

A Web-Based Clinical Decision-Support Tool for Predicting Bone Metastasis in Patients with Lung Cancer

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Abstract

Background:

Risk estimation of bone metastasis in lung cancer patients is essential for clinical decision-making. However, prediction models are often underutilized in daily practice due to limited accessibility and complexity.

Objective:

This study aimed to develop a nomogram and a web-based clinical tool to facilitate individualized risk prediction of bone metastasis in patients with lung cancer.

Methods:

A clinical prediction model derived from routinely available clinical variables was translated into a nomogram and implemented as a web-based application. The tool allows clinicians to input patient-specific parameters and obtain an estimated probability of bone metastasis along with risk stratification.

Results:

A user-friendly nomogram was developed to visually estimate individual risk of bone metastasis. The accompanying web-based tool provides rapid risk calculation and categorization using simple clinical inputs. The tool is designed to support clinical decision-making and may be particularly useful in district hospital settings.

Conclusion:

The proposed nomogram and web-based tool offer a practical approach to individualized risk assessment of bone metastasis in lung cancer patients and may enhance the clinical application of prediction models in routine practice.

Keywords: nomogram; bone metastasis; lung cancer; clinical decision support; web-based tool

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Introduction

Bone metastasis represented one of the most common and clinically significant complications of lung cancer, frequently leading to skeletal-related events such as pain, pathological fractures, spinal cord compression, and impaired mobility [1–3]. These complications substantially worsened patient quality of life and were associated with increased morbidity and mortality. As lung cancer remained one of the leading causes of cancer-related deaths worldwide, the clinical burden of metastatic bone disease continued to pose major challenges in oncology practice [4–7]. Epidemiological studies had shown that bone metastasis occurred in a considerable proportion of patients with lung cancer, particularly in those with advanced disease stages [8]. The presence of skeletal involvement often indicated aggressive tumor biology and poorer prognosis. Early identification of patients at high risk for bone metastasis was therefore clinically important to guide diagnostic evaluation, surveillance strategies, and timely therapeutic interventions [9–11]. Despite its clinical relevance, early risk assessment of bone metastasis in routine practice remained challenging. Advanced imaging modalities such as bone scintigraphy,

positron emission tomography, and magnetic resonance imaging were commonly used for detection; however, access to these investigations was often limited in district and regional hospitals [12]. In many clinical settings, decision-making relied primarily on routinely available clinical and laboratory information, underscoring the need for practical tools that could support individualized risk assessment without requiring advanced resources [13–16].

Several prediction models for bone metastasis in lung cancer had been developed and demonstrated acceptable predictive performance [17]. Nevertheless, the clinical impact of these models remained limited, as many were presented in statistical formats that were difficult to interpret and apply in daily practice. The lack of accessible, user-friendly interfaces hindered their translation from research settings into routine clinical use, particularly in resource-limited environments.

Web-based clinical decision-support tools had emerged as a promising approach to bridge this gap between prediction models and real-world clinical application [18,19]. By enabling rapid risk estimation using patient-specific data, web-based tools offered advantages in accessibility, interpretability, and ease of use. Such tools could support clinicians in risk stratification and clinical

decision-making, especially in settings with high patient volume and limited access to advanced diagnostic facilities.

However, evidence on the development and clinical application of web-based tools specifically designed to predict bone metastasis in patients with lung cancer remained limited. Existing studies primarily focused on model development or validation, with less emphasis on practical implementation and usability in routine clinical workflows [20]. This gap highlighted the need for translational research that prioritized real-world applicability and clinical relevance.

The novelty of the present study lay in the development and implementation of a web-based clinical decision-support tool derived from routinely available clinical parameters to estimate the risk of bone metastasis in patients with lung cancer. Rather than emphasizing statistical model derivation, this study focused on translating predictive information into an accessible digital tool that could be readily used in everyday clinical practice.

Therefore, the aim of this study was to develop and present a web-based clinical decision-support tool for individualized prediction of bone metastasis in patients with lung cancer. The tool was intended to support clinical decision-making by providing rapid, interpretable risk estimates using routinely collected clinical data, particularly in resource-limited healthcare settings.

Materials and Methods

Study Design and Setting

This study was designed as a translational tool development study using a retrospective cohort approach. The primary objective was to develop and present a web-based clinical decision-support tool to facilitate individualized risk prediction of bone metastasis in patients with lung cancer. The study utilized routinely collected clinical data from a district hospital in Banten Province, Indonesia, reflecting real-world clinical practice in a resource-limited setting.

Study Population

The study population consisted of adult patients diagnosed with lung cancer who received care at the study hospital during the predefined study period.

Inclusion criteria were:

- (1) confirmed diagnosis of lung cancer based on clinical, radiological, and/or histopathological findings; and
- (2) availability of complete clinical and laboratory data required for risk estimation. Exclusion criteria were:
 - (1) incomplete or missing data for key predictor variables; and
 - (2) lack of documented bone metastasis status in the medical records.

Outcome Definition

The primary outcome was the presence of bone

metastasis. Bone metastasis was defined based on documentation in medical records supported by imaging examinations, including bone scintigraphy, computed tomography, magnetic resonance imaging, or other radiological assessments as recorded by attending clinicians.

Predictor Variables

Predictor variables were selected a priori based on clinical relevance and evidence from previous literature. Routinely available clinical parameters included age, sex, serum calcium level, lung cancer stage, and histological subtype. All variables were extracted from medical records at the time of lung cancer diagnosis or initial clinical assessment to ensure temporal consistency with outcome evaluation.

Development of the Prediction Tools

The web-based clinical decision-support tool was developed to translate predictive information derived from routinely available clinical parameters into an accessible digital interface. The tool allowed clinicians to input patient-specific characteristics and automatically generated an estimated probability of bone metastasis.

Tool development emphasized simplicity, transparency, and interpretability to facilitate use in routine clinical practice without requiring advanced statistical expertise. The interface was designed to support rapid risk assessment during clinical encounters, particularly in settings with limited access to advanced diagnostic resources.

Figure 1. Flow Diagram of Patient Selection [Accessibility description]

The figure presents a flow diagram of patient selection. It starts with all patients diagnosed with lung cancer at the study hospital. Patients were then assessed for eligibility, with exclusions applied due to incomplete clinical data or missing documentation of bone metastasis. The final box shows the number of patients included in the analysis.

Model Performance and Validation

The predictive performance underlying the web-based tool was assessed in terms of discrimination and calibration. Discriminatory ability was evaluated using the area under the receiver operating characteristic curve, while calibration was examined by comparing predicted probabilities with observed outcomes. These assessments were used to describe the overall performance of the predictive approach implemented in the web-based tool.

Ethical Considerations

Ethical approval was obtained from the Health Research Ethics Committee of Banten Regional General Hospital, Indonesia (Approval No. 98/KEPK-RSUD/8/2024). The study involved retrospective analysis of anonymized medical records; therefore, the requirement for informed consent was waived. All data were handled confidentially, and no fabrication, manipulation, or

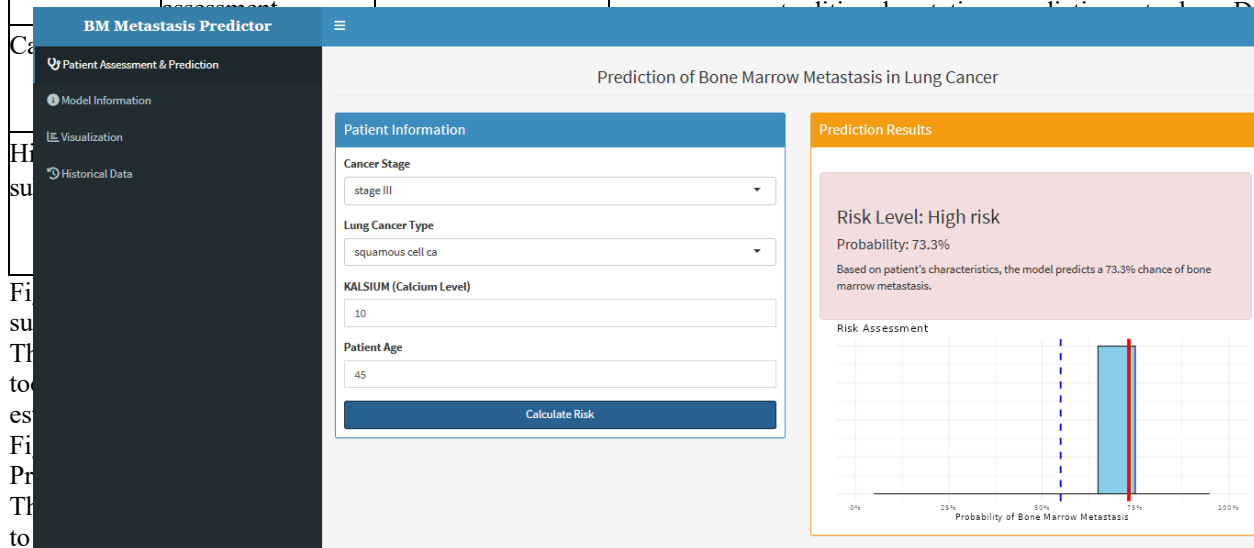
selective reporting of data occurred.

Result

A total of patients diagnosed with lung cancer were initially screened for eligibility. After applying predefined inclusion and exclusion criteria, patients with complete clinical data and documented bone metastasis status were included in the analysis. The patient selection process is summarized in Figure 1.

Table 1. Clinical variables used in the web-based clinical decision-support tool

Variable	Definition / Category	Role in risk prediction
Age	Patient age at lung cancer diagnosis (years)	Baseline demographic factor contributing to individualized risk estimation
Sex	Male / Female	Demographic characteristic incorporated for personalized risk assessment
Serum calcium level	Measured serum calcium value at initial clinical assessment	Biochemical marker associated with skeletal involvement



It includes model performance metrics, a bar chart illustrating relative variable contribution, and a clinical interpretation panel that summarizes individualized risk estimates.

Discussion

This study presented the development and clinical application of a web-based clinical decision-support tool for predicting bone metastasis in patients with lung cancer using routinely available clinical parameters. The primary contribution of this study was not the derivation of a new predictive model, but the translation of existing predictive information into an accessible digital tool designed for routine clinical use, particularly in

resource-limited healthcare settings.

The findings supported the feasibility of using simple clinical and laboratory variables to estimate the risk of bone metastasis in lung cancer patients. Previous studies have demonstrated that factors such as cancer stage, histological subtype, and biochemical markers are associated with metastatic spread to the bone [21,22]. The present study aligned with this body of evidence by integrating these routinely collected parameters into a practical decision-support interface, thereby facilitating individualized risk assessment without reliance on advanced diagnostic technologies [23–26].

Several prediction models for bone metastasis in lung cancer have been reported in the literature, often demonstrating moderate to good discriminatory performance. However, many of these models have remained confined to research settings due to their presentation in complex statistical formats. The present study addressed this translational gap by emphasizing usability and clinical interpretability. By providing a web-based interface that generates individualized risk estimates, the tool enabled clinicians to apply predictive information directly at the point of care, which may enhance clinical decision-making and prioritization of diagnostic evaluation [27,28].

The web-based format offered additional advantages

closer follow-up for bone metastasis. This risk-based approach has the potential to optimize clinical decision-making, particularly in settings with limited diagnostic resources, by supporting timely allocation of investigations and reducing unnecessary imaging in lower-risk patients.

Limitation

Despite these strengths, several limitations should be acknowledged. First, the study was based on retrospective data from a single center, which may limit generalizability to other populations and healthcare settings. Second, the performance metrics presented reflected internal evaluation of the predictive approach

implemented in the tool; external validation in independent cohorts was not performed. Third, although the web-based tool was designed to support clinical decision-making, it was not intended to replace clinical judgment or diagnostic imaging, and its use should be considered as an adjunct rather than a standalone diagnostic instrument.

Future Directions

Future research should focus on external validation of the web-based clinical decision-support tool using independent datasets from multiple centers and diverse healthcare settings. Such validation is essential to confirm the generalizability and robustness of the predictive approach across different patient populations. Prospective studies are also warranted to evaluate the clinical impact of the tool on decision-making processes, including its influence on diagnostic strategies, referral patterns, and utilization of imaging for bone metastasis detection. Assessing usability, clinician acceptance, and integration into routine clinical workflows will be important to optimize real-world implementation.

Further development of the tool may include the incorporation of additional clinical, laboratory, or imaging-related variables to enhance predictive accuracy. Integration with electronic medical record systems and adaptation for mobile platforms could improve accessibility and facilitate broader clinical adoption. Ultimately, these efforts may contribute to more personalized and timely management of patients with lung cancer at risk of bone metastasis.

Conclusion

In conclusion, this study presented a web-based clinical decision-support tool for predicting bone metastasis in patients with lung cancer using routinely available clinical parameters. The tool translated predictive information into an accessible and practical digital interface, supporting individualized risk assessment in routine clinical practice. This approach may be particularly useful in resource-limited settings to aid clinical decision-making and prioritization of further diagnostic evaluation. Future studies are needed to externally validate the tool and assess its impact on clinical outcomes.

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