballs outperformed conventional mudballs with a pollutant removal rate of 82.90%, showcasing the effectiveness of coconut dregs in clarifying water. Furthermore, in terms of chemical oxygen demand (COD) removal, coconut-dreg mudballs demonstrated a pollutant removal rate of 57.21%, indicating their efficient capacity for organic pollutant removal. This is also likely attributed to the adsorption properties of coconut dregs (Vievard et al., 2023). The enhanced removal percentage observed in coconut-dreg-based mudballs indicates their potential, also as a sustainable and effective solution for treating kitchen wastewater from poultry shops.

However, in comparison between the two types of kitchen wastewater, the coconut-dreg- based mudball exhibits a lower performance in treating kitchen wastewater from poultry shops compared to the other types of kitchen wastewater.

Table 3. Effectiveness of coconut-dreg-based mudballs in treating kitchen wastewater from poultry shops

Types of Mudballs	Parameters	Unit	Results			Removal Efficiency
			Initial	Final	Average	
Conventional mudballs	pH	-	5.41	8.41	6.91	N.A.
	Temperature	°C	24.7	22.6	23.65	N.A.
	Turbidity	NTU	134.87	38.71	86.8	71.30
	DO	ppm	0.20	0.11	0.18	45.00
	COD	mg/L	1894	855	1374.5	54.86
	NH3-N	mg/L	9.10	5.45	7.28	40.12
Coconut-dreg-based mudballs	pH	-	5.41	8.64	7.03*	N.A.
		°C	24.70	22.70	23.70	N.A.
	Turbidity	NTU	134.87	23.06	78.97*	82.90*
	DO	Ppm	0.20	0.11	0.19	45.00
	COD	mg/L	1894	810.50	1352.25	57.21*
	NH3-N	mg/L	9.1	2.7	5.9	70.32*

Note:
N.A. – Not Applicable for removal efficiency percentage
* – Highest reading for removal percentage
NH3-N – Ammoniacal Nitrogen, COD – Chemical Oxygen Demand, DO – Dissolved Oxygen

Remarkably, after treatment, the wastewater treated with coconut-dreg-based mudballs in poultry shops appears clearer than the wastewater treated with conventional mudballs, despite showing a reddish to darkened appearance from the outside. Interestingly, both treatments in the poultry shop's kitchen wastewater, whether using coconut-dreg-based or conventional mudballs, develop elements layer of fats, oils, and grease (FOG), indicating the efficacy of both treatments in different wastewater scenarios. The key distinction lies in the FOG layer distribution, with the coconut dregs treatment demonstrating better filtration based on the more developed surface layers compared to the conventional mudball treatment in kitchen wastewater from poultry shop. This enhanced surface-layer formation is likely due to the higher fibre content and natural porosity of coconut dregs, which promote greater adsorption and trapping of suspended solids and FOG particles.

The independent t-tests were employed to evaluate the effectiveness of two types of mudballs, conventional and coconut-dreg based, in treating kitchen wastewater from restaurants. Coconut-dreg-based mudballs showed significantly better performance than conventional mudballs in restaurant wastewater, particularly in improving turbidity ($p < 0.001$) and pH ($p = 0.013$), indicating superior clarification and buffering capacity. In contrast, no significant differences were observed between the two treatments in poultry shop wastewater (all $p > 0.05$), suggesting that both mudball types perform similarly under high-FOG poultry wastewater conditions. Overall, coconut dregs offer clear advantages in restaurant settings, while their benefits are less pronounced in poultry shop applications.

4. CONCLUSION

In conclusion, the utilization of coconut-dreg-based mudballs is more effective in treating kitchen wastewater from Food Service Establishments (FSE) compared to conventional mudballs. Specifically, coconut-dreg-based mudballs exhibit enhanced effectiveness in treating restaurant wastewater compared to poultry shop wastewater, as evidenced by notable disparities in average values and removal efficiency percentages across selected parameters.

This discrepancy is largely attributable to the varying pH levels of the wastewater sources, with restaurant wastewater being predominantly acidic while poultry shop wastewater tends to be more basic. Given those coconut-dreg-based mudballs possess inherent alkaline properties, they demonstrate a greater capacity to neutralise the acidic nature of restaurant wastewater, thereby facilitating more substantial improvements in treatment efficacy when compared to the less acidic poultry shop wastewater. These findings underscore the importance of considering the specific characteristics of wastewater sources when evaluating the performance of treatment methods.

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REFERENCES

Ahmad Nazri, M. A. B., & Ghazali, N. L. B. (2017). The Effectiveness EM Mudball and Banana Peels for Textile Wastewater Treatment. *MATEC Web of Conferences*, *87*, 01009.

Ahmad, I., Abdullah, N., Koji, I., Yuzir, A., Ahmad, M. D., Rachmadona, N., Al-Dailami, A., Show, P. L., & Khoo, K. S. (2023, June). Micro and macro analysis of restaurant wastewater containing fat, oil, grease (FOG): An approach based on prevention, control, and sustainable management. *Chemosphere*, *325*, 138236.

Al-Gheethi, A. (2019). Establish in-house: A pre-treatment method of fat, oil and grease (FOG) in kitchen wastewater for safe disposal. *International Journal of Integrated Engineering*, 11(2).171–177.

Bahri, S., Sundu, B., Damry, H. B., & Hutumo, G. S. (2020). Delipidation and Deproteination of Coconut Dregs Fermented with Aspergillus niger to Produce Prebiotic compounds. *Journal of Biology, Agriculture and Healthcare,* 10(6). 10-20.

Brown, N., Edwards, J., Yarita, S., & Chia, S. (2025). Brown Coconut Husks as Media Within an Anaerobic Filter for Improving On-Site Wastewater Treatment. Applied Sciences, 15(4), 1944.

Dharmarathne, N., Sato, N., Kawamoto, K., Sato, H., & Tanaka, N. (2013). Evaluation of wastewater treatment efficiency using coconut fiber biofilm reactor system with synthetic leachate. In 3rd international conference on engineering and applied science, Osaka, Japan.

EM Research Organization Inc. (EMRO). (2016). *EMMudBall 1*. EM Research Organization.

Gumogda, P. (2022). Modified Mudball-Effective Microorganism as Laundry Wastewater Cleansing Agent. *Psychology and Education: A Multidisciplinary Journal*, *5*(10), 851-862.

Gurd, C., Jefferson, B., & Villa, R. (2019). Characterisation of food service establishment wastewater and its implication for treatment. *Journal of environmental management*, *252*, 109657.

Madawala, C. K., Jahinge, T. H., Rathnayake, K. T., & Perera, B. A. (2023). Adsorption of cadmium (II) from aqueous solutions by coconut dregs residue: Kinetic and thermodynamic studies. *Separation Science and Technology*, 1-13.

Maharjan, A., & Ghimere, A. (2021). Application of activated effective microorganism, mudball and biosand filter for the treatment of dye wastewater. *Nepal Journal of Environmental Science*, *9(1)*, 41-48.

Mihelcic, J. R., Zimmerman, J. B., & Auer, M. T. (2014). *Environmental Engineering: Fundamentals, Sustainability, Design* (J. R. Mihelcic & J. B. Zimmerman, Eds.). Wiley.

Mohd Zin, N. B., Mohamad Yusof, B., Oslan, S. N., Wasoh, H., Tan, J. S., Ariff, A. B., & Halim, M. (2017). Utilization of acid pre-treated coconut dregs as a substrate for production of detergent compatible lipase by Bacillus stratosphericus. *AMB Express*, 7, 1-13.

Nasaruddin, N. S., & Radin Mohamed, R. M. S. (2021, December 8). An Overview of Activated Carbon Coconut Shell and Banana Trunk Fiber as Bio-Filter for Kitchen Wastewater Treatment. *Journal of Advancement in Environmental Solution and Resource Recovery*, 1(1), 29-35.

Nayyar, D., Nawaz, T., Noore, S., & Singh, A. P. (2021). Chapter 9 - Food Processing Wastewater Treatment: Current Practices and Future Challenges:. *Pollution Control Technologies: Current Status and Future Prospects*, 177-208.

Park, G.-S., Khan, A. R., Kwak, Y., Hong, S.-J., Jung, B., Ullah, I., Kim, J.-G., & Shin, J.-H. (2016). An improved effective microorganism (EM) soil ball-making method for water quality restoration. *Environmental Science and Pollution Research*, *23*, 1100–1107.

Parwin, R., & Paul, K. K. (2020). Assessment of kitchen wastewater quality for irrigation. *Applied Water Science*, 10(12), 240.

Rosni, N. K., Sanny, M., Bahranor, N. S. A., & Rukayadi, Y. (2020). Physicochemical characteristics, microbiological safety and sensory acceptability of coconut dregs during fermentation using Rhizopus oligosporus. *Food Research*, 4(5), 1402-1411.

Tan, S. H., & Wong, Y. S. (2019). Characterization of kitchen wastewater for effective management of food service establishments. *Water Science and Technology*, *79*(9), 1691-1699.

Uhlig, E., Bucher, M., Strenger, M., Kloß, S., & Schmid, M. (2024). Towards Reducing Food Wastage: Analysis of Degradation Products Formed during Meat Spoilage under Different Conditions. *Foods*, 13(17), 2751.

Vievard, J., Alem, A., Pantet, A., Ahfir, N. D., Arellano-Sánchez, M. G., Devouge-Boyer, C., & Mignot, M. (2023). Bio-Based Adsorption as Ecofriendly Method for Wastewater Decontamination: A Review. *Toxics*, 11(5), 404.

Zakri Ahmed, A. M. B., Jaafar, J., Othman, Z., & Ramli, S. (2019). Nitrogen Removal Enhancement in Extended Aeration System. *International Journal of Recent Technology and Engineering (IJRTE)*, 8(4), 6761-6768.

REVIEW ARTICLE

Wound healing properties of selected tropical fruits in Malaysia: A Narrative Review

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Abstract:

Reduction in healing time is crucial for minimizing pain and preventing wound-related complications. Wound dressings and topical products such as antibiotics are commonly used in chronic wound management; however, they can be costly and may be associated with adverse effects. Consequently, natural products have emerged as promising alternatives, as numerous plants and fruits possess wound-healing properties. This review focuses on five fruits from different genera—banana, papaya, mangosteen, pomegranate, and pineapple—that have been scientifically validated for their wound-healing potential between 2010 and 2025. Relevant studies were identified using the Scopus, PubMed, and ScienceDirect databases. Most wound-healing investigations employed *in vivo* models, demonstrating the efficacy of fruit extracts in accelerating wound closure and tissue repair. Although these fruits have shown significant wound-healing activity in experimental settings, further research, including the isolation and characterization of bioactive compounds, is necessary before the development of safe and widely accepted herbal therapies for wound management.

Keywords: Wound healing, banana, papaya, mangosteen, pomegranate, pineapple

1. INTRODUCTION

Wound refers to a physical injury that results in an opening or break in the skin, leading to disruption of normal anatomical structure and function (Farrow & Farrow, 2023). It may also be defined as a loss of tissue continuity with or without microbial infection (Schultz et al., 2023). Disruption of epithelial tissue can occur due to physical, chemical, thermal, immunological factors, or microbial colonisation (Schultz et al., 2023).

Wound healing, on the other hand, is a dynamic and complex biological process regulated by cytokines, growth factors, chemokines, and other mediators that coordinate tissue repair (Lukiswanto et al., 2019). It consists of four major phases: haemostasis, inflammation, proliferation, and remodelling. Haemostasis involves vasoconstriction and fibrin clot formation to prevent blood loss. The inflammatory phase begins when vascular leakage leads to local swelling, which helps control bleeding and reduce infection risk. During the proliferative phase, the wound undergoes contraction and is rebuilt with new extracellular matrix and collagen, a process that may extend over several weeks. Re-epithelialisation subsequently occurs as epithelial cells migrate across the wound bed to restore the protective barrier. In the final remodelling phase, collagen is reorganised from type III to type I until full wound closure is achieved. The progression of wound healing is commonly evaluated using parameters such as wound contraction rate, epithelialisation time, granulation tissue formation, and tensile strength. Histopathological analysis, particularly haematoxylin and eosin staining of granulation tissue, is widely used to assess cellular organisation, inflammation, and tissue maturation (Wallace, Basehore & Zito, 2023).

Healing is further impaired in individuals with conditions such as diabetes, obesity, anaemia, cardiovascular disease, immunosuppression, older age, smoking, and poor nutritional or hygienic status (Almadani et al., 2021; Gupta, Tan & Alvarez, 2024). Delayed wound closure increases susceptibility to infection and may lead to chronic wounds or keloids, both of which prolong recovery and elevate treatment costs. A wide variety of pathogens—including bacteria, viruses, and fungi—can infect wounds when they thrive within damaged tissues. Bacterial infection delays healing by degrading fibrin and reducing essential growth factors and extracellular matrix components (Okur et al., 2020).

Wound dressings and topical medications are commonly used to maintain a moist wound environment that promotes autolytic debridement, reduces pain, supports collagen synthesis, and enhances keratinocyte migration (Nuutila & Eriksson, 2021). Examples of dressings include hydrogel, hydrocolloid, alginate, and polymeric membrane dressings (Britto et al., 2023). However, they may cause allergic reactions, irritation, discomfort, or pain. Due to these challenges, natural products have attracted increasing attention as safer alternatives, given their lower toxicity and broad therapeutic potential.

Many medicinal plants exhibit wound healing activity. Previous studies—predominantly preclinical investigations consisting of *in vivo* wound healing studies in rodent models—have explored extracts from fruit seeds, peels, and pulp. In Malaysia, numerous studies have examined the wound healing and antimicrobial activities of local fruits. Accordingly, this review focuses exclusively on preclinical evidence related to the wound healing property of selected Malaysian fruits. The fruits reviewed include *Musa spp*., *Carica papaya*, *Garcinia mangostana*, *Punica granatum*, and *Ananas comosus* (Figure 1). These fruits were prominently featured in wound healing investigations, largely due to their rich phytochemical profiles, including phenolics, flavonoids, tannins, and proteolytic enzymes. In addition, their long-standing ethnomedicinal use for treating skin injuries, infections, and inflammatory conditions underscores their therapeutic relevance. Their accessibility and traditional use further support their relevance as potential natural sources of wound-healing and antimicrobial agents. Collectively, their prevalence, accessibility, cultural importance, and substantial preclinical evidence provide a strong rationale for focusing on these five fruits. Relevant studies published between 2010 and 2025 were identified through Scopus, PubMed, and ScienceDirect.

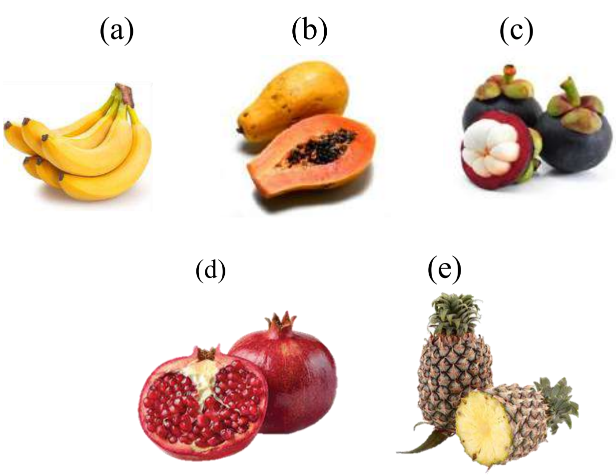

Figure 1. Tropical fruits in Malaysia (a) *Musa* spp. (banana), (b) *C. papaya* (papaya), (c) *G. mangostana* (d) P. *granatum* (pomegranate) (e) *A. comosus* (pineapple).

2. Selected Malaysian Fruits

These five fruits were selected for this review due to their widespread cultivation and ready availability in Malaysia.

2.1 Banana *(Musa* spp.*)*

Banana is the common name for the family Musaceae. It has been widely grown and the fruit is consumed all over the world. Banana fruits are known to have high nutrients that can give beneficial effects on the consumer. The highest percentage of minerals found in bananas is potassium, which prevents muscle spasms and reduces blood pressure, iron that can stimulate the production of hemoglobin, vitamin B6 which aids brain health and the body's immune system, vitamin C which promotes healing and growth of tissue, and fibres that can relieve constipation and diarrhea (Kumar et al., 2012). Other than that, various parts of banana plants such as leaves, stems, banana blossom, roots, and banana peel also have their own medicinal properties.

Banana peel extracts have been proven to have wound-healing properties. In 2023, Rizka et al. reported that their banana peel extract spray gel managed to enhance wound healing in a concentration-dependent manner via a rabbit burn model. The high-concentration formulation (20%) showed the most effective healing, comparable to the positive control. It also demonstrated faster wound closure and significantly increased collagen density and epidermal thickness compared to the negative control. In another study, excision wounds on rabbits treated with hydroalcoholic extract of 10% *Musa acuminata* peel with the addition of Eucerin, a commercial cream used as an ointment base showed complete healing on day 15 (Tamri et al., 2016). In addition, a group of researchers used unripe ground *Musa sapientum* peel with a combination of natrosol gel as treatment for surgical wounds in rats. Results of the study showed wound healing was more progressive in the experimental group compared to the control group. Application of the combination of *M. sapientum* peel extract and natrosol gel showed a significant difference in vascular proliferation, presence of mononuclear cells, fibroblast proliferation, and re-epithelisation at day 14 when compared to control (Von Atzingen et al., 2015).

The wound healing property of *M. sapientum* peel extract may be due to bioactive compounds in the extract. Puraikalan (2018) recorded the presence of a significant amount of tannin, which can promote wound healing by reducing the formation of reactive oxygen substances (ROS) in the extract of *M. sapientum* peel. High levels of ROS result in oxidative stress that can lead to cell and tissue damage causing delayed wound healing. In addition, it has been reported that the peels also harbor flavonoid, saponin, and phenol (Kibria et al., 2019). According to Aslam et al. (2018), excessive fibroblast activity can cause a delay in wound-healing in which flavonoids can provide a synergistic effect that can promote wound-healing by inhibiting the growth of fibroblasts.

Other than the peel, the stem of the banana plant also showed promising potential in wound-healing properties. The methanolic extract of *M. paradisiaca* stem was studied by Amutha and Selvakumari and there was a significant increase in percentage of wound closure by enhanced epithelisation in the treated rats. The treated group exhibited a faster rate of tissue regeneration compared to the control group (Amutha & Selvakumari, 2016).

2.2 Papaya *(Carica papaya)*

Carica papaya which is also known as papaya is a tropical fruit belonging to the family Caricaceae. The plant grows in tropical regions of the world such as Australia, Indonesia, Malaysia, and Thailand. Papaya fruits are good sources of vitamins such as vitamins A, C, and E as well as minerals such as potassium, calcium, and magnesium. These nutrients are very helpful in reducing the risk of cardiovascular diseases. Besides, papaya fruits also contain fibre and the enzyme papain that can improve digestive disorders or disturbances in the gastrointestinal tract thus promoting digestive health (Leitão et al., 2022). Other parts of papaya plants such as seeds, leaves, latex, and root also have nutrients and bioactive compounds that can give medicinal properties such as antioxidant, antimalarial, anti-inflammatory, antimicrobial, and anti-helminthic (Santana et al., 2019).

Carica papaya has beneficial effect on reducing necrosis and is frequently utilized in the management of wound healing (Siva et al., 2023). Papaya fruits have been reported to have antioxidant activities that can improve the wound-healing process (Nafiu & Rahman, 2015). In their study, the effects of unripe papaya pulp extracts on wound-healing have been demonstrated using biochemical assay. The results showed these extracts can increase the activity of catalase, superoxide dismutase, and glutathione peroxidase in excision wounds of rats. These endogenous antioxidant enzymes were able to neutralize free radicals such as reactive nitrogen species (RNS) and ROS that were released excessively by inflammatory cells into the wound (Gupta et al., 2002). Due to these activities, papaya pulp extracts exhibited complete wound-healing with faster epithelisation than the control (Nafiu & Rahman, 2015). In another study, histological view of oral wounds on rats that were treated with 75% papaya fruit extracts for fourteen days showed a perfect arrangement of epithelial cells and extracellular matrix. In contrast, epithelial cells were arranged separately and showed incomplete fibrillation in the controls (Hakim et al., 2019). Their study also reported that *C. papaya* extract significantly influenced the process of epithelisation and fibrillation in wound-healing. These healing actions are attributed to several properties such as the active ingredient, papain, being responsible for the enzymatic debridement of wounds. The presence of vitamin C, which is necessary for the transformation of proline into hydroxyproline, a particular marker, and element of the granulation tissue of the extracellular matrix in wounds, is the other contributing factor. Vitamin C also plays an important role in the healing process via the enhancement of collagen formation to support new tissue growth (Sarpooshi et al., 2017).

Papaya leaves extract cream (40%) was also shown to significantly reduce wound length in treated rats (Winarjo et al., 2021). Saponins, flavonoids, and alkaloids present in papaya leaves contribute to wound healing, particularly during the proliferative phase. Saponins have been shown to promote angiogenesis, stimulate fibroblast proliferation, and enhance type I collagen synthesis, while flavonoids increase vascularity through their antioxidant and vasodilatory properties (Agyare et al., 2016; Alam et al., 2023). These phytochemicals also exhibit antimicrobial and antiseptic effects that support infection control during the inflammatory phase. In addition, papain, a proteolytic enzyme found in papaya leaves, exerts anti-inflammatory activity by enhancing macrophage function and facilitating granulation tissue formation, wound contraction, and re-epithelialisation (Natarajan et al., 2014; Marlinawati et al., 2022).

2.3 Mangosteen *(Garcinia mangostana)*

Mangosteen is an exotic and tropical fruit usually found in Southeast Asia, especially in Malaysia, Thailand, and Indonesia. Mangosteen is also referred to as “the queen of fruits” because of its thick sepals that resemble a crown, and because of its sweet-sour taste. Mangosteen has been traditionally used to treat diarrhea and has been used as a topical agent. In addition, mangosteen pericarp exhibits antibacterial, antifungal, and anti-inflammatory activities in *in vivo* and *in vitro* studies (Tatiya-aphiradee et al., 2019).

It comprises phytochemicals, flavonoids, and polyphenols such as xanthones, anthocyanins, and phenolic acids (Zamarudin et al., 2023). Xanthones are among the metabolite components that are present in mangosteens and have been shown to possess anti-inflammatory activities toward wound healing. In 2019, Shafy et al. reported that the application of creams with mangosteen peel extracts (MPE) on excision wounds of rats was more effective for wound healing than Fucidin which was used as a standard treatment. In the same year, Sombolayuk et al. observed the effects of 5% and 10% MPE cream on the wounds of mice. In their study, they analysed the diameter of the wounds, re-epithelisation (RE), granulation tissue formation (GTF), and inflammatory cell count (ICC). The results showed both concentrations of MPE cream had significantly reduced the diameter of the wound when compared to the control after day 8 post treatments. In addition, both concentrations of MPE cream significantly decreased the number of ICC and significantly increased GTF and RE in wounds, thus showing better wound-healing compared to the control.

Anti-inflammatory activities in both MPE and α-mangostin was also reported by Tatiya-aphiradee et al. (2019) in which α-Mangostin is the most abundant xanthone in the mangosteen peel. Both α-mangostin and MPE were able to suppress the expression of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α), interleukin-1β, and interleukin-6 (IL-1β & IL-6), as well as toll-like receptor-2 (TLR-2) in MRSA, infected wounds of mice. A decrease in TLR-2 from day 5 to day 10 promoted wound-healing in both groups due to the suppression of TNF-α, IL-1β, and IL-6 when compared to the control. TLR-2 is involved in the detection of lipoteichoic acid derived from gram-positive bacteria and causes the release of TNF-α by macrophages and mast cells (Schröder et al., 2003). Over-excretion of these cytokines leads to excessive ROS formation causing tissue damage and degradation of the extracellular matrix, which can delay the process of wound-healing (Sombolayuk et al., 2019). A study by Wathoni et al. (2020) also demonstrated that the wound-healing ability of α-mangostin was enhanced when complexed with 2-hydroxypropyl-β-cyclodextrin in hydrogel formulation. However, MPE treatment showed better wound-healing than α-mangostin treatment. It may be due to the expression of the cytokines released from wounds treated with MPE was slightly lower than in wounds treated with α-mangostin. This may be explained by the presence of other constituents such as β-mangostin and phenolic compounds in MPE that also have anti-inflammatory properties (Aizat et al., 2019).

2.4 Pomegranate *(Punica granatum)*

Punica granatum is a scientific name for pomegranate and belongs to the Punicacae family. Pomegranate fruit is categorized as a berry and contains hundreds of edible seeds surrounded by red arils. Pomegranate fruit is a rich source of sugars, vitamins B and C, β-carotene, and organic acids. In addition, its peel, flesh, and seeds also contain various bioactive compounds such as alkaloids, polyphenols, flavonoids, and anthocyanins that exhibit antioxidant, antimicrobial, anti-inflammatory, and anti-cancer activities. It is also traditionally used as a treatment for diarrhea and hemorrhoids, and also to stop gum and nose bleeds (Shaygannia et al, 2016).

Various studies have shown that pomegranate extracts have beneficial effects on the process of wound-healing. Hayouni et al. (2011) applied methanol extracts of pomegranate peel ointment on the excision wounds of guinea pigs. The results showed wounds treated with methanol extracts of pomegranate peel ointment demonstrated 83.5% healing meanwhile untreated wounds showed 43% healing on day 16. In another study, pomegranate peel extracts (PPE) can heal deep-second degree burn wounds in rats faster than the control (Ma et al., 2015). On day 21, the area of the burn wound treated with PPE (0.21 cm^2) was smaller than the control group (2.42 cm^2). Indeed, histological findings on day 14 showed the increase of collagen fibres, fibroblasts, and new granulation tissues, and inflammatory cells were decreased in wounds treated with PPE. Whereas in the control group, only a few fibroblasts and granulation tissues were found. Furthermore, Lukiswanto et al. (2019) also reported similar findings on burn wounds of albino rats that were treated with 10% whole pomegranate fruit extract that was standardised with 40% ellagic acid. It was suggested that 40% or more of ellagic acid in pomegranate extracts can support the optimal process of burn wound-healing which showed significant results in collagen formation.

The antioxidant properties of pomegranate extracts play an important role in promoting wound-healing. Hayouni et al. (2011) reported that pomegranate peel extracts exhibited strong antioxidant activity, which was comparable to known antioxidants; Trolox and BHA. Due to its antioxidant activity, it can promote wound-healing by protecting the cells and tissue from oxidative stress. Various bioactive compounds were found in the pomegranate peel extracts which may contribute to the antioxidant properties such as ellagic acid, delphinidin-3-glucoside, punicalagin A, and punicalagin B (30).

2.5 Pineapple *(Ananas comosus)*

Pineapple belongs to the family Bromeliaceae and it has become one of the major crops in Malaysia, besides banana and papaya. Its fruits are best consumed fresh or as juice, since it exhibits high sugar and moisture content that can keep the body hydrated. Pineapple fruits contain essential nutrients, minerals, and enzymes that can give health benefits when consumed. For example, vitamin B and fibre are good for digestive health, vitamin C can prevent gum disease, manganese, is a mineral that is required for the development of bones and tissue, and bromelain that can reduce redness and swelling. Furthermore, pineapple can be used as disinfectant, anti-inflammatory, and anti-helminthic agents (Hossain et al., 2015; Sharma et al, 2024; Rahminiwati et al., 2025).

Several studies have reported that pineapple peel and pulp were widely administered as wound healing agents. A study was conducted to compare the efficiency of pineapple peel extracts and povidone-iodine on the wound of rats. The results showed pineapple peel extracts reduced the length of the wound (0.36 cm) faster than povidone-iodine (0.56 cm) after day 8. These results indicated that pineapple peel extracts were more efficient as a wound treatment than povidone-iodine, even though it is usually used as an antiseptic agent to treat the wound (Arif & Siwanto, 2017).

Similarly, in another study, the application of base cream with pineapple fruit extracts on wounds infected with MRSA rats showed almost complete healing (99.06%) at day 15 compared to control which showed 54.36% of wound-healing (Prakoso et al., 2018). The histological observation of the wound that was treated with pineapple fruit extracts showed the presence of fibroblast, an increase in collagen deposition, and predominant CD8+ infiltration in the dermal part of the skin of rats. Meanwhile, in control, it showed minimal expression of collagen deposition with severe hemorrhage and mild expression of CD8+. CD8+ plays an important role in immune defense as its function is to kill bacteria by detecting foreign antigens that are expressed by infected cells (Shepherd & McLaren, 2020).

Colletti et al. (2024) demonstrated that bromelain, a proteolytic enzyme complex derived from pineapple, modulates key inflammatory pathways by reducing pro-inflammatory mediators and promoting tissue remodeling, highlighting its therapeutic potential in enhancing wound-healing processes. Recently, Handajani et al. (2025) reported that a nanoemulgel formulation significantly accelerated healing of traumatic ulcers in a preclinical model. In another study conducted by Badriyya et al. (2020), bromelin was found to decrease the volume of exudate in inflamed wounds of mice and decrease the number of leucocytes from 4 to 6 days after the application of bromelain gel. Bromelain, which can also be found in pineapple crown leaves aids in necrotic tissue debridement and hastens the healing process with the presence of escharase. This compound remains among the primary options for burn wound treatments as well as in cases of postoperative injuries, easing patients' pain and inflammation (Chakraborty et al., 2021).

4. CONCLUSION

Wound healing is a great challenge in many health conditions, especially involving infections of the skin and the wound itself, which are the most frequent complications affecting humans and animals. Thus, the search for new wound-healing agents continues unabated. Medicinal plants have been used for a long time in wound-healing, despite the lack of scientific evidence verifying their efficacy. This review, therefore, describes the wound-healing activity of five tropical fruits in Malaysia. Extracts prepared from different parts of banana (*Musa* spp.), papaya (*C. papaya)*, mangosteen (*G. mangostana)*, pomegranate (*P. granatum)*, and pineapple (*A. comosus)* have been demonstrated to have properties that may benefit wound-healing. However, despite the success of these fruit extracts in promoting wound-healing there was little information on the specific bioactive compounds responsible, nor elucidation of their mode of action. In addition, it is difficult to hypothesize which fruit will give the best wound-healing effect. Even though experimental evidence has been acquired for each documented fruit, their studies are not comparable as their assays and models used were not standardized. We provide this data in the belief that these fruits could one day deliver novel remedies and therapy for today's therapeutic challenges.

REFERENCES

Aizat, W.M., Jamil, I.N., Ahmad-Hashim, F.H., & Noor, N.M. (2019). Recent updates on metabolite composition and medicinal benefits of mangosteen plant. *PeerJ, 7*, e6324. https://doi: 10.7717/peerj.6324

Agyare, C., Boakye, Y. D., Bekoe, E. O., Hensel, A., Dapaah, S. O., & Appiah, T. (2016). Review: African medicinal plants with wound healing properties. *Journal of Ethnopharmacology, 177*, 85–100. https://doi.org/10.1016/j.jep.2015.11.008

Alam, G., Singh, M. P., & Singh, A. (2023). Flavonoids as wound healing agents: A review. *Pharmacological Research – Modern Chinese Medicine, 7*, 100234.https://doi.org/10.1016/j.prmcm.2023.100234

Almadani, Y.H., Vorstenbosch, J., Davison, P.G., & Murphy, A.M. (2021). Wound Healing: A Comprehensive Review. *Seminars in Plastic Surgery, 35(3)*, 141-144. doi: 10.1055/s-0041-1731791.

Amutha, K., & Selvakumari, U. (2016). Wound healing activity of methanolic stem extract of Musa paradisiaca Linn. (Banana) in Wistar albino rats. *International Wound Journal*, *13*(5), 763.

Arif, S., & Siwanto, J. (2017). Pineapples Extract as Replacement of Povidon Ioudium in Incision Wound Healing. *ARC Journal of Surgery, 3(2)*, 4–7.

Aslam, M.S., Ahmad, M.S., Riaz, H., Raza, S.A., Hussain, S., Qureshi, O., et al. (2018). Role of Flavonoids as Wound Healing Agent. Phytochemicals - Source of Antioxidants and

Role in Disease Prevention; Available from: undefined/state.item.id

Badriyya, E., Salman, R.P.A., Dillasamola, D., Aldi, Y., & Husni, E. (2020). Topical Anti-Inflammatory Activity of Bromelain. *Pharmacognosy Journal, 12(6)*, 1586–93.

Britto, E.J., Nezwek, T.A., Popowicz, P., & Robins, M. (2023). Wound Dressings. Surgery (United Kingdom) [Internet]. 40(1), 25–32. https://www.ncbi.nlm.nih.gov/books/NBK470199/

Chakraborty, A.J., Mitra, S., Tallei, T.E., Tareq, A.M., Nainu, F., Cicia, D., et al. (2021). Bromelain a Potential Bioactive Compound: A Comprehensive Overview from a Pharmacological Perspective. *Life, 11(4),* 317.

Colletti, A., Procchio, C., Pisano, M., Martelli, A., Pellizzato, M., & Cravotto, G. (2024). An Evaluation of the Effects of Pineapple-Extract and Bromelain-Based Treatment after Mandibular Third Molar Surgery: A Randomized Three-Arm Clinical Study. *Nutrients, 16(6)*, 784. https://doi.org/10.3390/nu16060784

Farrow, M. J., & Farrow, G. (2023). *Wound care*. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK574087/

Gupta, A., Singh, R.L., & Raghubir, R. (2002). Antioxidant status during cutaneous wound healing in immunocompromised rats. *Molecular and Cellular Biochemistry, 241*(1–2), 1–7. https://doi.org/10.1023/A:1020893808599

Gupta, R., Tan, J., & Alvarez, O. M. (2024). Cellular senescence and impaired wound healing: New insights into chronic wound pathology. *Ageing Research Reviews, 98*, 102247. https://pubmed.ncbi.nlm.nih.gov/39558972/

Hakim, R.F., & Fakhrurrazi, D. (2019). Effect of Carica papaya Extract toward Incised Wound Healing Process in Mice (Mus musculus) Clinically and Histologically. *Evidence-Based Complementary and Alternative Medicine*, 1–5.

Handajani, J., Widjijono, S.H, Cahyani, Y.D, Rahma, S.Z. (2025). Effect of Ananas comosus nanoemulgel on traumatic ulcers in the inflammatory phase. Journal of Taibah University Medical Sciences, 20(2), 201–208.

Hayouni, E.A., Miled, K., Boubaker, S,, Bellasfar, Z., Abedrabba, M., Iwaski, H., et al. (2011). Hydroalcoholic extract based-ointment from Punica granatum L. peels with enhanced in vivo healing potential on dermal wounds. *Phytomedicine, 18*(11), 976–84.

Hossain, M.F., Akhtar, S. & Anwar, M. (2015). Nutritional Value and Medicinal Benefits of Pineapple. *International Journal of Nutrition and Food Sciences, 5*, 4(1), 84.

Kibria, A.A., Rahman, M., & Kar, A. (2019). Extraction and Evaluation of Phytochemicals from Banana Peels (Musa sapientum) and Banana Plants (Musa paradisiaca). *Malaysian Journal of Halal Research, 2*(1), 22–6.

Kumar, K.P.S., Bhowmik, D., Duraivel, S., Umadevi, M. (2012). *Traditional and Medicinal Uses of Banana, 1*(3), 51–63.

Leitão, M., Ribeiro, T., García, P.A., Barreiros, L., Correia, P. (2022). Benefits of Fermented Papaya in Human Health. *Foods, 11*(4), 563.

Lukiswanto, B.S., Miranti, A., Sudjarwo, S.A., Primarizky, H., & Yuniarti, W.M. (2019). Evaluation of wound healing potential of pomegranate (Punica granatum) whole fruit extract on skin burn wound in rats (Rattus norvegicus). Journal of Advanced Veterinary and Animal Research, 6(2), 202–207. https://doi.org/10.5455/javar.2019.f330

Ma, K., Du, M., Liao, M., Chen, S., Yin, G., Liu, Q., et al. (2015). Evaluation of wound healing effect of Punica granatum L. peel extract on deep second-degree burns in rats. *Tropical Journal of Pharmaceutical Research, 14*(1), 73–78.

Marlinawati, I. T., Nurhidayah, S., Santoso, S., & Irwanto, Y. (2022). Effect of Papaya Leaf Extract Gel (Carica papaya) on Incision Wound Healing in Rattus norvegicus. *Medical Laboratory Technology Journal, 8*(2), 102–111. https://doi.org/10.31964/mltj.v0i0.455

Natarajan, S., Williamson, D., Stiltz, A. J., & Harding, K. (2000). Advances in wound care and healing technology. *American Journal of Clinical Dermatology*, *1*(5), 269–275. https://doi.org/10.2165/00128071-200001050-00002

Nafiu, A. B., & Rahman, M. T. (2015). Anti-inflammatory and antioxidant properties of unripe papaya extract in an excision wound model. *Pharmaceutical Biology*, *53*(5), 662–671. https://doi.org/10.3109/13880209.2014.932395

Nuutila, K., & Eriksson, E. (2021). Moist wound healing with commonly available dressings. *Advances in Wound Care*, *10*(12), 685–698. https://doi.org/10.1089/wound.2020.1232

Okur, M. E., Karantas, I. D., Şenyiğit, Z., Üstündağ Okur, N., & Siafaka, P. I. (2020). Recent trends on wound management: New therapeutic choices based on polymeric carriers. *Asian Journal of Pharmaceutical Sciences*, *15*(6), 661–684. https://doi.org/10.1016/j.ajps.2019.08.004

Puraikalan, Y. (2018). Characterization of proximate, phytochemical and antioxidant analysis of banana (Musa sapientum) peels/skins and objective evaluation of ready to eat/cook product made with banana peels. *Current Research in Nutrition and Food Science, 6*(2), 382–91.

Prakoso, Y. A., Setiyo Rini, C., & Wirjaatmadja, R. (2018). Efficacy of *Aloe vera*, *Ananas comosus*, and *Sansevieria masoniana* cream on the skin wound infected with MRSA. *Advances in Pharmacological Sciences*, 2018, 4670569. https://doi.org/10.1155/2018/4670569

Rahminiwati, M., Dilla, M. A., & Rokhmah, N. N. (2025). Potential anthelmintic activity of pineapple fruit (Ananas comosus) and mango leaf juice against Ascaridia galli worms in vitro model. *Journal of Parasite Science, 9*(2).

Rizka, R., et al. (2023). Wound-healing and antimicrobial activities of a Musa-based spray gel: Preclinical evaluation. *Journal of Herbal Medicine & Pharmacology, 12*(4), 567-574.

Santana, L.F., Inada, A.C., Santo, B.L.S.E., Filiú, W.F.O., Pott, A., Alves, F.M., et al. (2019). Nutraceutical Potential of Carica papaya in Metabolic Syndrome. *Nutrients* [Internet], 11(7). https://pubmed.ncbi.nlm.nih.gov/31315213/

Sarpooshi, H. R., Haddadi, M., Siavoshi, M., & Borghabani, R. (2017). Wound healing with vitamin C. *Translational Biomedicine*,*8*(4),139–143. https://doi.org/10.2174/2212796807666170905152703

Schröder, N.W.J., Morath, S., Alexander, C., Hamann, L., Hartung, T., Zähringer, U., et al. (2003). Lipoteichoic acid (LTA) of Streptococcus pneumoniae and Staphylococcus aureus activates immune cells via Toll-like receptor (TLR)-2, lipopolysaccharide-binding protein (LBP), and CD14, whereas TLR-4 and MD-2 are not involved. *Journal of Biological Chemistry, 278*(18),15587–94.

Schultz, G. S., et al. (2023). Consensus guidelines for wound healing: Definitions and mechanisms. *Wound Repair and Regeneration, 31*(1), 1–14. https://doi.org/10.1111/wrr.13010

Shafy, G. M., Jassim, A. M. N., & Mohammed, M. T. (2019). Study of phytochemical, antioxidant and anti-inflammatory of mangosteen (*Garcinia mangostana*) and its ability to wound healing. *Plant Archives*, *19*(1), 665–673.

Sharma, A., Kumar, L., Malhotra, M., & Singh, A. P. (2024). *Ananas comosus* (pineapple): A comprehensive review of its medicinal properties, phytochemical composition, and pharmacological activities. *Journal of Drug Delivery and Therapeutics*, *14*(5), 148–157.

Shaygannia, E., Bahmani, M., Zamanzad, B., & Rafieian-Kopaei, M. A. (2016). Review study on *Punica granatum* L. *Journal of Evidence-Based Complementary & Alternative Medicine*, *21*(3), 221–227. https://doi.org/10.1177/2156587216633875

Shepherd, F. R., & McLaren, J. E. (2020). T cell immunity to bacterial pathogens: Mechanisms of immune control and bacterial evasion. *International Journal of Molecular Sciences*, *21*(17), 1–32. https://doi.org/10.3390/ijms21176332

Siva, S., Sekar, M., Prakash, S., Arifullah, M. & Fazulah, M. (2023). Systematic review Effectiveness of conventional management and Carica papaya on influencing wound healing: A systematic review and meta-analysis. *Biomedicine, 43*, 825.

Sombolayuk, H.B., Djawad, K., Wahab, S., Miskad, U.A., Alam, G., & Pattelongi, I. (2019). The effectivity of topical mangosteen pericarp extract cream on wound healing in Swiss albino mice. *Journal of Biological Research (Italy), 92*(2), 61–4.

Tamri, P., Hemmati, A., Amirahmadi, A., Zafari, J., Mohammadian, B., Dehghani, M., et al. (2016). Evaluation of wound healing activity of hydroalcoholic extract of banana (Musa acuminata) fruit's peel in rabbit. *Pharmacologyonline*, 203–8.

Tatiya-aphiradee, N., Chatuphonprasert, W., & Jarukamjorn, K. (2019). Anti-inflammatory effect of Garcinia mangostana Linn. pericarp extract in methicillin-resistant Staphylococcus aureus-induced superficial skin infection in mice. *Biomedicine and Pharmacotherapy, 111*, 705–13.

Von Atzingen, D., Mendonça, A. R. dos A., Filho, M., Alvarenga, V., Assis, V., Penazzo, A., et al. (2015). Repair of surgical wounds in rats using a 10% unripe *Musa sapientum* peel gel. *Acta Cirurgica Brasileira*, *30*(9), 586–592. https://doi.org/10.1590/S0102-865020150090000006

Wallace, H. A., Basehore, B. M., & Zito, P. M. (2023). Wound healing phases. In *StatPearls*. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK470443/

Wathoni, N., Sari, D.P., Suharyani, I., Motoyama, K., Mohammed, A.F.A., Cahyanto, A., et al. (2020). Enhancement of α-mangostin wound healing ability by complexation with 2-hydroxypropyl-β-cyclodextrin in hydrogel formulation. *Pharmaceuticals, 13*(10), 1–16.

Winarjo, G.A., Arifin, F., Oenarta, D.G. (2021). Comparison of the effectiveness of giving binahong leaf (Anredera cordifolia (Ten) Steenis) and papaya leaf (Carica papaya) on skin wound healing in white rat (Rattus novergicus). *Journal of Widya Medika Junior, 3*(2).

Zamarudin, Z., Abdullah Sani, M. S., Nordin, N. F. H., Amid, A., & Mohd Hashim, A. (2023). Mangosteen (Garcinia mangostana): Extraction, purification, bioactivities and toxicities. *Halalsphere, 3*(2), 13–27. https://doi.org/10.31436/hs.v3i2.74