

Cost-effectiveness and clinical outcomes of artificial intelligence-enhanced screening for diabetic foot ulcers: A simulation study

Yan Sun¹ PhD, Lixia Ge¹ MPH, Yee Gary Ang¹ MBBS, Zhiwen Joseph Lo² PhD, Huiling Liew³ FRCP, Donna ML Tan⁴ MCFP(S)(FM), Daniel Chew^{3,5} MRCP, John Arputhan Abisheganaden^{1,5} MRCP

Dear Editor,

Diabetic foot ulcers (DFUs) are a serious complication of diabetes mellitus, with a lifetime risk estimated to be between 19% and 34%.¹ Without timely prevention and management, DFUs can lead to lower extremity amputations (LEAs) and premature death.^{2,3} DFUs also impose significant healthcare and societal costs, especially in Southeast Asia.^{4,5} Regular foot screenings are essential for preventing these complications.

Countries in Southeast Asia generally follow the guidelines set by the 2023 International Working Group on the Diabetic Foot,⁶ which recommend foot screening frequency based on their risk stratification system: annually for very low risk, once every 6–12 months for low risk, once every 3–6 months for moderate risk and once every 1–3 months for high risk. However, adherence to these guidelines reveals significant challenges and variability in practice due to barriers such as resource limitations and staff shortages. In Singapore, the Agency for Care Effectiveness recommends differentiated screening intervals: annually for low-risk patients, every 6 months for moderate-risk patients and every 3–4 months for high-risk patients.⁷ Low-risk patients are defined as those without any of the following risk factors: calluses, deformities, peripheral artery disease, neuropathy, previous foot ulcers or amputations. Evidence⁸ suggests that the risk of ulceration in low-risk patients remains stable over time. We estimated that 60–80% patients with diabetes can be classified as low risk, and their annual DFU incidence risk is lower than 1% based on data from our cluster's Chronic Disease Management Datamart (CDMD),⁹ raising concerns about overscreening and inefficient resource allocation.

Artificial intelligence (AI) offers a potential solution by enabling personalised risk-tailored screening.¹⁰ This study evaluated the cost-effectiveness and

clinical outcomes of AI-enhanced screening versus routine annual screening for low-risk patients. Using an XGBoost-based predictive model, the AI-enhanced screening approach involves screening based on individual risk: patients flagged as positive are screened annually, while negative low-risk patients are screened every 3 years. The predictive model achieved an area under the receiver operating characteristics curve of 0.81, with a sensitivity of 0.7 and a specificity of 0.8. A cohort of 500,000 low-risk patients with diabetes in Singapore, with an average age of 50 years, was simulated over a lifetime to assess the long-term impact of the AI-enhanced screening.

A Markov state-transition model was constructed to simulate disease progression through 5 health states: diabetes, DFU, minor LEA, major LEA and death. Model parameters, including both base values and distributions of disease transition probabilities and costs (Table 1), were derived from CDMD⁹ and validated against international sources.^{11,12} Direct medical cost for foot screening, examination, consultation, DFU treatment and management, LEA procedures, and related services were included in the cost analysis. Effectiveness was measured in quality-adjusted life years (QALYs), based on EuroQoL-5 Dimension data from a Singapore study.¹³ A 3% discount rate was applied for both costs and effectiveness. The incremental cost-effectiveness ratio (ICER) was then assessed to determine the most cost-effective screening strategy using gross domestic product (GDP) per capita as the willingness-to-pay (WTP) threshold as commonly used in Singapore. Other outcomes measured in the simulation included the number of patients screened, DFU detections, minor and major LEAs performed, and deaths. Monte Carlo micro-simulations with 1000 samples, randomly drawn from parameter distributions, were performed for probability sensitivity analysis (PSA) to account for

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¹ Department of Health Services and Outcomes Research, National Healthcare Group, Singapore

² Vascular Surgery Service, Department of Surgery, Woodlands Health, Singapore

³ Department of Endocrinology, Tan Tock Seng Hospital, Singapore

⁴ National Healthcare Group Polyclinics, Singapore

⁵ Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore

Correspondence: Dr Yan Sun, Department of Health Services and Outcomes Research, National Healthcare Group Pte Ltd, Level 4 Annex @ National Skin Centre, 1 Mandalay Rd, Singapore 308205.

Email: yan_sun@nhg.com.sg

Table 1. Model parameters and their values^a used in the study.

Parameter	Base value	Range
Progression rate		
Annual progression risk from DM to DFU	0.8%	N (0.8%, 0.2%)
Annual progression risk from DFU to minor LEA	6.1%	N (6.1%, 1%)
Annual progression risk from DFU to major LEA	3.5%	N (3.5%, 1%)
Annual progression risk from minor LEA to major LEA	23.7%	N (23.7%, 0.5%)
Mortality rate	Gompertz function: $a * e^{b*age} / 1000$ where a=0.03, b=0.1	a, b: constant
Increased progression due to delayed detection of DFU	25%	Random sampling from [0–50%]
Cost		
Cost per foot screening	SGD56	Constant
Annual cost of DM-related medical services	SGD1099	N (1099, 116)
Annual cost of DFU-related medical services	SGD4002	N (4002, 1489)
Annual cost of minor LEA-related medical services	SGD7546	N (7546, 9928)
Annual cost of major LEA-related medical services	SGD15,188	N (15,188, 20,587)
Utility		
Utility of low-risk DM patient	0.95	Random sampling from [0.9–0.95]
Utility of DFU	0.8	Random sampling from [0.75–0.85]
Utility of minor LEA	0.6	Random sampling from [0.5–0.7]
Utility of major LEA	0.3	Random sampling from [0.2–0.4]
Sensitivity and specificity		
Sensitivity of AI model	0.7	Random sampling from [0.6–0.7]
Specificity of AI model	0.8	Random sampling from [0.7–0.8]

AI: artificial intelligence; DFU: diabetic foot ulcer; DM: diabetes mellitus; LEA: low extremity amputation
N (mean, standard deviation) stands for normal distribution.

^a Parameter values were derived from our cluster’s Chronic Disease Management Datamart

uncertainties in model parameters. Results were summarised in cost-effectiveness acceptability curves (CEAC) and expected loss curves (ELC) to determine the optimal screening strategy under uncertainty.¹⁴ The CEAC shows the chance of each strategy being the most cost-effective and picks the one with the highest chance. The ELC shows the potential cost of choosing the wrong strategy and selects the one with the lowest risk of loss.

AI-enhanced screening resulted in an average lifelong cost of SGD54,272 per patient, compared to SGD55,587 for annual screening, saving

SGD1315 per patient. The lifelong effectiveness for AI-enhanced screening was 23.150 QALYs per patient, which is slightly lower than 23.154 QALYs for annual screening with a minimal difference of 0.004 QALYs per patient. AI-enhanced screening required 4,372,523 DFU screenings, compared to 11,178,861 screenings under annual screening. LEA rates were similar between strategies, with 52,720 minor and 68,646 major LEAs for AI-enhanced screening versus 52,689 minor and 68,710 major LEAs for routine screening. AI screening led to 26 additional deaths. ICER was SGD292,181 per QALY

gained, well below Singapore's GDP per capita in 2023 (SGD110,000), indicating that AI-enhanced screening was more cost-effective than annual screening.

PSA showed that AI-enhanced screening had an average cost of SGD52,178 and effectiveness of 22.866 QALYs, compared to SGD53,993 and 22.876 QALYs for routine screening. ICER from PSA was SGD174,572 (standard deviation SGD13,296) per QALY gained. Both CEAC and ELC indicated that AI-enhanced screening was optimal when WTP was below SGD180,000 per QALY.

AI-enhanced DFU screening optimises healthcare resource allocation by tailoring screening intervals based on individual risk, leading to long-term cost savings. This aligns with government initiatives to reduce healthcare expenditure while maintaining high standards of care, benefiting both patients and healthcare systems. In resource-constrained settings, this approach could alleviate healthcare burdens and enable better resource allocation. The findings are relevant not only for Singapore but also for other countries in Southeast Asia and globally, where diabetes incidence is high and healthcare resources are limited. Malaysia, Indonesia and Thailand could benefit from similar AI-driven strategies, adapted to local healthcare systems. The predictors used in our AI model are routinely collected, facilitating easy adoption and adaptation across different healthcare settings. This flexibility allows the model to be tested and validated in diverse regions, ensuring it can be adjusted for local infrastructure, patient demographics and resource availability. Such adaptability ensures broader applicability and smoother integration into various health systems.

In conclusion, this study demonstrates that AI-enhanced DFU screening can offer significant cost savings while maintaining high standards of care. By tailoring screening intervals based on individual risk, healthcare systems can improve resource efficiency while maintaining high standards of care. Future research should focus on validating these findings in diverse populations and addressing ethical concerns to ensure that AI-driven healthcare innovations are accessible to all.

Ethics statement

This study was approved by the National Healthcare Group Institutional Domain Specific Ethics Review Board (2019/01045). Informed consent from patients was not required as the study used anonymised administrative data.

Declaration

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