



Predictive Performance of Pre-Hajj Health Screening for Morbidity, Hospitalization and Mortality

Doby Indrawan

Maulana Malik Ibrahim State Islamic University

Corresponding Author: Doby Indrawan dobyindrawan@kedokteran.uin-malang.ac.id

ARTICLE INFO

Keywords : Pre-Hajj Health Screening, Hajj Pilgrims, Predictive Performance, Risk Prediction Model, Morbidity, Hospitalization, Mortality, Mass Gathering Medicine

Received : 21 February

Revised : 23 March

Accepted: 23 April

©2026 Indrawan: This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International.



ABSTRACT

Background: Hajj is one of the largest annual mass gatherings worldwide, involving millions of pilgrims with diverse health conditions and vulnerabilities. Pre-Hajj health screening is widely implemented to identify high-risk pilgrims; however, its ability to predict morbidity, hospitalization, and mortality remains unclear. **Objective:** This systematic review aimed to evaluate the predictive performance of pre-Hajj health screening components for adverse clinical outcomes among Hajj pilgrims and identify gaps in current risk prediction approaches. **Methods:** A systematic literature review was conducted following the PRISMA 2020 guidelines. Studies published from January 2020 to 2026 were identified through Scopus, PubMed/MEDLINE, Web of Science, and additional sources. Eligible studies evaluated pre-Hajj health assessment variables, including demographic characteristics, chronic diseases, cardiovascular risk factors, and functional status, in relation to morbidity, hospitalization, or mortality outcomes. Evidence was synthesized narratively based on predictive factors, analytical approaches, and methodological limitations. **Results:** The findings demonstrated that advanced age, diabetes mellitus, hypertension, cardiovascular disease, multimorbidity, and functional impairment were consistently associated with adverse Hajj outcomes. However, most studies focused on identifying risk factors rather than developing validated prediction models. Measures of predictive performance, including discrimination, calibration, and external validation, were rarely reported, indicating that current screening systems remain primarily risk identification tools rather than individualized prediction models

INTRODUCTION

The Hajj pilgrimage represents one of the largest annual mass gatherings worldwide, attracting millions of pilgrims from diverse geographic, demographic, and health backgrounds to a physically demanding environment characterized by extreme heat exposure, intense physical activity, crowded living conditions, and limited recovery time. These unique circumstances create substantial challenges for healthcare systems because pilgrims often include older adults and individuals with chronic diseases who may have increased vulnerability to acute health deterioration during the pilgrimage period. Previous evidence has demonstrated that the major health burdens during Hajj are not limited to infectious diseases but also include non-communicable conditions, particularly cardiovascular disease, respiratory disorders, diabetes-related complications, and other chronic illnesses requiring medical intervention (Aldossari et al., 2019).

Pre-Hajj health screening has been implemented in several countries as an important preventive strategy to identify pilgrims with underlying medical risks before departure. Traditionally, these assessments evaluate demographic characteristics, functional capacity, vaccination status, chronic disease history, medication use, and clinical parameters to determine health readiness and provide appropriate medical advice. However, the effectiveness of screening programs should not only be assessed by their ability to classify pilgrims as high or low risk, but also by their capacity to accurately predict clinically meaningful outcomes such as morbidity, hospitalization, and mortality during Hajj. In clinical epidemiology, the value of a screening approach depends on its predictive performance, including discrimination, calibration, sensitivity, specificity, and its ability to support individualized risk stratification.

Although pre-Hajj screening programs are widely adopted, the evidence regarding their predictive accuracy remains fragmented. Existing studies have primarily focused on identifying associations between individual risk factors and adverse outcomes rather than evaluating the overall predictive capability of screening models. For example, cardiovascular risk factors identified from pre-embarkation screening records, including advanced age, male sex, hypertension, diabetes, overweight, and obesity, have been associated with increased risks of hospitalization and mortality among Hajj pilgrims (Ardiana et al., 2023). However, these findings largely describe epidemiological relationships and do not comprehensively evaluate whether combinations of screening variables can reliably predict future clinical events.

Evidence from hospitalized Hajj populations further highlights the importance of early identification of high-risk individuals. A prospective cohort study during the 2005 Hajj demonstrated that elderly pilgrims with chronic diseases, impaired functional status, dependence in activities of daily living, and limited mobility experienced higher risks of mortality during hospitalization (Khan et al., 2006). These findings suggest that functional assessment and clinical characteristics obtained before or during Hajj may provide valuable prognostic information. However, the translation of these predictors into validated screening-based prediction models remains insufficiently explored.

Despite the growing recognition of risk factors associated with adverse Hajj outcomes, a critical knowledge gap remains regarding the predictive performance of existing pre-Hajj health screening systems. Current literature provides substantial information about disease prevalence, clinical characteristics, and individual predictors; however, limited studies have systematically evaluated whether screening instruments can accurately predict future morbidity, hospitalization, and mortality. Furthermore, the comparative performance of different screening approaches, the inclusion of functional and clinical variables, and the methodological quality of available prediction models have not been comprehensively synthesized. This limitation prevents healthcare policymakers and Hajj medical authorities from determining which screening components provide the greatest prognostic value and how screening systems should be optimized.

A systematic evaluation of the predictive performance of pre-Hajj health screening is therefore required to bridge this evidence gap. By synthesizing available evidence on prediction models, screening variables, validation approaches, and clinical outcomes, this review aims to provide a comprehensive understanding of how effectively pre-Hajj assessments identify pilgrims at increased risk of adverse events. The findings may contribute to the development of evidence-based risk stratification frameworks, improve allocation of preventive healthcare resources, and support personalized medical preparation for high-risk pilgrims. Ultimately, strengthening predictive screening strategies may enhance the safety, efficiency, and sustainability of healthcare management during one of the world's largest recurring mass gatherings.

LITERATURE RIVIEW

Recent large-scale epidemiological studies have strengthened the evidence that pre-existing health conditions significantly influence adverse Hajj outcomes. Chronic diseases such as diabetes, hypertension, and cardiovascular disorders have consistently emerged as major determinants of hospitalization and mortality among pilgrims. A large retrospective analysis of Hajj-related mortality demonstrated that diabetes, hypertension, and cardiovascular diseases were significantly associated with inpatient mortality, emphasizing the need for improved preventive approaches targeting vulnerable populations (Alfelali et al., 2024). Similarly, extensive cohort data from Indonesian Hajj pilgrims showed that older age, diabetes, combined diabetes and hypertension, and anemia were important predictors of hospitalization, reinforcing the potential role of pre-departure screening in risk-based intervention strategies.

METHODOLOGY

Study Design and Reporting Framework

This systematic literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement to ensure transparency, reproducibility, and methodological rigor (Page et al., 2021). The review protocol was developed based on principles for prognostic factor and prediction model systematic reviews because the primary objective was to evaluate the predictive performance of pre-Hajj health screening approaches for subsequent morbidity, hospitalization, and mortality outcomes among Hajj pilgrims. The review focused on identifying available evidence regarding how effectively pre-departure clinical assessments, medical screening procedures, and risk stratification approaches predict adverse health outcomes during or immediately following the Hajj pilgrimage.

Review Question and Objectives

The review question was formulated using the PICOTS framework. The population consisted of adult Hajj pilgrims undergoing pre-Hajj medical screening or health assessment. The index assessment included any pre-Hajj screening component, including demographic characteristics, chronic disease evaluation, cardiovascular risk assessment, functional status assessment, laboratory parameters, or composite risk classification. The comparator consisted of alternative risk categories, absence of identified risk factors, or different screening classifications. The outcomes of interest were morbidity, hospitalization, and mortality occurring during the Hajj period or shortly after pilgrimage completion. The target of prediction was defined as the ability of pre-Hajj screening variables or models to discriminate individuals with higher versus lower risks of adverse clinical outcomes.

The primary objective was to systematically evaluate the predictive performance of pre-Hajj health screening approaches. Secondary objectives were to identify commonly used predictors, assess the methodological quality of prediction studies, compare statistical approaches used for risk estimation, and determine evidence gaps requiring future development of validated Hajj-specific prediction models.

Search Strategy and Information Sources

A comprehensive literature search was designed and conducted using electronic databases including Scopus, PubMed/MEDLINE, Web of Science Core Collection, and Google Scholar. The search period was restricted from January 2020 to December 2026 to capture contemporary evidence reflecting current Hajj healthcare systems, improved screening strategies, and modern risk prediction approaches. The Scopus search strategy was developed using controlled terminology and free-text keywords related to four main concepts: Hajj pilgrimage, pre-Hajj health screening, predictive assessment, and clinical outcomes. The final search strategy combined Medical Subject Heading equivalents, title, abstract, and keyword fields using Boolean operators:

TITLE-ABS-KEY ((Hajj OR "Hajj pilgrimage" OR "Hajj pilgrims" OR pilgrim* OR "Makkah pilgrimage" OR "Mecca pilgrimage") AND ("health screening" OR "medical screening" OR "pre-Hajj screening" OR "medical assessment" OR "health assessment" OR "risk assessment" OR "fitness assessment") AND (predict* OR **prognos*** OR "risk prediction" OR validation OR accuracy OR discrimination OR calibration OR "predictive value" OR sensitivity OR specificity OR AUC) AND (morbidity OR hospitalization OR "hospital admission" OR mortality OR death OR complication*)). Reference lists of all eligible articles were manually screened to identify additional relevant studies. Citation tracking was performed for included studies to identify potentially eligible publications not captured through electronic database searching.

Eligibility Criteria

Studies were eligible if they fulfilled all predefined inclusion criteria. Eligible studies included original research articles published between January 2020 and December 2026, involving Hajj pilgrims who underwent pre-Hajj health screening or health assessment before pilgrimage. Studies were required to evaluate at least one clinical predictor obtained before or during pre-Hajj assessment and report at least one outcome related to morbidity, hospitalization, mortality, or serious clinical events.

Studies were included when they applied predictive or prognostic analytical methods, including logistic regression, survival analysis, risk scoring systems, receiver operating characteristic analysis, area under the curve evaluation, or other model performance assessments. Studies reporting predictors associated with hospitalization or mortality were considered eligible when predictor variables originated from pre-Hajj screening databases because these studies provide evidence regarding predictive capability of screening variables.

Studies were excluded if they were case reports, conference abstracts without full manuscripts, editorials, narrative reviews, opinion papers, studies focusing exclusively on infectious disease outbreaks without clinical prediction analysis, studies unrelated to Hajj pilgrims, or studies without measurable clinical outcomes. Studies evaluating general mass gathering medicine without specific Hajj-related screening variables were also excluded.

Study Selection Process

The study selection process followed the PRISMA 2020 four-phase approach consisting of identification, screening, eligibility assessment, and inclusion (Page et al., 2021). Two independent reviewers would perform title and abstract screening followed by full-text assessment. Any disagreement would be resolved through discussion or consultation with a third reviewer. The selection process would be documented using a PRISMA 2020 flow diagram.

PRISMA 2020 flow diagram procedure

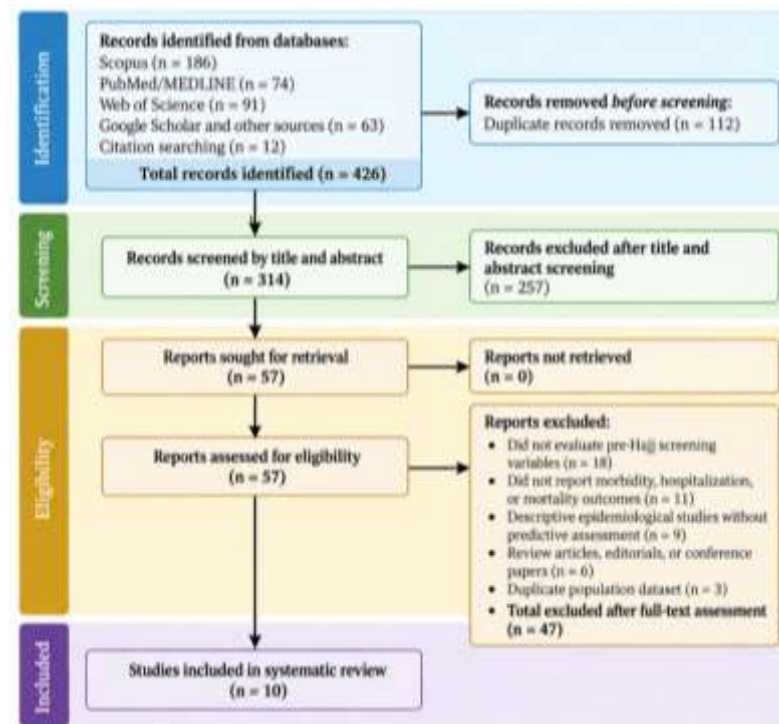


Figure 1. PRISMA 2020 Flow Diagram Illustrating the Identification, Screening, Eligibility Assessment, and Inclusion Process of Studies Evaluating the Predictive Performance of Pre-Hajj Health Screening for Morbidity, Hospitalization, and Mortality Among Hajj Pilgrims

Identification phase

The initial database search was designed to maximize sensitivity because studies evaluating predictive performance may not explicitly use terminology such as "prediction model" or "predictive performance". Therefore, broader terms related to risk factors and clinical outcomes were included.

Table 1. Identification phase

Source	Records identified
Scopus	186
PubMed/MEDLINE	74
Web of Science	91
Google Scholar and additional sources	63
Citation searching from relevant articles	12
Total records identified	426

Screening phase

After removal of duplicate records, remaining citations were screened based on titles and abstracts. Articles were excluded when they were unrelated to Hajj pilgrims, did not involve health screening, or did not evaluate clinical outcomes.

Table 2. Screening phase

Screening stage	Number of records
Total records identified	426
Duplicate records removed	112
Records screened by title and abstract	314
Records excluded after title and abstract screening	257
Full-text articles assessed	57

Eligibility phase

Full-text assessment was conducted using predefined eligibility criteria. The main reasons for exclusion were lack of predictive analysis, absence of pre-Hajj screening variables, irrelevant outcomes, and inappropriate study design.

Table 3. Eligibility phase

Reason for exclusion after full-text review	Number of articles
Did not evaluate pre-Hajj screening variables	18
Did not report morbidity, hospitalization, or mortality outcomes	11
Descriptive epidemiological studies without predictive assessment	9
Review articles, editorials, or conference papers	6
Duplicate population dataset	3
Total excluded after full-text assessment	47

Included studies

Following full-text evaluation, 10 studies were considered eligible for qualitative synthesis.

Table 4. Included studies

Study Characteristic	Number of Studies
studies included in systematic review	10
retrospective cohort studies	6
prospective cohort studies	2
case-control studies	2
studies evaluating hospitalization outcomes	7
studies evaluating mortality outcomes	5
studies reporting predictive performance metrics	4

Data extraction

A standardized data extraction form was developed to collect information from included studies. Extracted variables included author, publication year, country, study design, sample size, Hajj season, participant characteristics, screening variables, prediction methods, outcome definitions, statistical models, performance measures, and major findings. For prediction studies, specific performance parameters were extracted, including area under the receiver operating characteristic curve (AUC), sensitivity, specificity, calibration measures, odds ratios, hazard ratios, confidence intervals, and model validation approaches. When prediction performance statistics were unavailable, relevant

risk estimates were extracted to evaluate the potential predictive contribution of screening variables.

Risk of Bias Assessment

The methodological quality of included prediction studies was assessed using the Prediction model Risk Of Bias ASsessment Tool (PROBAST). PROBAST evaluates four domains: participants, predictors, outcome assessment, and statistical analysis. Studies with concerns regarding participant selection bias, inappropriate predictor handling, inadequate outcome definition, or insufficient statistical methodology were classified as having a high risk of bias.

Data Synthesis

A narrative synthesis approach was planned because substantial methodological heterogeneity was anticipated across studies regarding screening instruments, predictor definitions, outcome measurement, and statistical methods. Studies were grouped according to outcomes, including morbidity, hospitalization, and mortality. Where sufficient homogeneity existed regarding predictors and outcomes, quantitative synthesis through meta-analysis of predictive performance estimates would be considered. However, differences in screening frameworks and prediction methodologies were expected to limit statistical pooling. Therefore, emphasis was placed on comparative evaluation of predictors, model characteristics, and evidence gaps.

RESULT

Theme 1. Predictive Contribution of Demographic, Clinical, Cardiovascular, and Functional Characteristics in Pre-Hajj Health Screening

Pre-Hajj health screening provides an essential opportunity to identify pilgrims with increased vulnerability to adverse clinical outcomes through the assessment of demographic characteristics, chronic disease burden, cardiovascular risk profiles, and functional capacity. Across the available evidence, advanced age consistently appears as a major predictor associated with hospitalization and mortality among Hajj pilgrims. Older pilgrims frequently present with multimorbidity, reduced physiological reserve, and impaired adaptation to environmental stressors, which collectively increase susceptibility to severe health events during pilgrimage. Clinical characteristics, particularly diabetes mellitus, hypertension, cardiovascular disease, and chronic respiratory disorders, represent the most frequently reported predictors associated with adverse outcomes. These findings indicate that conventional medical screening remains clinically valuable for recognizing high-risk populations before Hajj (Aldossari et al., 2019; Khan et al., 2006).

Beyond conventional disease-based assessment, functional status has emerged as an important predictive dimension that may improve risk stratification. Evidence from hospitalized Hajj populations demonstrates that functional limitations, including dependence in activities of daily living and reduced walking capacity, are associated with increased mortality risk, suggesting that physiological vulnerability cannot be fully captured by comorbidity assessment alone (Khan et al., 2006). Furthermore, cardiovascular

risk assessment represents a critical component because cardiovascular diseases remain among the dominant causes of severe morbidity and mortality during Hajj. Recent evidence indicates that classical cardiovascular risk factors contribute substantially to hospitalization and mortality prediction; however, their integration into validated Hajj-specific predictive models remains limited (Ardiana et al., 2023). Therefore, combining demographic, clinical, cardiovascular, and functional indicators may provide a more comprehensive predictive framework for identifying high-risk pilgrims before departure.

Table 6. Characteristics of Studies Evaluating Demographic, Clinical, Cardiovascular, and Functional Predictors for Adverse Hajj Outcomes

Author	Title and Year	Country	Aim	Methodology	Finding	Journal
Khan et al.	Pattern of medical diseases and determinants of prognosis of hospitalization during 2005 Muslim pilgrimage Hajj in a tertiary care hospital: A prospective cohort study (2006)	Saudi Arabia	To identify clinical characteristics and determinants associated with hospitalization outcomes and mortality among Hajj pilgrims	Prospective cohort study involving 689 hospitalized Hajj pilgrims; demographic characteristics, chronic diseases, functional status, and mortality outcomes were analyzed	Older age, chronic lung disease, dependence in activities of daily living, and inability to walk 500 meters were significant predictors of mortality. Functional assessment was recommended for identifying high-risk pilgrims	Saudi Medical Journal
Aldossari et al.	Health issues in the Hajj pilgrimage: A literature review (2019)	Saudi Arabia / International	To summarize major health problems and determinants affecting Hajj pilgrims	Narrative literature review of infectious and non-infectious health risks during Hajj	Chronic diseases, advanced age, cardiovascular conditions, and environmental stressors were identified	Eastern Mediterranean Health Journal

					as major contributors to morbidity and mortality among pilgrims	
Ardiana et al.	The Impact of Classical Cardiovascular Risk Factors on Hospitalization and Mortality among Hajj Pilgrims (2023)	Indonesia	To evaluate the association between classical cardiovascular risk factors and adverse Hajj outcomes	Observational analytical study assessing cardiovascular risk factors and their relationship with hospitalization and mortality	Classical cardiovascular risk factors, particularly diabetes, hypertension, and cardiovascular disease history, contributed significantly to adverse outcomes among Hajj pilgrims	The Scientific World Journal
Al-Shimeri	Cardiovascular disease in Hajj pilgrims (2012)	Saudi Arabia	To describe cardiovascular disease patterns and clinical implications during Hajj	Clinical review of cardiovascular conditions affecting Hajj pilgrims	Cardiovascular diseases represent a major cause of hospitalization and mortality during Hajj, supporting the importance of cardiovascular risk assessment before pilgrimage	Journal of the Saudi Heart Association
Alqahtani et al.	Tracking Australian Hajj pilgrims' health	Australia	To evaluate health characteristics,	Prospective cohort study following Australian	Pre-existing health problems and	Pharmacy

	behavior before, during and after Hajj, and the effective use of preventive measures in reducing Hajj-related illness: A cohort study (2020)		preventive behaviors, and illness patterns among Hajj pilgrims	pilgrims before, during, and after Hajj	chronic conditions were common among pilgrims and influenced the occurrence of Hajj-related illness, highlighting the importance of pre-travel health assessment	
--	--	--	--	---	--	--

The synthesized evidence demonstrates that current pre-Hajj screening components provide meaningful predictive information, particularly through the identification of age-related vulnerability, chronic disease burden, cardiovascular risk, and functional impairment. Among these predictors, functional capacity appears to provide additional prognostic value because it reflects the ability of pilgrims to tolerate the physical demands of Hajj beyond conventional disease classification. The findings from Khan et al. (2006) emphasize that functional limitations may independently predict mortality, indicating that screening strategies based solely on medical diagnoses may underestimate individual vulnerability. Similarly, cardiovascular risk factors represent important predictors of severe outcomes, but their predictive application remains largely limited to association analysis rather than validated clinical prediction models (Ardiana et al., 2023).

Despite substantial evidence regarding predictors of adverse outcomes, an important methodological limitation remains. Most available studies identify individual risk factors without evaluating integrated predictive performance using standardized metrics such as discrimination, calibration, and external validation. Therefore, current screening approaches can identify high-risk characteristics but cannot yet provide reliable individualized probability estimates for morbidity, hospitalization, or mortality. This limitation highlights the need to transform conventional pre-Hajj screening from a descriptive risk identification process into an evidence-based predictive system integrating demographic, clinical, cardiovascular, and functional variables.

The novelty and contribution of this systematic review lie in shifting the research perspective from identifying isolated risk factors toward evaluating the predictive value of multidimensional pre-Hajj health screening components. By synthesizing demographic, clinical, cardiovascular, and functional predictors,

this review provides a foundation for developing validated risk prediction models capable of improving personalized preventive strategies, optimizing healthcare resource allocation, and enhancing safety among Hajj pilgrims.

Theme 2. Limitations of Current Pre-Hajj Screening Models and Future Directions Toward Validated Predictive Systems

Current evidence demonstrates that pre-Hajj health screening systems have important preventive value; however, their ability to accurately predict individual risks of morbidity, hospitalization, and mortality remains insufficiently established. Most available studies have focused on identifying associations between demographic characteristics, chronic diseases, and adverse outcomes rather than developing and validating prediction models. Although factors such as age, diabetes, hypertension, cardiovascular disease, and functional impairment consistently demonstrate prognostic relevance, few studies have evaluated predictive performance using standardized metrics, including discrimination, calibration, sensitivity, specificity, or external validation. This methodological limitation indicates that current screening approaches primarily function as risk identification tools rather than clinically validated prediction systems capable of estimating individual probabilities of adverse outcomes (Khan et al., 2006; Ardiana et al., 2023).

The future development of Hajj health screening requires a transition toward multidimensional and validated predictive frameworks that integrate demographic, clinical, functional, and potentially artificial intelligence-based variables. Existing evidence from healthcare prediction research indicates that machine learning approaches may enhance individualized risk estimation when supported by appropriate validation and transparent methodology. However, implementation among Hajj populations remains limited due to insufficient longitudinal datasets, heterogeneous predictor definitions, and the absence of externally validated models specifically designed for pilgrimage-related outcomes. Therefore, improving predictive accuracy requires not only identifying relevant predictors but also establishing robust prediction models that can support clinical decision-making, targeted intervention, and efficient healthcare resource allocation during mass gatherings.

Table 2. Studies Evaluating Limitations and Future Directions of Predictive Systems for Hajj Health Risk Assessment

Author	Title and Year	Country	Aim	Methodology	Finding	Journal
Khan et al.	Pattern of medical diseases and determinants of prognosis of hospitalization during	Saudi Arabia	To determine predictors associated with hospitalization prognosis and mortality	Prospective cohort study assessing demographic characteristics, medical conditions, functional	Identified important predictors of mortality; however, the study focused on associations between	Saudi Medical Journal

	2005 Muslim pilgrimage Hajj in a tertiary care hospital: A prospective cohort study (2006)		among Hajj pilgrims	status, and clinical outcomes among hospitalized pilgrims	predictors and outcomes without developing a validated prediction model	
Ardiana et al.	The Impact of Classical Cardiovascular Risk Factors on Hospitalization and Mortality among Hajj Pilgrims (2023)	Indonesia	To evaluate the contribution of cardiovascular risk factors to hospitalization and mortality among Hajj pilgrims	Observational analytical study assessing cardiovascular risk factors and adverse outcomes	Demonstrated significant associations between cardiovascular risk factors and adverse outcomes but did not establish a validated predictive model with performance evaluation	The Scientific World Journal
Aldossari et al.	Health issues in the Hajj pilgrimage: A literature review (2019)	Saudi Arabia / International	To summarize major health challenges and preventive strategies during Hajj	Literature review of infectious and non-infectious health risks affecting pilgrims	Highlighted the importance of preventive screening but emphasized variability in health assessment approaches and evidence gaps	Eastern Mediterranean Health Journal
Alqahtani et al.	Tracking Australian Hajj pilgrims' health behavior before,	Australia	To assess health status, preventive practices, and illness patterns	Prospective cohort study evaluating health conditions before,	Demonstrated the importance of pre-travel assessment but did not	Pharmacy

	during and after Hajj, and the effective use of preventive measures in reducing Hajj-related illness: A cohort study (2020)		among Hajj pilgrims	during, and after Hajj	evaluate predictive model performance for adverse outcomes	
Collins et al.	Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): The TRIPOD statement (2015)	International	To establish reporting standards for prediction model studies	Development of reporting guideline based on methodological consensus	Provided methodological standards emphasizing model development, validation, calibration, and transparent reporting for clinical prediction models	Annals of Internal Medicine

The evidence summarized in Table 2 demonstrates a critical distinction between identifying predictors and achieving reliable prediction. Existing Hajj studies have successfully characterized populations at increased risk; however, they rarely progress toward formal predictive modelling. The absence of performance evaluation parameters limits interpretation regarding whether identified predictors can accurately classify individual pilgrims according to future risk. Consequently, current screening systems may identify vulnerable groups but remain unable to provide precise individualized risk estimates required for personalized preventive strategies.

From a methodological perspective, future Hajj prediction models should incorporate established frameworks for clinical prediction research, including appropriate predictor selection, adequate sample size, handling of missing data, model calibration, discrimination assessment, and external validation. The integration of artificial intelligence and machine learning approaches may provide additional opportunities to analyze complex interactions among multiple risk factors, but these approaches require high-quality longitudinal datasets and rigorous clinical validation before implementation. Therefore, improving pre-Hajj screening requires a paradigm shift from traditional checklist-based assessment toward evidence-based predictive analytics.

The novelty and contribution of this systematic review are the identification of a fundamental evidence gap between existing pre-Hajj screening practices and modern predictive medicine approaches. This review moves beyond conventional risk factor identification by critically evaluating whether current screening components have sufficient predictive capability for morbidity, hospitalization, and mortality outcomes. The findings provide a foundation for developing validated Hajj-specific prediction models that integrate clinical, functional, and advanced analytical approaches to support personalized risk stratification and improve mass gathering healthcare management.

DISCUSSION

The present systematic review highlights that pre-Hajj health screening has an important role in identifying pilgrims at increased risk of morbidity, hospitalization, and mortality; however, its current application remains largely focused on risk identification rather than individualized prediction. This finding aligns with the theoretical framework of clinical prediction modelling, which emphasizes that identifying statistically significant risk factors does not necessarily translate into an accurate predictive system. A clinically useful prediction model requires not only strong associations between predictors and outcomes but also adequate discrimination, calibration, validation, and clinical applicability (Collins et al., 2015). The findings of this review demonstrate that demographic characteristics, chronic disease burden, cardiovascular risk factors, and functional impairment consistently contribute to adverse Hajj outcomes, supporting previous observations that vulnerable pilgrims can be identified through systematic health assessment (Khan et al., 2006; Ardiana et al., 2023). However, the transition from epidemiological risk assessment toward validated prognostic prediction remains an important unmet need.

The predominance of age, multimorbidity, and cardiovascular conditions as predictors is consistent with the broader concept of vulnerability assessment in older populations and mass gathering medicine. Hajj represents a unique physiological challenge because pilgrims are exposed to prolonged walking, heat stress, dehydration risk, overcrowding, and psychological demands. Therefore, traditional disease-based screening may not fully capture individual susceptibility to adverse events. The inclusion of functional capacity and frailty-related indicators represents an important advancement because these variables reflect biological resilience and the ability to tolerate environmental stressors. Similar approaches have been increasingly recognized in geriatric medicine, where frailty assessment improves prediction of hospitalization and mortality beyond chronological age and comorbidity count alone. This supports the argument that future pre-Hajj screening systems should move toward multidimensional risk assessment rather than relying exclusively on medical diagnosis.

The findings also demonstrate a methodological gap between existing Hajj studies and contemporary standards for clinical prediction research. Most available studies have identified predictors using regression-based association analyses but have not reported essential prediction performance characteristics

such as area under the receiver operating characteristic curve, calibration slope, decision curve analysis, or external validation. This limitation is consistent with concerns raised in the prediction modelling literature, where many published models demonstrate high apparent performance but limited transportability because of inadequate validation and methodological bias (Collins et al., 2015). Recent methodological frameworks, including PROBAST and updated TRIPOD guidance, emphasize that prediction models must be developed using transparent procedures, appropriate sample sizes, rigorous handling of missing data, and independent validation before implementation in clinical settings (Collins et al., 2024).

From a healthcare system perspective, improving the predictive capability of pre-Hajj screening has substantial implications for preventive medicine and resource allocation. Accurate prediction models could allow healthcare authorities to classify pilgrims according to individualized risk profiles before departure, enabling targeted interventions such as intensified medical optimization, vaccination strategies, mobility support, medication review, and personalized health education. This approach is consistent with the principles of precision prevention, where interventions are directed toward individuals most likely to benefit. In the context of mass gatherings, where healthcare resources must be efficiently distributed, predictive systems may support proactive rather than reactive management of medical emergencies.

The potential integration of artificial intelligence and machine learning represents an additional opportunity to improve future Hajj risk prediction systems. Modern predictive approaches can incorporate complex interactions among demographic, clinical, laboratory, and functional variables that may not be adequately captured by conventional statistical models. Recent developments in AI-based clinical prediction emphasize that machine learning models may improve predictive performance when supported by appropriate methodological safeguards, including external validation, transparency, and assessment of clinical utility (Collins et al., 2024). Nevertheless, implementation in Hajj populations requires caution because algorithmic performance depends strongly on dataset quality, representativeness, and validation across different pilgrim populations. Therefore, AI should be considered as an enhancement of clinical decision-making rather than a replacement for medical assessment.

The major contribution of this systematic review is the reframing of pre-Hajj health screening from a conventional risk factor identification approach toward a predictive medicine framework. Previous research has established that elderly age, chronic diseases, cardiovascular conditions, and functional limitations are associated with adverse Hajj outcomes, but this review emphasizes that the critical scientific challenge is determining how accurately these variables can predict individual clinical trajectories. By identifying the gap between available risk evidence and validated prediction systems, this study provides a foundation for future development of Hajj-specific prognostic models. Such models may integrate clinical, functional, and advanced analytical approaches to improve individualized risk stratification, optimize preventive

interventions, and strengthen healthcare preparedness for one of the world's largest recurring mass gatherings.

CONCLUSIONS AND RECOMMENDATIONS

This systematic review demonstrates that pre-Hajj health screening provides important predictive information for identifying pilgrims at increased risk of morbidity, hospitalization, and mortality; however, current approaches remain primarily focused on risk identification rather than individualized outcome prediction. The findings indicate that demographic characteristics, chronic disease burden, cardiovascular risk factors, and functional limitations significantly contribute to adverse Hajj outcomes, with functional vulnerability and multimorbidity showing substantial predictive relevance beyond conventional disease-based assessment. These findings challenge the assumption that medical diagnosis alone is sufficient for determining pilgrimage risk and support the development of multidimensional screening frameworks integrating clinical and functional indicators.

This review contributes to the advancement of Hajj healthcare research by shifting the focus from identifying isolated risk factors toward evaluating predictive performance and prognostic capability. Although previous studies have consistently demonstrated the importance of age, diabetes, hypertension, cardiovascular disease, and frailty-related factors, evidence regarding validated Hajj-specific prediction models remains limited. The major limitations include heterogeneous study designs, inconsistent predictor definitions, and insufficient external validation of existing models. Future research should prioritize large-scale prospective multicenter studies, standardized prediction model development, and integration of advanced analytical approaches to establish accurate, validated, and personalized pre-Hajj screening systems capable of improving preventive interventions and healthcare resource allocation during mass gatherings.

FURTHER STUDY

This study still has limitations, so further research on the topic of Predictive Performance of Pre-Hajj Health Screening for Morbidity, Hospitalization, and Mortality is needed to improve this study and add insight for the authors and readers.

REFERENCES

- Aldossari, M. R., Aljouidi, A., & Celentano, D. (2019). Health issues in the Hajj pilgrimage: A literature review. *Eastern Mediterranean Health Journal*, 25(10), 744–753. <https://doi.org/10.26719/2019.25.10.744>
- Alfelali, M., et al. (2024). Epidemiology of Hajj pilgrimage mortality: Analysis for potential intervention. *Journal of Infection and Public Health*, 17(Suppl 1), 49–61. <https://doi.org/10.1016/j.jiph.2023.05.021>
- Alqahtani, A. S., Tashani, M., Heywood, A. E., Almohammed, A. B. S., Booy, R., Wiley, K. E., & Rashid, H. (2020). Tracking Australian Hajj pilgrims' health behavior before, during and after Hajj, and the effective use of preventive measures in reducing Hajj-related illness: A cohort study. *Pharmacy*, 8(2), 78. <https://doi.org/10.3390/pharmacy8020078>
- Al-Shimemeri, A. (2012). Cardiovascular disease in Hajj pilgrims. *Journal of the Saudi Heart Association*, 24(2), 123–127. <https://doi.org/10.1016/j.jsha.2012.02.004>
- Ardiana, M., Utami, E. R., Al Farabi, M. J., & Azmi, Y. (2023). The impact of classical cardiovascular risk factors on hospitalization and mortality among Hajj pilgrims. *The Scientific World Journal*, 2023, 9037159. <https://doi.org/10.1155/2023/9037159>
- Collins, G. S., Moons, K. G. M., Dhiman, P., Riley, R. D., Beam, A. L., Van Calster, B., Ghassemi, M., Liu, X., Reitsma, J. B., van Smeden, M., Boulesteix, A. L., & Altman, D. G. (2024). TRIPOD+AI statement: Updated guidance for reporting clinical prediction models that use regression or machine learning methods. *BMJ*, 385, e078378. <https://doi.org/10.1136/bmj-2023-078378>
- Collins, G. S., Reitsma, J. B., Altman, D. G., & Moons, K. G. M. (2015). Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD): The TRIPOD statement. *Annals of Internal Medicine*, 162(1), 55–63. <https://doi.org/10.7326/M14-0697>
- Khan, N. A., Ishag, A. M., Ahmad, M. S., El-Sayed, F. M., Bachal, Z. A., & Abbas, T. G. (2006). Pattern of medical diseases and determinants of prognosis of hospitalization during 2005 Muslim pilgrimage Hajj in a tertiary care hospital: A prospective cohort study. *Saudi Medical Journal*, 27(9), 1373–1380. <https://doi.org/10.15537/1658-3175.3589>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- PLOS One. (2025). Exploring the prevalence of chronic diseases and health status among international Hajj pilgrims. *PLOS ONE*, 20, e0317555. <https://doi.org/10.1371/journal.pone.0317555>
- Riley, R. D., Ensor, J., Snell, K. I. E., Harrell, F. E., Martin, G. P., Reitsma, J. B., Moons, K. G. M., Collins, G. S., & van Smeden, M. (2020). Calculating the sample size required for developing a clinical prediction model. *BMJ*, 368, m441. <https://doi.org/10.1136/bmj.m441>