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ORIGINAL RESEARCH ARTICLE

Cost-Utility Analysis of the Caresyntax Platform to Identify Patients at Risk of Surgical Site Infection Undergoing Colorectal Surgery

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Abstract

Background Surgical site infections (SSIs) account for up to 18% of all healthcare-associated infections (HAIs). The Caresyntax data-driven surgery platform incorporates the most common risk factors for SSI, to identify high-risk surgical patients before they leave the operating theatre and treat them prophylactically with negative pressure wound therapy (NPWT). An economic analysis was performed to assess the costs and health outcomes associated with introduction of the technology in the English healthcare setting.

Methods A hybrid decision tree/Markov model was developed to reflect the treatment pathways that patients undergoing colorectal surgery would typically follow, both over the short term (30-day hospital setting) and long term (lifetime). The analysis considered implementation of Caresyntax's platform-based SSI predictive algorithm in the hospital setting, compared with standard of care, from an English National Health Service (NHS) perspective. The base-case analysis presents results in terms of cost per quality-adjusted life-year (QALY) gained, as well as operational impact.

Results The base-case analysis indicates that the intervention leads to a cost saving of £55.52m across the total NHS colorectal surgery patient population in 1 year. In addition, the intervention has a 98.36% probability of being cost effective over a lifetime horizon. The intervention results in the avoidance of 19,744 SSI events, as well 191,911 excess hospital bed days saved.

Conclusion Caresyntax's platform-based SSI predictive algorithm has the potential to result in cost savings and improved patient quality of life. Additionally, operational gains for the healthcare provider, including reduced infection rates and hospital bed days saved, have been shown through the economic modeling.

1 Introduction

Healthcare-associated infections (HAIs), which arise as a direct result of a medical or surgical procedure, or due to direct contact with a particular healthcare setting [1], have a European-wide prevalence rate ranging from 4.6 to 9.3% [2]. English national health survey data indicate that the three

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Key Points for Decision Makers

Economic modeling results indicate that Caresyntax's platform-based SSI predictive algorithm has a 98.36% probability of being cost effective, and a 94.54% probability of being cost saving, compared with standard of care.

Given the estimated population size undergoing colorectal surgery, the intervention has the potential to lead to cost savings in excess of £55 million over 1 year for the English NHS. In addition, the platform would lead to lower SSI rates and reduced hospital bed days.

Despite certain data limitations in the existing economic analysis, a robust economic model exists for re-analysis once further data become available. The model may be utilized by decision makers to inform optimal management of colorectal surgery patients to achieve reduced SSI rates.

most commonly occurring HAIs in acute care hospitals are pneumonia and other respiratory infections (22.8%), urinary tract infections (UTIs) (17.2%), and surgical site infections (SSIs) (15.7%) [3]. Presenting as an infection which occurs in the part of the body where the surgery took place, SSIs are estimated to account for up to 18% of all HAIs, with the rate varying depending on the type of procedure received [3–6]. Major sources of infection are microorganisms (most commonly, Gram-positive bacteria such as *Staphylococcus aureus*) on the patient's skin and, on occasion, the alimentary tract or female genital tract [7, 8]. The most common risk factors for SSIs include old age, a compromised immune system, poor nutritional status, infection or colonization at a remote body site, and the length of the patient's pre-operative stay (increasing exposure to pathogens) [7].

Surgical site infections are associated with significant morbidity and mortality, with patients experiencing SSIs at an increased risk of death and 60% more likely to be admitted to the intensive care unit (ICU). Additionally, it is estimated that patients are more than five times more likely to be readmitted to hospital following discharge due to occurrence of an SSI [7]. Due to their impact on the re-hospitalization rate, and the need for additional treatments in the aftermath of infection, the economic burden associated with SSIs is also significant. Totty et al. explored the impact of SSIs on hospitalization rates, treatment costs, and patient health-related quality of life (HRQoL) following vascular surgery, based on data from 144 patients at a large teaching hospital in England. Their study showed that SSIs were associated with 9.72 days' length of stay in hospital (92% increase in length of stay [$p < 0.001$]), with an additional cost of £3776.00 per patient (including a mean antibiotic cost of £532.00), with increased readmission rates due to SSI ($p = 0.017$) [9]. At a population level, SSIs are estimated to cost the National Health Service (NHS) in the UK approximately £700 million per annum [10].

Most SSIs can be treated with antibiotics, with the type of bacteria causing the infection determining the choice of antibiotic used, although further surgery may be required to treat some infections [11]. Alternative interventions take a preventative approach, with the efficacy of negative pressure wound therapy (NPWT) for the prevention of SSIs demonstrated in previous studies [12, 13]. Guidelines have been developed for the prevention and management of SSIs in England, with extensive recommendations developed for both healthcare professionals and patients during the pre-operative, intra-operative, and post-operative phases of surgery (National Institute for Health and Care Excellence [NICE] National Guidelines [NG] 125) [14]. Despite this, there remains a lack of standardized methodology for post-discharge surveillance, which leads to a limited understanding, and potential under-reporting, of SSIs in the post-acute and home care areas [15]. This is a particularly challenging aspect to the prevention of SSIs, given that most infections only become apparent after discharge from hospital [15]. For these reasons, the early identification of patients at high risk of SSIs in the hospital setting is imperative to reducing SSI rates and lowering their associated economic impact.

The Caresyntax data-driven surgery platform has been developed with the goal of improving patient outcomes through a combination of real-world analytics, ambient support technologies, and artificial intelligence applications. One of the applications of the platform is to estimate the risk of post-operative SSI using patients' pre- and intra-operative data, enabling the stratification of patients into risk categories for the occurrence of SSI. The platform allows for the identification of those patients at high risk of experiencing an SSI while still in the operating theatre, enabling the implementation of a clinically proven, preventative intervention such as NPWT, to reduce the risk of post-operative SSI [16]. A 13-item predictive machine-learning algorithm based upon the most commonly reported risk factors for SSI was validated against an appropriate clinical data source (comprising 3440 surgical patients) and is the basis for SSI prediction in this platform. Of the 13 items, there are eight pre-operative and five intra-operative characteristics used to identify at-risk patients before they leave the theatre [17].

This study assesses the costs and health outcomes associated with the introduction of a predictive risk stratification application (Caresyntax platform from Caresyntax Corporation, Inc.) prior to use of NPWT, in the English NHS setting. An economic decision model was developed to assess the cost effectiveness of using the Caresyntax platform in NHS hospitals, amongst a patient population undergoing colorectal surgery who are at potential risk of SSI.

2 Methods

A hybrid decision tree/Markov model was developed to estimate costs and health outcomes over the short- and long-term, compared with standard of care amongst a cohort of patients undergoing colorectal surgery. The short-term decision tree model captures health outcomes up to 30 days (duration up to hospital discharge), with the long-term Markov model capturing patient survival over a lifetime horizon. The basis of the economic modeling hypothesis is that accurately identifying those patients who are likely to experience SSI at an early stage in the patient treatment pathway has the potential to reduce short-term adverse healthcare-related outcomes, including readmission rates and extended hospital stays, while improving long-term patient survival and quality of life (QoL). Clinical experts were consulted to inform the clinical plausibility and accuracy of the economic model, as well as the model assumptions. An independent health economist with a clinical background (MRH) was consulted during the model development process, while a range of clinical experts provided input related to model parameter assumptions (acknowledged in the Statements and Declarations). Consensus was reached between experts based on a simple majority rule.

The economic analysis was performed from an English NHS and personal social services (PSS) perspective, with a discount rate of 3.5% applied, as recommended in the NICE methods guide for treatments that result in long-term health benefits [18]. The Professional Society for Health Economics and Outcomes Research (ISPOR)'s 'Principles of Good Practice for Decision Analytic Modeling in Health-Care Evaluation' guidelines were followed in developing and populating the model [19].

2.1 Description of the Comparators

The economic model structure is presented in Fig. 1. Patients who are undergoing surgery enter the short-term decision tree model by either receiving evaluation for risk of SSI with the Caresyntax platform (intervention) or not (comparator), i.e., standard of care. All patients in the comparator arm either receive NPWT or not, with evaluation of subsequent risk of SSI based on clinical assessment alone. Patients in the comparator arm may then either experience SSI or not, with differing probabilities depending on whether the patient received previous NPWT or not. Patients experiencing SSI may require a hospital readmission or an extended hospital stay, with both of these outcomes modeled. The probabilities of requiring either hospital readmission or extended hospital stay are the same regardless of whether patients received previous NPWT or not and are incurred only in the event of SSI. Finally, the 30-day decision tree model structure for the comparator arm ends by capturing the proportion of patients either alive or dead at discharge.

In the intervention arm of the model, patients are initially evaluated using the Caresyntax platform and are categorized into 'positive' or 'negative' groups on the basis of the results, which are indicative of the likelihood of patients experiencing a subsequent SSI. However, the accuracy of the Caresyntax platform in identifying patients who are likely to experience SSI is also considered, with patients being further distinguished into the diagnostic categories of 'true positive' (TP), 'false positive' (FP), 'true negative' (TN), and 'false negative' (FN). These diagnostic categories are considered for the purpose of estimating model outcomes only, while in clinical practice patients who are 'positive' would progress to receive NPWT, and patients who are 'negative' would not receive NPWT. Therefore, in the model, all TP and FN patients (i.e., all positive patients) are at risk of experiencing a subsequent SSI, but only patients in the TP arm of the model undergo NPWT as these patients have been accurately identified as being at risk of SSI with the Caresyntax platform. FN patients, on the other hand, have been inaccurately identified as negative despite being at risk of SSI and do not receive NPWT. Therefore, the improved outcomes (i.e., reduced SSI rates, subsequent readmission, and reduced hospital resource utilization) amongst the TP cohort through use of the Caresyntax platform and NPWT is captured in the model. All FP and TN patients (i.e., all negative patients) do not experience a subsequent SSI and will not be readmitted or incur an extended hospital stay.

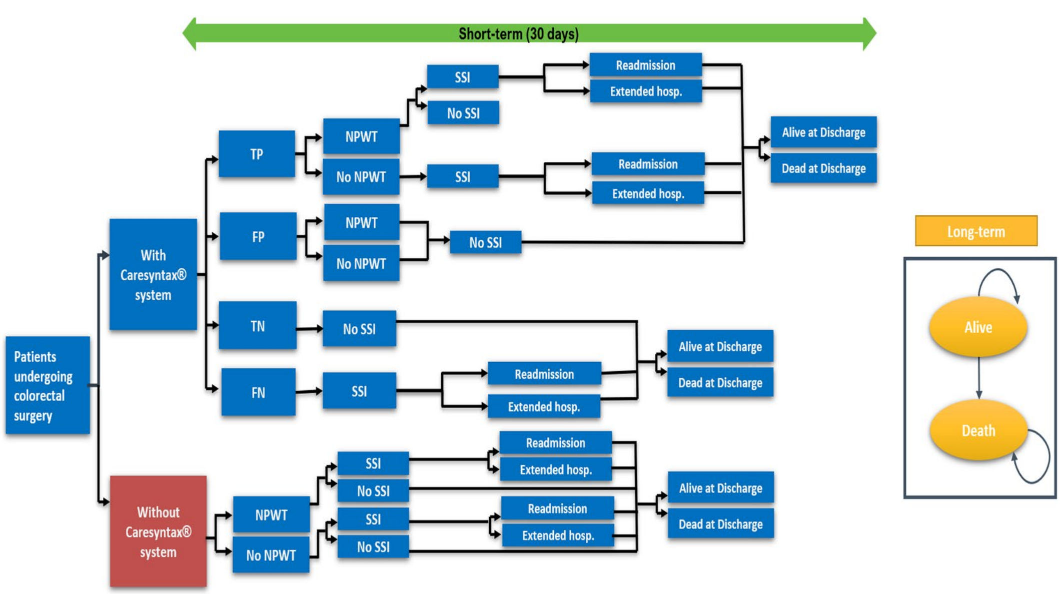

Fig. 1 Decision tree and Markov model structure. *FN* false negative, *FP* false positive, *NPWT* negative pressure wound therapy, *SSI* surgical site infection, *TN* true negative, *TP* true positive

However, the unnecessary utilization of resources through performance of NPWT amongst the FP patient group is captured in the analysis. As in the comparator arm, patients in the intervention arm are categorized as either being alive or dead at discharge.

Following the decision tree model, all patients who are alive at discharge in each arm of the model enter a Markov model where their long-term survival is captured (1-year cycle length).

2.2 Model Inputs

All model inputs (clinical, utility, and cost parameters) are outlined in the following sections. Model input values, as well as assigned distributions and ranges of values, are presented in Table 1.

2.2.1 Clinical Effectiveness Parameters

In the base-case analysis, the incidence rate of SSI following colorectal surgery was informed by data from a study by Falconer et al., which assessed a quality improvement approach for reducing SSI in colorectal surgery [20]. This study looked at SSI rates, reported by type and endoscopic status, in pre- and post-intervention periods. Alternative data from studies by Tanner et al. [28], and Woods et al. [17] were used to explore the uncertainty surrounding this value in scenario analysis (see 'Analysis' section). Information on the diagnostic accuracy (sensitivity and specificity) of the Caresyntax platform was obtained from Woods et al., which explored the clinical and economic value of the platform [17]. In the base-case analysis, a sensitivity of 81.00% and specificity of 78.00% was applied based on the required presence of four or more risk factors. Alternative combinations of sensitivity and specificity were explored in scenario analysis based on differing diagnostic accuracy values reported in Woods et al., according to the reported cut-score threshold [17].

Data on the utilization of NPWT following a positive Caresyntax result, and on the utilization of NPWT in the standard-of-care arm of the model (i.e., compliance of surgeons in delivering the technique) were estimated based on assumption and clinical expert opinion, respectively (100% and 50.00% compliance rates assumed for the intervention arm and the standard-of-care arm, respectively). Previous observational studies, which performed non-randomized comparisons between NPWT and standard wound dressing for the prevention of SSI, were identified [29–32], with data indicating that use of NPWT amongst surgical patients may range from 12.60% to 54.45% without prior diagnostic intervention, which validated the 50.00% value applied in the base-case analysis for the standard-of-care arm. The uncertainty surrounding these values was also explored in sensitivity analysis, and in scenario analysis. Finally, the relative risk of SSI associated with NPWT was estimated at 0.49, based on data from Strugala and Martin, which involved a meta-analysis of comparative trials evaluating a prophylactic single-use NPWT system for the prevention of surgical site complications. This figure was estimated based on a fixed-effects meta-analysis of 10 RCTs of varying patient numbers (fixed effects relative risk, 0.49, 95% CI 0.34–0.69; $p < 0.00001$) [21].

2.2.2 Utilities and Mortality

The mean 7-day and 30-day utility values associated with SSI/no SSI were obtained from NICE NG125 for the prevention and management of SSIs in England, which reported a health economic modeling study to assess the costs and health outcomes associated with alternative strategies for the prevention of SSI [14]. In this economic model, utility values were sourced from a study by Pinkney et al., 2013, which assessed EQ-5D at baseline and post-operatively amongst 735 laparotomy patients in the UK [33] and was deemed to be closest to NICE's reference case [34]. In this study, SSI occurred amongst 184 patients, which allowed the associated impact on utility to be assessed [33]. The 7-day and 30-day utility values (with and without SSI) were weighted to create parameters to account for utility with and without SSI at 30 days. Therefore, the utility of patients with SSI at 30 days was estimated based on a calculation which considered the utility of patients over the first 7 days, and the utility of patients over the remaining 23 days of the month. The same method was applied to calculate the utility of patients without SSI at 30 days. These parameters were used to calculate overall utility in each arm of the model at 30 days, with subsequent utility values utilized in the Markov component of the model based on age-related utility decrements.

Information on the 30-day mortality rate after colorectal surgery was obtained from Byrne et al., which involved a population-based cohort study comparing 30-day and 90-day mortality rates after colorectal surgery [22]. The additional risk of mortality associated with SSI was obtained from a systematic review and meta-analysis by Zywot et al. 2017 [23]. The hazard ratio of mortality with SSI was consequently calculated as 1.37. The utility values, and mortality rates, considered in the short-term model had an impact on the cumulative life-years, and quality-adjusted life-years (QALYs), lived over the long term, which were captured in the Markov model.

2.2.3 Healthcare Resource Use and Costs

The proportion of SSI cases that require readmission was estimated at 18.00%, using data from the surveillance of SSIs in NHS hospitals in England from April 2019 to March

Table 1 Model input parameters

Parameter	Base-case value	Distribution	Distribution parameter	Sensitivity analysis range (low–high value)	References
Clinical inputs					
SSI incidence rate following colorectal surgery	16.40%	Beta (α,β)	$\alpha = 321.16$ $\beta = 1637.12$	15.00–18.00%	Falconer et al. 2021 [20]
Sensitivity of Caresyntax platform	81.00%	Beta (α,β)	$\alpha = 10.14$ $\beta = 2.36$	55.00–98.00%	Woods et al. 2022 [17]
Specificity of Caresyntax platform	78.00%	Beta (α,β)	$\alpha = 44.51$ $\beta = 12.92$	67.00–88.00%	Woods et al. 2022 [17]
Compliance rate amongst surgeons in delivering NPWT following positive Caresyntax platform results	100%	Fixed		80.00–100%	Assumption
Compliance rate amongst surgeons in delivering NPWT with standard of care	50.00%	Beta (α,β)	$\alpha = 48.02$ $\beta = 48.02$	40.00–60.00%	Expert opinion
Relative risk of SSI associated with NPWT	0.49	Beta (α,β)	$\alpha = 15.36$ $\beta = 15.99$	0.34–0.69	Strugala and Martin 2017 [21]
Utility and mortality inputs					
Mean 7-day utility score with SSI	0.50	Beta (α,β)	$\alpha = 136.72$ $\beta = 134.55$	0.45–0.56	NICE guidelines (NG125) [14]
Mean 7-day utility score without SSI	0.53	Beta (α,β)	$\alpha = 559.78$ $\beta = 504.44$	0.50–0.56	NICE guidelines (NG125) [14]
Mean 30-day utility score with SSI	0.65	Beta (α,β)	$\alpha = 236.30$ $\beta = 130.06$	0.60–0.69	NICE guidelines (NG125) [14]
Mean 30-day utility score without SSI	0.73	Beta (α,β)	$\alpha = 786.33$ $\beta = 289.36$	0.70–0.76	NICE guidelines (NG125) [14]
30-day mortality rate after colorectal surgery	8.50%	Beta (α,β)	$\alpha = 351.51$ $\beta = 3783.86$	7.65–9.35%	Byrne et al. 2013 [22]
Additional risk of SSI mortality following colorectal surgery	3.00%	Beta (α,β)	$\alpha = 372.64$ $\beta = 12{,}048.54$	2.70–3.30%	Zywot et al. 2017 [23]
Mortality with SSI (hazard ratio)	1.37	Fixed			Calculation (mortality rate calculated based on data from Byrne et al. 2013 [22] and Zywot et al. 2017 [23])
Healthcare resource use and cost inputs					
Proportion of SSI cases that require readmission	18.00%	Fixed			Calculated from NHS England data 2019–20 [24]
SSI inpatient and readmission	8.00%	Beta (α,β)	$\alpha = 1516.76$ $\beta = 16{,}757.49$	8.00–9.00%	NHS England data 2019–20 [24]
SSI inpatient	7.00%	Beta (α,β)	$\alpha = 1034.73$ $\beta = 14{,}181.85$	6.00–7.00%	NHS England data 2019–20 [24]
Mean SSI-related extended length of stay (days)	9.72	Gamma (α,β)	$\alpha = 384.16$ $\beta = 0.03$	8.75–10.69	Totty et al. 2021 [9]
Caresyntax platform monthly subscription (£)	4407.00	Fixed			Caresyntax Corporation, Inc. [16]
Average cost of Caresyntax platform per patient per month (£)	67.83	Fixed			Calculation
Additional staff (nurse) time to use the Caresyntax platform per patient (£)	2.00	Fixed			Clinical expert input
Average cost of staff (nurse) time per hour (£)	51.00	Fixed			PSSRU 2021 [25]

Table 1 (continued)

Parameter	Base-case value	Distribution	Distribution parameter	Sensitivity analysis range (low–high value)	References
Average cost of Caresyntax platform plus staff time per patient (£)	69.53	Fixed			Calculation
Cost of NPWT per kit (£)	130.00	Gamma (α,β)	$\alpha = 384.16$ $\beta = 0.34$	117.00–143.00	Medical technologies guidance (MTG43) [26]
Proportion of patients for whom the NPWT needs to be replaced one time	10.00%	Beta (α,β)	$\alpha = 345.74$ $\beta = 3111.70$	9.00–11.00%	Assumption
Cost of an additional hospitalization stay due to SSI (per day) (£)	375.43	Gamma (α,β)	$\alpha = 384.16$ $\beta = 0.98$	337.89–412.98	Totty et al. 2021 [9]
Cost of readmission due to SSI episode (£)	5740.00	Gamma (α,β)	$\alpha = 384.16$ $\beta = 14.94$	5165.98–6313.98	NHS Reference Costs 2021 [27]
Mean antibiotic cost (£)	598.43	Gamma (α,β)	$\alpha = 384.16$ $\beta = 1.56$	538.58–658.27	Totty et al. 2021 [9]

NPWT negative pressure wound therapy, *PSSRU* personal social services research unit, *SSI* surgical site infection

2020 [24]. This value was calculated using information on the percentage of patients undergoing large bowel surgery who required inpatient services only, and who required inpatient services and readmission (Table 1) [24]. Data from Totty et al. were used to inform the mean number of excess hospital days that would be required due to the occurrence of SSI (9.72) [9], with alternative data from Coello et al. explored in scenario analysis [35]. The monthly subscription price of the Caresyntax platform of £4407.00 was obtained from the Caresyntax Corporation and was used in the base-case analysis [16]. This price, combined with data from NHS Digital on the number of hospitals in England (541), the average number of operating theatres per hospital (4), and the number of patients undergoing a surgical procedure that could benefit from the Caresyntax platform (1,687,053 patients across colorectal, cardiac, and orthopedic indications) [36], were used to estimate the average cost of using the Caresyntax platform per patient per month. Staff nurse time was also considered to calculate a final cost per patient for the base-case analysis, inclusive of costs associated with healthcare staff (£69.53) [25].

The cost of an NPWT kit was calculated based on information from NICE MTG43 (£130.00) [26], with an assumption that an additional 10.00% of patients would require a replacement NPWT. The cost of an additional hospitalization day due to SSI was calculated at £375.43, with the mean antibiotic cost calculated at £598.43, based on data from Totty et al. [9]. Finally, the cost of a readmission episode was estimated at £5740.00, based on data from the NHS Reference Costs 2020–2021 [27]. Costs and healthcare resource utilization were only considered in the short-term model, with no costs incurred in the Markov model (only long-term survival and QoL). All costs included in the model were valued at a 2021 price year (£).

2.3 Analysis

2.3.1 Base-Case Analysis

A cost-utility analysis was performed to assess the cost per QALY gained associated with introducing the Caresyntax platform in England, compared with the standard of care. In addition, the change in the number of SSI events incurred following the introduction of the platform, and the number of SSI-related excess hospital bed days that would be avoided following the introduction of the intervention, were estimated. The base-case cost-utility analysis was run probabilistically so that the level of confidence in the output of the analysis could be quantified. Probabilistic analyses allow for the uncertainty surrounding model input parameter values to be explored [37]. Results related to the number of SSI events incurred, and the number of excess hospital bed days due to SSI, were estimated deterministically. Cost and utility results were estimated amongst the overall population and on an individual patient basis, while SSI-related results were estimated amongst the overall population. The overall starting population size was estimated at 759,032 colorectal surgery patients, based on NHS Digital data [36]. As costs and healthcare resource utilization were only considered in the short-term model, the incremental cost results and impact of the intervention on healthcare resources were reported over the first year of the analysis, while incremental QALY results were based on a lifetime analysis.

In the probabilistic analysis, a Monte Carlo simulation was performed, with appropriate distributions assigned to model input parameters. 5000 iterations of the model were run, with plausible values from the assigned distributions selected, and appropriate probabilistic output was produced (i.e., cost-effectiveness plane and cost-effectiveness acceptability curve [CEAC]). The cost-effectiveness plane presents a scatterplot of results from the multiple model iterations, while the CEAC presents the likelihood of the intervention being cost effective across a range of willingness-to-pay (WTP) thresholds. The WTP threshold is the value that a decision maker may apply to assess the potential 'value for money' of a healthcare intervention based on the cost per QALY value calculated, with NICE in the UK typically using a WTP threshold of £20,000–£30,000 per QALY gained for the reimbursement of healthcare technologies [38].

2.3.2 One-Way Sensitivity Analysis

In order to explore the uncertainty surrounding individual model parameters, a series of one-way deterministic sensitivity analyses (DSA) were also performed. Such analyses allow for the exploration of the impact that particular model parameters have on the overall results, with other parameters held constant. A tornado diagram of results was produced, with the parameter variations informed by either the 95% confidence interval (CI) of the individual parameter or where this information was unavailable, based on a ± 10% parameter variation. Two separate DSAs were performed; one to explore the impact of parameter variations on incremental costs and the other to explore the impact on the net monetary benefit (NMB) of the intervention. The NMB of an intervention is an alternative way of presenting the results of a cost-effectiveness analysis; the NMB is calculated as (incremental benefit × threshold [£20,000 in the base-case analysis]) − incremental cost [39], with a positive value indicating that the intervention represents value for money.

2.3.3 Scenario Analyses

A number of scenario analyses were performed to examine the impact of adjusting defined parameters to alternative values, based on either data from the literature or on assumptions. Table 2 presents these scenarios and the values applied to the defined parameters. The results of these analyses were presented in terms of the impact on cost savings per patient, as well as on QALYs gained.

3 Results

3.1 Base-Case Analysis

Results of the base-case probabilistic analysis, presented in Table 3, indicate that use of the Caresyntax data-driven surgery platform and its SSI risk stratification algorithm for application of NPWT results in a cost saving of £73.15 per patient over 1 year (£551.11 cost per patient with the Caresyntax platform), compared with standard of care (£624.26) (1-year cost saving of £55.52m across the total NHS colorectal surgery patient population [36]). In addition, the intervention results in a QALY gain of 0.01 per patient over a lifetime horizon (11.62 with the Caresyntax platform vs 11.61 with the standard of care) (QALY gain of 7415.74 across the total population [36]). Therefore, the Caresyntax platform is a 'dominant' strategy, meaning that it is less costly and more effective compared with the current standard of care. Further results of the probabilistic analysis, presented in Table 3 and Fig. 2, show that the intervention is less costly and more effective than the comparator in the majority of model simulations (cost-effectiveness plane), and has a > 95.00% probability of being cost effective across all WTP thresholds presented (£5000–£50,000) (CEAC). Table 3 also shows that introduction of the Caresyntax platform results in a reduction in the number of SSI events incurred amongst the total population over 1 year (− 19,744). Additionally, 191,911 excess hospital bed days related to SSI are saved following introduction of the intervention, amongst the total population.

3.2 One-Way Sensitivity Analysis

Figure 3 presents the results of the one-way sensitivity analysis, exploring the impact of individual parameter variation on the incremental cost of the intervention (base-case analysis = £73.15). Results show that the most impactful parameters are the sensitivity of the Caresyntax platform (high parameter value increasing the cost savings to £134.00 per patient); the relative risk of SSI associated with NPWT (low parameter value increasing the cost savings to £108.00 per patient); and the compliance rate amongst surgeons in delivering NPWT following positive Caresyntax platform results (low parameter value reducing the cost savings to £21.00 per patient). Notably, in all sensitivity analyses performed other than when the low value for sensitivity of the Caresyntax platform is applied, the intervention remains cost saving compared with standard of care. Figure 4 presents results of the DSA related to absolute NMB of the intervention (base-case NMB = £270.91), with the tornado diagram indicating that the same parameters are most impactful in this analysis. As shown in Fig. 4, the NMB value is always

Table 2 Scenario analyses

Scenario analyses (UK NHS and PSS perspective)				
Introduction of Caresyntax platform				
Parameter	Base-case value	Alternative value 1	Alternative value 2	Alternative value 3
SSI incidence rate following colorectal surgery	16.40%	24.00% (Tanner et al. [28])	14.40% (Woods et al. [17])	
Sensitivity of Caresyntax platform*	81.00%	98.10% (cut-score threshold ≥ 2) (Woods et al. [17])	90.60% (cut-score threshold ≥ 3) (Woods et al. [17])	37.70% (cut-score threshold ≥ 6) (Woods et al. [17])
Specificity of Caresyntax platform*	78.00%	23.80% (cut-score threshold ≥ 2) (Woods et al. [17])	52.40% (cut-score threshold ≥ 3) (Woods et al. [17])	94.00% (cut-score threshold ≥ 6) (Woods et al. [17])
Compliance rate amongst surgeons in delivering NPWT following positive Caresyntax platform results	100%	50.00%	70.00%	90.00%
Compliance rate amongst surgeons in delivering NPWT with standard of care	50.00%	30.00%	70.00%	90.00%
Time horizon	Lifetime	30 days		
Proportion of SSI cases that require readmission	18.00%	15.00%	30.00%	50.00%
Mean SSI-related extended length of stay (days)	9.720	9.40 (Coello et al. [35])	13.20 (Coello et al. [35])	

*Alternative sensitivity and specificity values were adjusted in combination

NHS National Health Service, *NPWT* negative pressure wound therapy, *PSS* personal social services, *SSI* surgical site infection

Table 3 Base-case incremental outcomes

Base-case analysis (UK NHS and PSS perspective)			
Introduction of Caresyntax platform			
	Caresyntax	Standard of care	Incremental (Δ)
Overall costs (total population)	£418,313,749.56	£473,835,578.02	− £55,521,828.46
Cost per patient	£551.11	£624.26	− £73.15
Overall QALYs (total population)	8,819,048.59	8,811,632.85	7415.74
QALYs per patient	11.62	11.61	0.01
SSI events (total population)	72,994.56	92,738.53	− 19,743.97
Excess hospital bed days due to SSI (total population)	709,507.11	901,418.51	− 191,911.40
Probability of being cost effective	98.36%		
Probability of being cost saving	94.54%		

NHS National Health Service, *PSS* personal social services, *SSI* surgical site infection, *QALY* quality-adjusted life-year

positive regardless of whether a low or high value is selected for all parameters, indicating that the intervention represents value for money in all cases.

3.3 Scenario Analyses

Results of the scenario analyses are presented in Appendix 1 (Table S1, see electronic supplementary material [ESM]). Findings indicate that the SSI rate following colorectal surgery is a strong determinant of costs, with the cost savings increasing to £117.17 per patient when alternative data from Tanner et al. (value of 24.00%) are used in the analysis [28]. Variation of the sensitivity and specificity parameters for the Caresyntax platform has little impact on the overall results until the sensitivity value is decreased to 37.70% and specificity is increased to 94.00%. In this scenario, the intervention is cost incurring (+ £58.95 per patient) and the QALY gains are reduced to + 0.004. The compliance

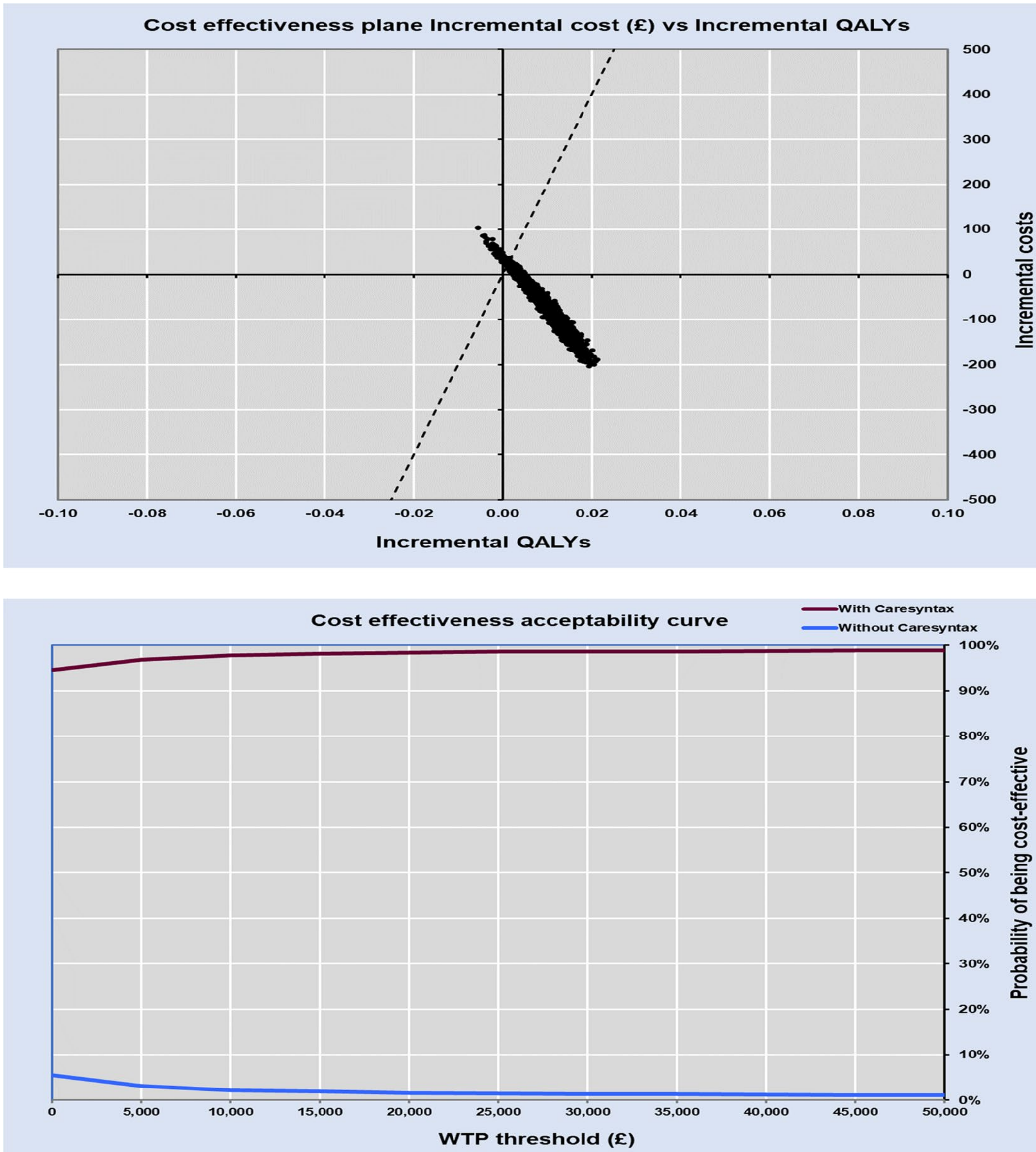

Fig. 2 Incremental cost-effectiveness plane and acceptability curve—Caresyntax platform vs standard of care: base-case probabilistic analysis. *QALY* quality-adjusted life-year, *WTP* willingness to pay

rate amongst surgeons in delivering NPWT following positive Caresyntax platform results was found to be a strong determinant of overall results, as shown also in the DSA. When compliance is decreased from the base-case value of 100–50.00%, the intervention is cost-incurring (+ £56.39) and results in a QALY loss of 0.003. The opposite effect is seen in the compliance rate amongst surgeons in delivering NPWT with the standard of care. In this case, when the compliance rate is decreased, the cost savings of the Caresyntax platform increase and vice versa. As shown in Table S1, when compliance in the standard-of-care arm is increased to 90.00%, the intervention is both cost-incurring (£19.00) and less effective (– 0.003) (see ESM). The results of scenario analyses indicate that provided the compliance rate amongst surgeons in delivering NPWT in the standard of care arm remains below the sensitivity of the Caresyntax platform, the intervention remains cost saving. When the mean SSI-related extended length of stay (days) is increased to 13.20 based on data from Coello et al. [35], the cost savings associated with the intervention increase to – £97.22 per patient. The full list of scenario analyses and the associated results are presented in Table S1 (see ESM).

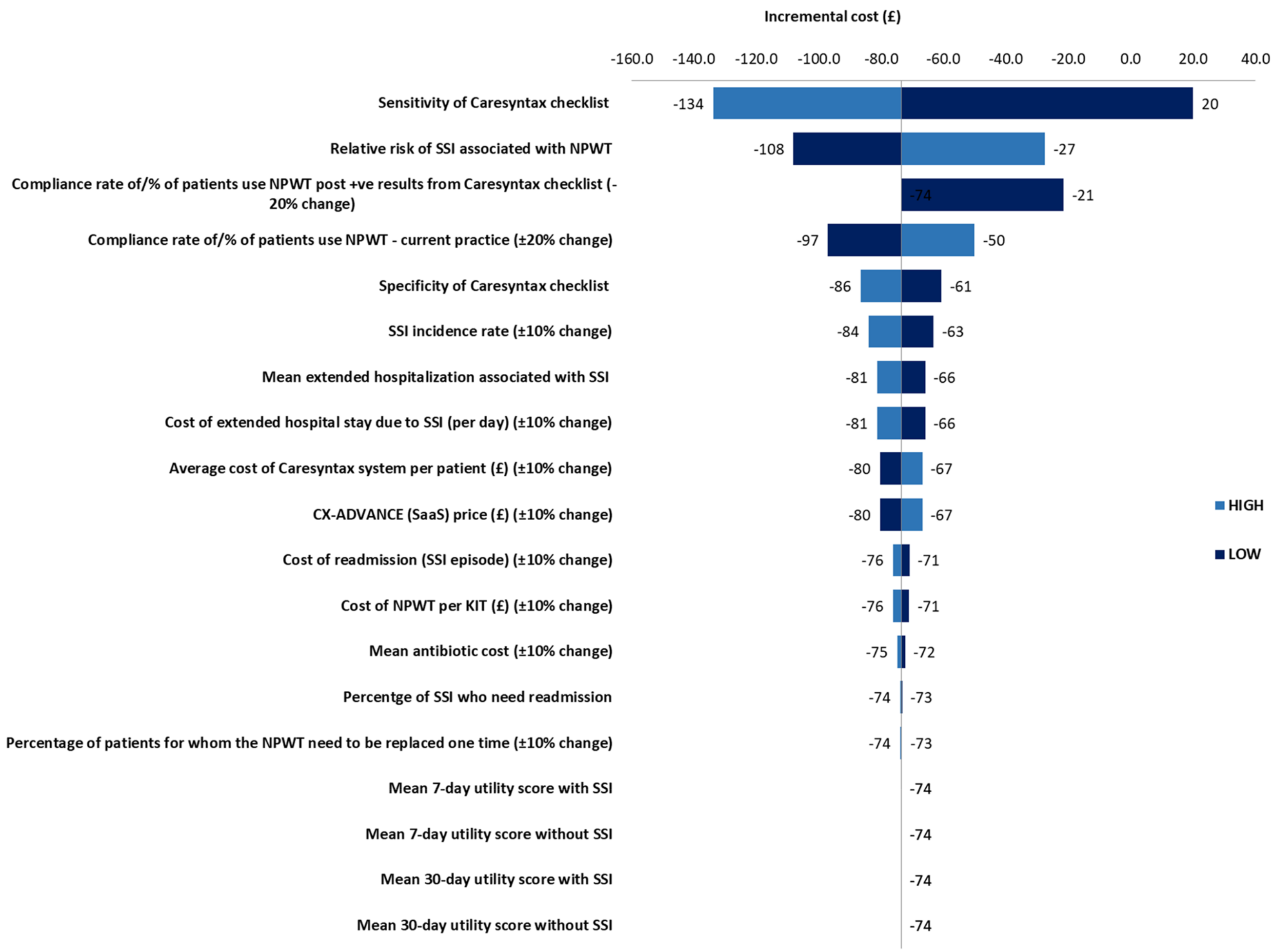

Fig. 3 One-way sensitivity analysis—Tornado diagram (incremental costs). *NPWT* negative pressure wound therapy, *SSI* surgical site infection

4 Discussion

The impact of SSIs on patient outcomes and healthcare costs is significant, due to the associated need for an extended stay in hospital, more nursing care, additional wound dressings, and the rate of readmission and further surgical intervention [40]. In this study, an economic decision-analytic model has been developed to quantify the potential cost savings and the impact on patient QoL that a predictive platform to identify those patients at high risk of experiencing subsequent SSI may have. The model allows decision makers to not only consider the short-term cost and health outcome implications associated with introduction of the platform, but also allows long-term survival and QALY gains to be estimated, which is only possible through use of a simulation model such as this. The impact of the diagnostic accuracy of the platform, as well as the prevalence of the condition, on healthcare resource use and clinical outcomes can also be assessed through use of the developed model. In the NHS, cost-effectiveness evidence is considered when evaluating new technologies, with modeling approaches implemented to explore long-term outcomes [34].

Compared with standard of care, intervention guided by use of the Caresyntax data-driven surgical platform has the potential to generate cost savings of £73.15 per patient over 1 year. Additionally, an improvement in QoL (+ 0.01 QALYs per patient) over a lifetime horizon with the Caresyntax platform has been shown through the economic modeling. While cost savings are relatively low on an individual patient basis, extrapolated over the estimated population of patients who may benefit from the intervention in England based on data from NHS Digital, i.e., those patients undergoing colorectal surgeries (759,032) [36], the intervention would result in an overall cost saving in excess of £55 million over 1 year. Similarly, when we extrapolate the QoL gain amongst individual patients over the overall population, we see an increase of 7416 QALYs over a lifetime horizon, which highlights the long-term benefits associated with the Caresyntax platform.

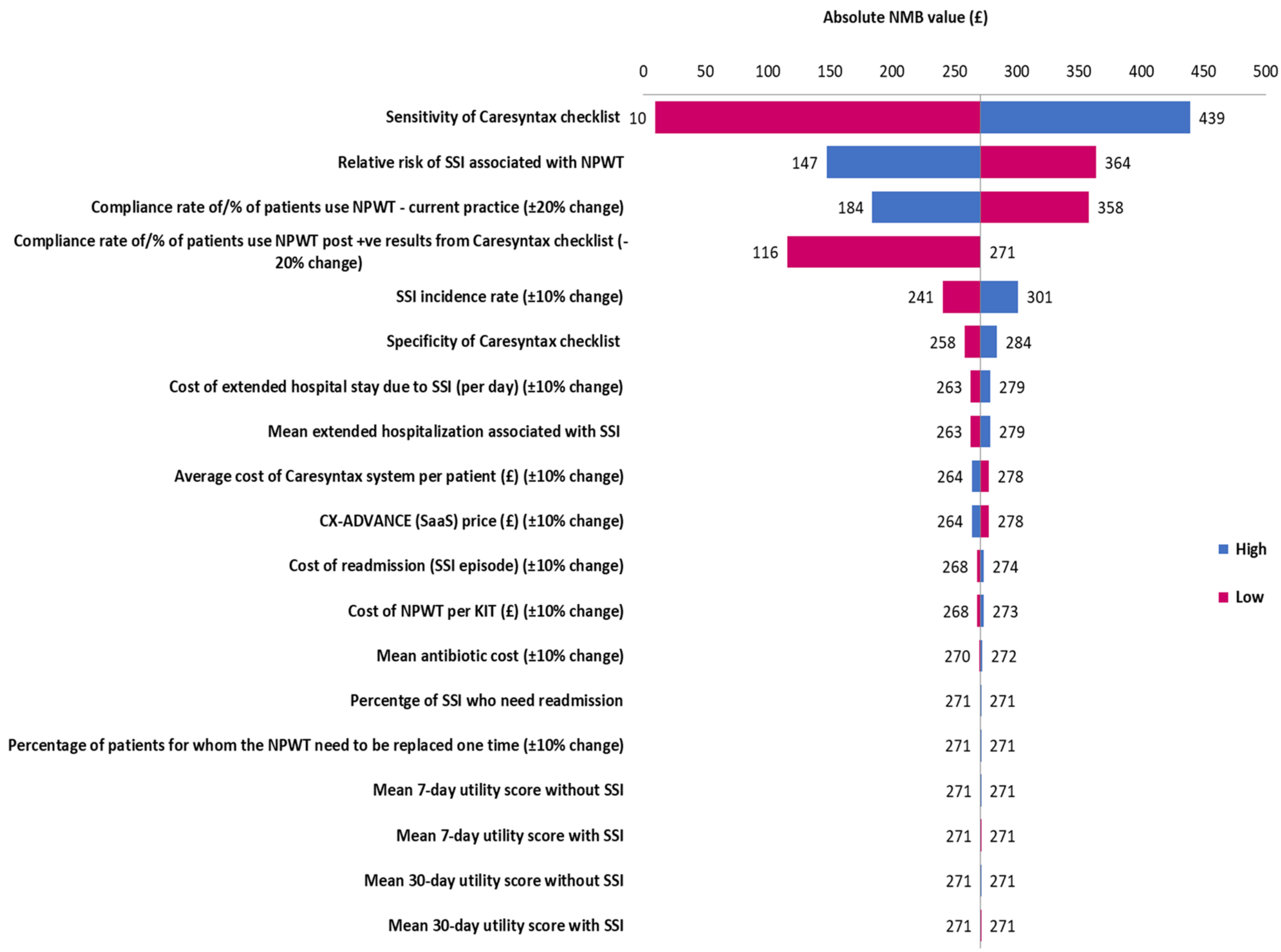

Fig. 4 One-way sensitivity analysis—Tornado diagram (net monetary benefit, i.e., incremental benefit × threshold (£20,000 in the base-case analysis) − incremental cost). *NMB* net monetary benefit, *NPWT* negative pressure wound therapy, *SSI* surgical site infection

Cost savings consist of the reduction in costs associated with a reduced length of stay in hospital due to lower SSI rates, fewer readmissions to undergo further treatment or surgery, and reduced costs associated with NPWT due to the fact that only those patients identified as high risk would proceed to treatment. As seen in the results, introduction of the Caresyntax platform would reduce the number of SSI events across the total population over 1 year (−19,744), while also reducing the number of excess hospital bed days due to SSI (−191,911). These cost savings more than compensate for the additional costs associated with administering the Caresyntax platform in the hospital setting. Sensitivity analyses indicated that the results were most sensitive to the diagnostic performance of the tool (sensitivity of the platform in accurately identifying positive cases), but that the intervention remained cost saving in the majority of cases, regardless of the parameter variations made (based on 95% CI or ± 10% parameter variation).

Multiple scenario analyses were also performed to explore alternative model and parameter assumptions. Additional parameters found to be strong drivers of results were the SSI rate following colorectal surgery, and the compliance rate amongst surgeons in delivering NPWT following positive Caresyntax platform results. When the compliance rate is decreased from 100 (base-case analysis) to 50.00% (as assumed in the standard-of-care arm), then the intervention actually becomes cost-incurring (+ £56.39). This, however, is likely an extreme scenario given that the objective of the intervention is to identify at-risk patients and ensure that they undergo the most appropriate follow-up treatment.

A number of procedure-specific SSI risk models have been developed. One of the earliest to predict risk across a wide range of surgeries was the National Nosocomial Infections Surveillance [NNIS] Basic SSI Risk Index, an infection risk index developed to predict the likelihood that an infection will develop following an operation based on detailed patient information related to demographic characteristics, infections and related risk factors, pathogen and their antimicrobial susceptibilities, and outcomes [41]. A study by van Walraven and Musselman aimed to improve on perceived limitations of the earlier NNIS Basic SSI Risk Index, with their surgical site infection risk score (SSIRS) model [42]. Their work described development of an internally validated model to predict the risk of SSI within 30 days of an operation which, based on the author's assessment, was better able to discriminate while maintaining calibration than the NNIS Basic SSI Risk Index [42]. The work that we have presented, however, builds upon previous studies by demonstrating the clinical efficacy (and associated economic benefit) of a risk prediction platform that is considered for the purpose of patient stratification prior to the administration of a clinically proven therapy such as NPWT.

In addition to the array of clinical literature around risk prediction models for SSI, previous work has also been performed exploring the cost effectiveness of interventions to prevent SSI, which can be compared to the results presented here. Chomsky-Higgins and Kahn explored the cost effectiveness of interventions for the prevention of SSI from a US healthcare perspective [43]. Their work found that process-based interventions and wound protection devices were superior to 'no intervention' in all cases, with double-ring devices resulting in greater cost savings than simpler devices such as single-ring devices. While this study demonstrated the economic dominance of the preventative interventions assessed, as we have also shown in our analysis, the focus was not on a tool to predict risk of SSI but rather on the use of interventions for prevention amongst all patients undergoing colorectal surgery (regardless of previously assessed risk of SSI) [43]. Further studies have focused on the cost effectiveness of surveillance programmes for SSI in the aftermath of surgical procedures. The study by Wloch et al. describes an analysis of the economic burden of SSI and the cost benefits of implementing a surveillance programme for SSI amongst patients who have undergone caesarean section in England [44]. Their work found that the benefits of a surveillance strategy can outweigh the costs through reductions in the incidence of SSI. While the mode of SSI prevention differs, these findings are consistent with the results from our own analysis, which also highlight the significant costs associated with SSI and the potential for an effective preventative strategy to be cost effective.

While the economic modeling methodology is based on best-practice guidelines [19], there are limitations to the overall analysis which should be highlighted. As described earlier, there is a degree of uncertainty surrounding the proportion of the surgeon population that would comply with use recommendations for NPWT following a positive result with the Caresyntax platform. While in the base-case analysis it is assumed that 100% of surgeons comply with NPWT application following a positive result (as this is the intention of the intervention), this likely reflects an over-estimation, as a certain percentage of surgeons may choose not to apply NPWT despite positive results. Similarly, in the standard-of-care arm of the analysis, the base-case analysis estimated, based on clinical expert input, that only 50.00% of patients initially undergo NPWT following clinical assessment, meaning that the remaining 50.00% do not and, therefore, subsequently experience the higher rates of SSI associated with not undergoing the procedure. Additionally, it was not possible to consider the diagnostic accuracy associated with clinical assessment and the impact on utilization of NPWT in the standard-of-care arm, as was considered for the Caresyntax platform, due to heterogeneities in clinical assessment techniques and an absence of data on sensitivity and specificity related to clinical assessment of SSI risk in the literature. The parameters related to utilization of NPWT in each arm of the model are strong drivers of the overall results, as shown in scenario analysis, and the uncertainty surrounding these values should be highlighted. Finally, there is an underlying assumption that NPWT resources are available in all institutions in which the Caresyntax platform is installed, which may not be the case.

Despite these data limitations, a robust economic model has been developed to explore the cost effectiveness of the Caresyntax platform, and improved evidence may be used to populate the model once further clinical data become available.

5 Conclusion

A platform to identify colorectal surgery patients at risk of SSI has been developed by Caresyntax Corporation, Inc. The economic evaluation presented shows that this tool has the potential to reduce costs and improve patient QoL over a lifetime horizon, while delivering healthcare system operational benefits (i.e., reduced SSI rates and a lower number of excess hospital bed days). The cost-saving potential of this platform outweighs the increased costs associated with its implementation in an English hospital setting.

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of General and Oncological Surgery – Surgery C, The Chaim Sheba Medical Center, Israel).

Authors' Contributions MJ, MRH, and AM were responsible for designing and developing the economic model, performing the economic analysis, and interpreting the results. MJ and MRH designed the study and interpreted the results. EM was responsible for drafting the first manuscript. All authors critically reviewed the manuscript. All authors reviewed and approved the final version of the manuscript.

Declarations

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Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Availability of data and material The information reported in this manuscript is sufficient to replicate the results of the study.

Code availability Code used to perform the economic modeling was provided to the journal's peer reviewers for their reference when reviewing the manuscript.

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