From health economics modelling to artificial intelligence integration: Understanding cost-effectiveness in wound care decision-making

Chronic wounds continue to present clinical and economic burden to healthcare systems worldwide, necessitating more informed and value-driven decision-making processes. This article introduces a comprehensive framework for evaluating the cost-effectiveness of wound care interventions, particularly wound dressings, by integrating health economics approaches and tools such as Markov models, quality-adjusted life years and Monte Carlo simulations. It highlights the limitations of traditional procurement practices focused solely on unit price and advocates for a shift toward total care cost and outcome-based assessments. Through illustrative modelling scenarios, this article demonstrates how more expensive dressings may ultimately offer superior clinical and economic value; for example, by reducing exudate management failures, infection rates, labour intensity and cost, and variability in care outcomes. Furthermore, this article explores the emerging role of artificial intelligence and machine learning in improving the personalisation, predictability and adaptability of cost-effectiveness analyses in real-time clinical environments. The interdisciplinary scientific approach described here aims to guide clinicians, wound care specialists, and healthcare administrators in adopting data-driven, patient-centred strategies that can balance economic efficiency with improved health and quality of life outcomes.

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Key words
- Chronic wounds
- Markov modeling
- Monte Carlo simulations
- Wound dressings
- Value analysis and value-based care

Chronic wounds, including diabetic foot ulcers, venous leg ulcers, and pressure ulcers and injuries, are a major and growing challenge in modern healthcare. These wounds are often difficult to heal, prone to infection, and associated with prolonged treatment durations, frequent healthcare visits and considerable costs. As healthcare systems worldwide face increasing pressure to manage limited resources more efficiently, understanding the true value of wound care interventions, in both prevention and treatment contexts, has become essential, at any management level of wound care (Padula et al, 2019; Kapp et al 2023a, 2023b).

Wound dressings are a particularly interesting topic in this context, as they are relatively low-cost consumables within a healthcare environment, but their application and removal decisions and practice require expensive clinical expertise and work time. Moreover, dressings are the oldest medical devices in history, which implies that extensive information on the cost of their implementation should be available, but that information is underused for health economy studies. Indeed, historically, decisions about wound dressing selection have often focused on (only) comparing the upfront cost of materials or units. However, it is clear that this narrow view fails to account for the broader economic and clinical picture, which is much more complex. For example, a dressing that costs less per unit may require more frequent changes, or lead to more infections, or often fail in exudate management and thereby delay the wound healing, which will ultimately result in greater costs and poorer patient outcomes. Conversely, more expensive dressings might reduce infection risk, or very rarely fail in exudate management, or otherwise (e.g. through biological activity) accelerate the healing, thereby lowering the overall treatment costs and improving quality of life.

To address these important complexities of clinical reality, cost-effectiveness evaluation studies can be designed and conducted, to provide a more comprehensive framework for decision-making. Such comprehensive evaluations consider not only the direct product costs, but also labour, clinical outcomes and timeline of treatment, and overall, the patient well-being over time.

This article introduces fundamental concepts of cost-effectiveness evaluations in wound care, including the use of decision-analytic tools such as Markov models and quality-adjusted life years (QALYs). The article serves both as an educational introduction to the topic of cost-effectiveness in wound care, and as a call to update procurement decision practices based on the contents therein. The information contained here is useful for clinicians, wound care specialists and hospital administrators, who should make themselves familiar with modern health economics methods that support evidence-based decisions, and are able to balance economic efficiency with clinical effectiveness and patient experience, which is pivotal for value-based healthcare.

What is cost-effectiveness in wound care?

Cost-effectiveness in wound care refers to evaluating not only how much a treatment costs, but how much benefit it provides in relation to that cost. In other words, it aims to answer the fundamental question: Are we getting good value for money in terms of patient outcomes?

In the context of wound dressings, this means going beyond the simple comparison of product prices, which is unfortunately the typical practice of "value analysis" committees in healthcare facilities worldwide, and can be a very misleading route to take. While one wound dressing might appear cheaper on the surface, its use in a given clinical setting and for treating certain wound types may require more frequent changes, imply longer healing times, or result in a higher rate of complications, such as infections or exudate leakages causing skin maceration, or common medical adhesive-related skin injuries. These factors can substantially increase the total cost of care. Conversely, a more expensive dressing might reduce these downstream costs by promoting faster healing or preventing such complications, ultimately saving time, resources, and improving patient outcomes.

There are two main types of costs considered in such evaluations:

- Direct costs, which include the price of the dressing itself, ancillary materials (e.g. tapes, cleaning solutions), and any related clinical procedures.
- Indirect costs, which reflect the broader impact on healthcare resources, and especially nursing labour for dressing changes, extended clinic visits, expert time such as podiatrist, vascular or plastic surgeon consultations, hospital stays, and treatment of complications such as infections.

In addition to cost, clinical effectiveness is a critical component. This includes measures like the time it takes for a wound to close (or nearly close), the risk of developing infections, or the rate of wound recurrences. These outcomes not only influence costs but also affect the patient experience and their quality of life. To compare treatments in a structured way, health economists often use a metric known as the incremental cost-effectiveness ratio (ICER; Ghosh et al, 2023). This compares the difference in cost between two interventions with the difference in their effectiveness. A lower ICER indicates better value for money, and in some cases, a new dressing may even be both more effective and less costly, what is known as dominant in economic terms. Ultimately, cost-effectiveness evaluations are not about finding the cheapest product, but about identifying those specific interventions that deliver the most benefit per unit of cost. This shift in thinking, from simple direct cost to (longer-term) value, is fundamental for making informed, evidence-based choices, both clinical and administrative, in wound care.

Overview of Markov models in wound care

Chronic wounds evolve over time, with patients transitioning through different stages of healing, potential complications, and recovery. To capture and formulate these different optional "wound care patient journey" routes through the healthcare system in a structured manner, which would also allow quantitative description of the likelihood of each event (e.g. progress in healing, contracting infection or wound deterioration), health economists often use Markov models. A Markov model is a powerful simulation tool for predicting the long-term costs and outcomes of various medical interventions, including wound care preventative interventions and treatments (Gefen et al 2020; Yaniv et al, 2024).

Specifically, a Markov model breaks the wound healing process into a series of defined health states, such as unhealed wound (non-infected), infected wound, healed wound, or death (either wound-related or unrelated) [Figure 1]. Each virtual patient then "moves" between these possible states in the model over time, at daily, weekly, monthly or any other time intervals, which are called timesteps. At each timestep, a patient may stay in the same state or transition to another, such as from an unhealed wound to a healed wound, or from an infected wound to death, based

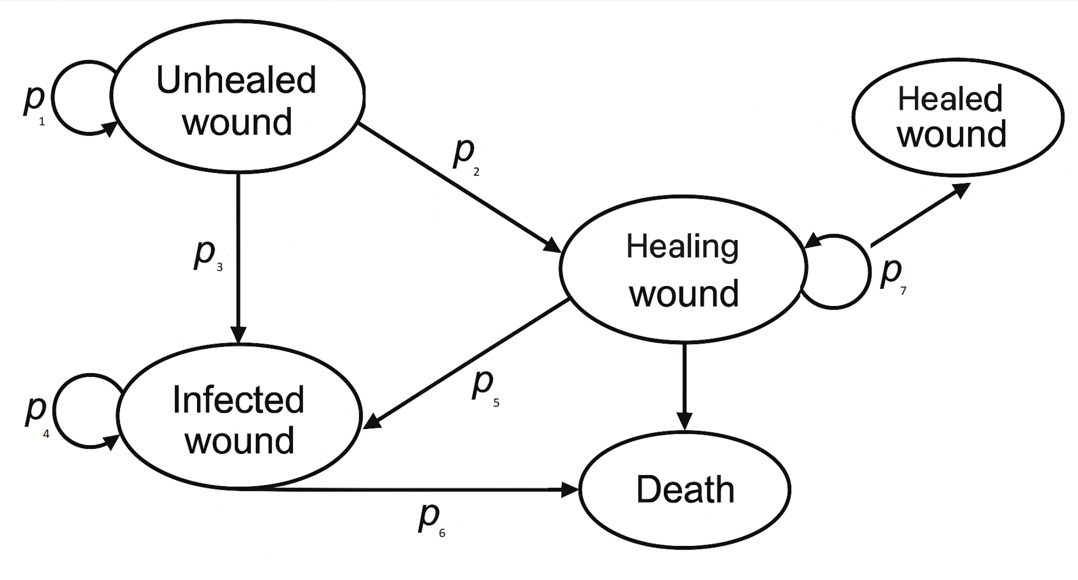

Figure 1

Figure 1. Simplified Markov model for wound progression showing four health states: Unhealed wound, infected wound, healing wound, and death. Arrows represent possible transitions between states (straight arrows), or of remaining within the same state (round arrows), with associated probabilities (p_1, p_2, p_3, ...). This representation of a model includes the possibility of regression, such as reinfection after initial healing. The Death state is called an absorbing state, i.e., once entered, no further transitions occur. Likewise, the healed wound is represented here as absorbing state but this is not necessarily the case, as it can also be assumed that a healed wound can deteriorate, i.e. to reoccurrence. Some relations can exist between the probabilities, e.g. $p_1 + p_2 + p_3 = 1$, which indicates that at each cycle of an unhealed wound state, one of the following can occur: the wound may remain unhealed (with probability p_1) or progress positively to healing (with probability p_2), or become infected (with probability p_3). After a sufficient number of cycles of healing (with probability p_7) elapsed, the wound may be considered clinically healed (sufficiently closed). This model illustrates how patients can move through different wound outcomes over time, allowing calculations of the cumulative cost of care associated with the time intervals spent at each state and the transitioning between states.

on transition probabilities which are derived from clinical data, e.g. epidemiological data. For example, if a particular wound dressing reduces the likelihood of infection by a known extent, patients using that dressing would have a lower probability of transitioning from an unhealed but uninfected wound to an infected wound state. This allows the model to simulate not only the expected clinical pathway but also the accumulation of costs associated with each health state over time, for each virtual patient. This is because each state in the model has associated costs (e.g. dressing and supplementary materials, nursing time, potential infection treatment, need to see a specialist consultant, etc) and outcomes (e.g. quality of life or utility scores being increased or decreased). As many patients move through the model, simulated statistical data accumulates regarding the total expected cost and clinical effectiveness of each wound dressing option which is tested. This allows for a comparison of different treatment strategies over a fixed time horizon.

To illustrate, consider two hypothetical wound dressings, A and B. Dressing A is cheaper per unit but requires more frequent changes and a higher infection rate was observed for patients receiving it. Dressing B costs substantially more per unit but known to need fewer changes for a comparable usage time and the infection risk is lower. A Markov model can quantitatively simulate how these differences affect both the cost and health outcomes over time, in a population of patients, and based on that, identify which dressing provides better value overall, not just in unit price, but in cost-effectiveness. One of the key strengths of Markov models is their ability to reflect realistic clinical pathways for certain patient populations. Wound healing is rarely linear, patients may regress (e.g. develop an infection after initial progress), plateau or experience recurrent wounds. Some patients may have risk factors or underlying conditions relevant to wound healing, e.g. diabetes, vascular disease, or immune system disorders. By accommodating these complexities and representing such sub-populations, a Markov model provide a more accurate, time-based view of treatment performance and resource use. Hence, Markov modelling offers a structured, evidence-based framework for comparing wound dressing strategies, not just by their immediate effects, but by their broader impact on healing trajectories, costs, and outcomes over time.

Incorporating quality of life and uncertainty

In cost-effectiveness evaluations, clinical outcomes and costs alone do not provide the full picture, particularly in chronic wound care, where patient comfort, mobility, and well-being are critical. To address this, health economists incorporate quality of life into economic models using a measure called the quality-adjusted life year (QALY). A QALY combines both the quantity and quality of the life lived. Each health state, such as an unhealed wound, an infected wound, or a progressing (healing) wound, is assigned a utility value between 0 (equivalent to death) and 1 (perfect health). For example, an infected wound may have a utility value of 0.5 (due to pain, immobility, or risk of hospitalisation), whereas a healing wound may be rated at 0.75, and a fully recovered or asymptomatic patient may approach 1.0. The total QALYs gained from a treatment over a given period is calculated by multiplying the time spent in each health state by its respective utility. This allows treatments to be evaluated not only in terms of whether they work, but how well they support the patient's well-being during the healing process.

When comparing two wound dressings, for instance, a more expensive option may yield higher QALYs by reducing pain or accelerating the recovery. The ICER then expresses the additional cost per additional QALY gained, providing a standardised way to compare interventions across wound care, and even across other medical specialties [Box 1].

In addition to quality of life, uncertainty is a key element in any real-world healthcare decision. Not every patient responds the same way to a wound dressing, and costs may vary between patient populations and settings. To address this, Monte Carlo simulations are commonly used. These simulations randomly vary key input values fed into the Markov model, such as the age and gender of patients, or their susceptibility to infection (e.g. patients receiving chemotherapy or who are otherwise immunodeficient are more likely to contract infections) or to recover from infection (which is lower, e.g. if they have vascular disease or diabetes). Thousands of iterations or more can be run by the computer to simulate the cost of treating each virtual patient with their randomly selected patient-specific conditions and associated set of probabilities [Figure 1]. This eventually results in a distribution of simulated costs and clinical outcomes, which allows decision-makers to understand the range of possible costs and clinical outcomes, and identify best-case and worst-case scenarios. By combining QALYs and Monte Carlo methods, cost-effectiveness evaluations in wound care thus become more robust and reflective of real-world, clinically relevant conditions. These computer modelling frameworks hence support evidence-based decisions that prioritise not only budget efficiency, short and long-term, but also meaningful improvements in patient health and experience.

Demonstrative example and simulation insights

To demonstrate how cost-effectiveness evaluations work in practice, let us explore a simplified example comparing two hypothetical wound dressings, dressing X and dressing Y, used over a 26-week period for patients with chronic wounds [Table 1].

While dressing X is cheaper per unit, it requires twice as many changes and results in greater infection rates. In contrast, dressing Y costs more upfront, but reduces both the labour costs and infection-related complications. When the full costs, including nursing time and additional treatments, are accounted for, the total cost per patient may look like Table 2.

Despite the higher unit price, dressing B results in a substantially lower overall cost. Additionally, it improves healing outcomes and reduces infection rates, potentially translating into a higher QALY gain for patients.

With that said, when treating a patient population where complications are more frequent and labour demands are higher, costs will rise considerably; for example, if dressing

Box 1. Quality-adjusted life year.

A **quality-adjusted life year (QALY)** is a standardised measure used in health economics to assess the value of medical interventions. A QALY is the change in utility value induced by a treatment multiplied by the duration of effect of that treatment, i.e., it combines both the **quality of life** and **length of life** into a single metric:

QALY = (utility value of a state) × (time spent in that health state)

A single (one) **QALY** can represent **one year of life in perfect health**. If a treatment results in one year of life at a quality of life valued at 0.5, e.g., due to moderate pain or limited mobility, then the QALY equals **0.5**. Utility values always range between 0 (equivalent to death) and 1 (perfect health), and are typically derived from patient surveys or clinical studies. Use of QALYs enables comparisons of the **effectiveness of different treatments**, not just in terms of survival, but also how well they support the functional and emotional well-being of patients.

Table 1: Characteristics of two hypothetical wound dressings.

Criteria	Dressing X	Dressing Y
Unit cost per dressing	$10	$25
Dressing changes/week	2	1
Infection probability for the 26-week period	20%	10%
Healing rate (26 weeks)	50%	60%

Table 2: Cost per patient of using each of the two hypothetical wound dressings.

Criteria	Dressing X	Dressing Y
Dressing cost*	$520	$650
Nursing labour ($50/week)**	$2,600	$1,300
Infection treatment ($500 per case)	$500 × 20% = $100	$500 × 10% = $50
Total cost per patient	**$3,220**	**$2,000**

** Usage time of 26 weeks × change frequency × unit cost*
*** Usage time of 26 weeks × hourly cost ($50 per week) × change frequency*

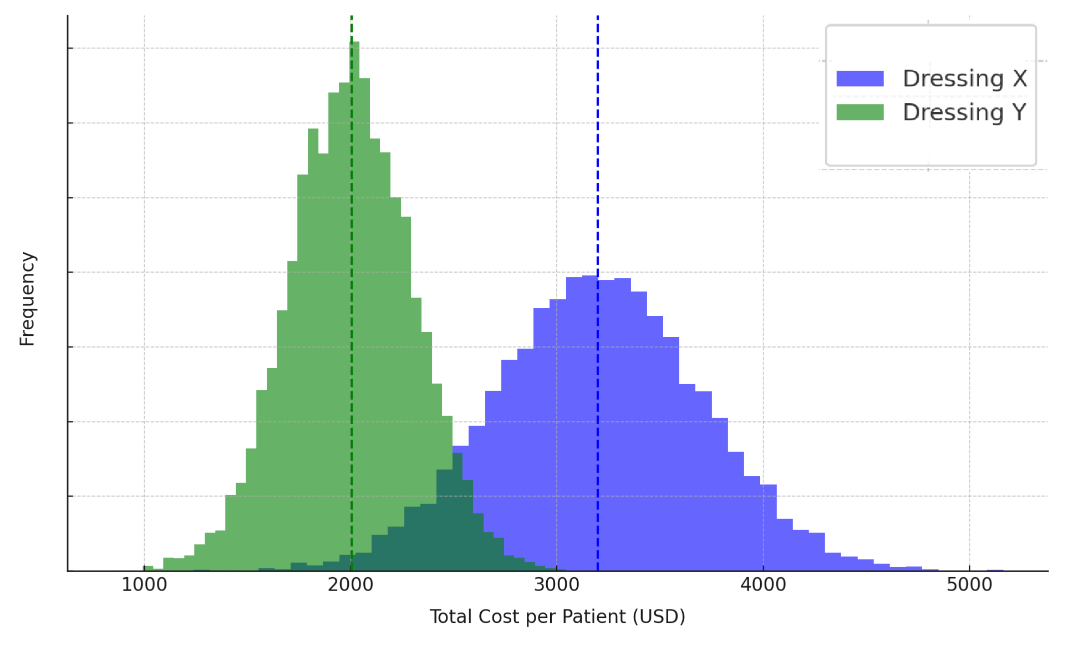

Figure 2

Figure 2. Illustration of Monte Carlo simulation results showing cost distributions for the two hypothetical wound dressings discussed here, dressings X and Y. Dressing X exhibits a wide spread in total costs due to higher variability in infection rates and treatment needs, while dressing Y shows a narrower, and importantly, more predictable cost distribution. Dashed lines indicate the mean cost for each dressing, and the uncertainty in cost is represented by means of the histograms. This example illustrates how the more expensive dressing Y can result in more consistent, predictable and potentially lower total costs compared to a less expensive dressing if only evaluated by unit price (dressing X).

Y is applied to treat a high-risk patient group (e.g. patients receiving chemotherapy) where the infection probability is 35%, and patients with infected wounds require two changes per week, the cost per patient (using the same dressing) will rise to $1,300 (dressing cost) + $2,600 (nursing labour) + $175 (for expected infection-related costs, 0.35 × $500) = $4,075. This highlights the need for a tailored dressing selection based on patient characteristics, not just product pricing.

To reflect uncertainty in costs, healing rates, and infection probabilities, Monte Carlo simulations can further be used. These models input probability distributions for key variables, such as dressing costs, labour rates and infection outcomes, and run thousands of iterations to simulate a wide range of possible real-world scenarios. In such simulations, dressing X might show a wide cost distribution, with some patients experiencing high costs due to frequent infections, and dressing Y, while more expensive per unit, may demonstrate lower variability and more predictable cost outcomes across different scenarios [Figure 2]. This type of analysis helps healthcare providers and policymakers assess not only which treatment is likely to be more cost-effective on average, but also which one offers more consistent value and carries less financial risk.

Key takeaways for clinicians and decision-makers

Cost-effectiveness analyses as explained in this article offer a comprehensive, patient-centred framework for evaluating wound dressings. Shifting from price-based decisions to value-based assessments empowers healthcare providers to make smarter, evidence-driven choices that improve both clinical and patient outcomes and the financial sustainability. Key takeaways for implementation of these concepts are:

- **Unit cost is never the full story:** While wound dressing prices are often the first and easiest comparison point in procurement or clinical decision-making, they are only one component of the total care cost, and not necessarily the most expensive component. A dressing with a lower unit price may lead to higher overall costs due to increased labour, more frequent changes, or higher likelihood of complications such as infections, failure in exudate management and delayed healing.
- **Always consider the total cost of care when making purchase decisions:** Effective wound management must account for both direct and indirect costs. These include not only the dressing materials, but also any ancillary materials needed for the wound care (as related to the dressing type selection or not), nursing time, specialist consultations, and the costs of managing complications (coupled with the likelihood of complications to occur). A higher-cost dressing may be more cost-effective if it reduces dressing change frequency and therefore the labour time of clinicians, or shortens healing times, or lowers complication rates, or any combination of these.

- **The clinical outcomes are a key consideration in purchase decisions:** Clinical effectiveness, especially the ability of a dressing to support healing, properly manage exudate and prevent infections, directly affects both cost and patient well-being. Improved healing outcomes not only reduce healthcare utilisation but also enhance patient quality of life, which is measurable through QALYs. The impact of purchase decisions on the clinical outcomes should be regularly evaluated to assess whether and how the outcomes were affected by a change of product or introduction of new product.
- **Adopt and use evidence-based validated decision-analytic tools:** Decision-analytic frameworks such as the Markov models and Monte Carlo simulations discussed here can provide robust, quantitative insights into treatment value over time, after being appropriately adjusted to the clinical setting and validated against historical data. These tools allow clinicians and administrators to assess not just average outcomes, but also variability and risk under real-world conditions.
- **How treatment affects the quality of life of patients is a key metric:** Treatments should be evaluated not only based on how well they heal wounds in the short-term, but also with respect to how they affect the patient experience. Health economy measures such as QALYs enable standardised comparisons by combining clinical effectiveness with quality-of-life considerations.
- **Tailor decisions to patient populations:** No single dressing is optimal for all patients. Factors such as age, skin fragility, systemic comorbidities, the wound aetiology, infection risk, and the specific care setting should inform dressing selection to maximise cost-effectiveness, clinical and quality of life outcomes in specific patient groups.
- **Predictability and consistency of costs are valuable:** In addition to lower mean costs, wound care treatments, including selection of dressings with more predictable outcomes can reduce the financial and logistical burdens on healthcare institutes and systems. Reduced variability in performance is particularly important in resource-constrained environments, and should be seen as integral to financial risk management of the institution.

Integrating AI with health economics models in wound care

As healthcare systems increasingly adopt

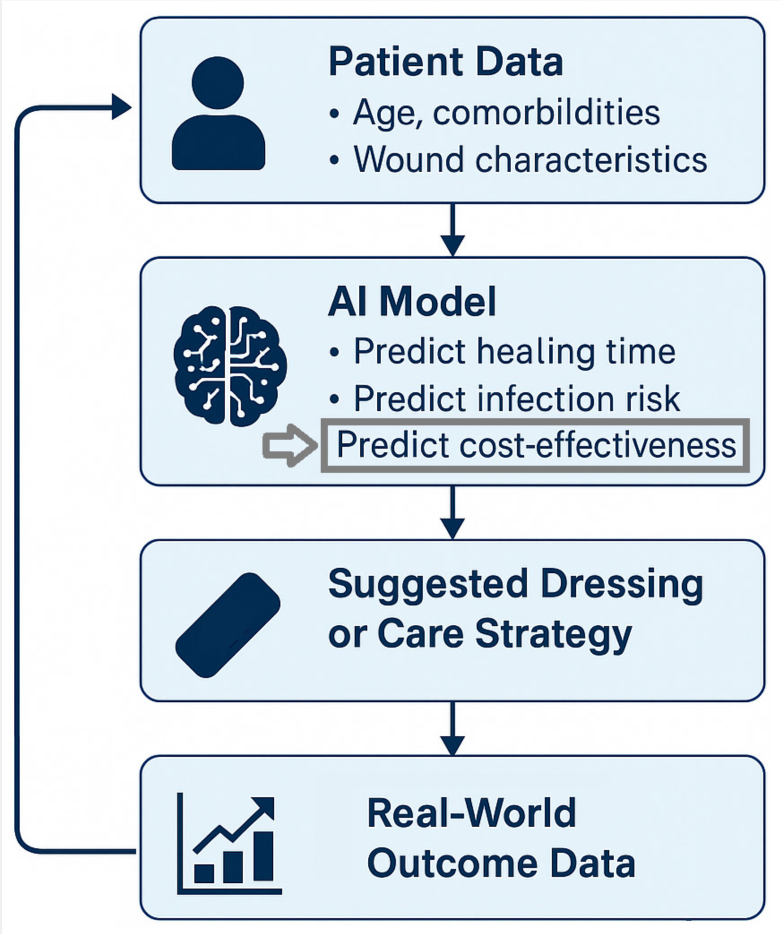

Figure 3

Figure 3. Concept for AI-supported decision-making tool in wound care utilising a data-driven personalisation approach. Supervised machine learning (ML) models can effectively forecast clinical outcomes such as the healing time, an infection risk, or the likelihood of wound recurrence based on data mining of patient profiles, information in the electronic health records and individual or group treatment histories. These predictions can then feed into health economics models in order to better estimate the long-term costs and benefits of different wound dressings or wound care strategies. As new data accumulates regarding the impact of the implemented treatment technologies (or practices) on clinical outcomes or quality of life, it can be fed back to the AI/ML system to refine cost-effectiveness predictions.

digital solutions, artificial intelligence (AI) presents a powerful opportunity to enhance not only research and development but also cost-effectiveness modelling in wound care (Gefen, 2025). While Markov models and Monte Carlo simulations already provide robust frameworks for evaluating clinical and economic outcomes, their predictive power and adaptability can be significantly further amplified when integrated with AI techniques, particularly with machine learning (ML). Health economics models can be empowered by AI in several key ways:

- **Data-driven personalisation:** Machine learning algorithms can analyse large datasets from electronic health records (EHRs), as well as from wearable sensors and imaging platforms to identify patient-specific factors that influence the wound healing trajectories, such as comorbidities, wound aetiology and characteristics, or relevant biomarker trends. These insights can inform or refine the transition probabilities within Markov models [Figure 1], enabling more individualised and dynamic simulations.

- **Predictive modelling of clinical outcomes:** Supervised ML models can effectively forecast clinical outcomes such as healing time, infection risk, or likelihood of recurrence based on data mining of patient profiles, EHR information and treatment histories. These predictions can then feed into health economics models in order to better estimate the long-term costs and benefits of different wound dressings or wound care strategies [Figure 3].
- **Real-time decision support:** AI-enhanced simulations can be embedded into clinical decision support systems, helping clinicians choose the most cost-effective dressings for their patients in real time, based on current patient data and institutional cost structures. This would shift cost-effectiveness modelling frameworks from being purely retrospective analyses to becoming point-of-care, real-time tools.
- **Optimisation and scenario planning:** Reinforcement learning and other advanced AI techniques can help identify optimal treatment strategies over time, especially in complex, resource-constrained environments. The AI can simulate thousands of scenarios rapidly to guide policy and procurement decisions under uncertainty.
- **Continuous learning and model updating:** Unlike static models, AI-powered systems can continuously learn from newly collected clinical data, improving their accuracy and relevance over time. This adaptive capability supports real-world implementation and evolution of cost-effectiveness tools as clinical practices and technologies continue to evolve.

Importantly, it should be noted that integrating AI with current health economics modelling also pose challenges, including data quality and reliability, model transparency, and the need for clinical validation. However, the synergy between the predictive capabilities of AI and the structured economic logic of current Markov and Monte Carlo models offers a compelling path forward. Future research and pilot programs should, therefore, explore this promising convergence, aiming to deliver precision-guided, value-based wound care that dynamically adapts to patient needs and healthcare system constraints. ●

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