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Cost utility analysis of continuous and intermittent versus intermittent vital signs monitoring in patients admitted to surgical wards

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ABSTRACT

Background: Complications after surgical procedures are common and can lead to a prolonged hospital stay, increased rates of postoperative hospital readmission, and increased mortality. Monitoring vital signs is an effective way to identify patients who are experiencing a deterioration in health. SensiumVitals is wireless system that includes a lightweight, digital patch that monitors vital signs at two minute intervals, and has shown promise in the early identification of patients at high risk of deterioration.

Objective: To evaluate the cost-utility of continuous monitoring of vital signs with SensiumVitals in addition to intermittent monitoring compared to the usual care of patients admitted to surgical wards.

Methods: A *de novo* decision analytic model, based on current treatment pathways, was developed to estimate the costs and outcomes. Results from randomised clinical trials and national standard sources were used to inform the model. Costs were estimated from the NHS and PSS perspective. Deterministic and probabilistic sensitivity analyses (PSA) were conducted to explore uncertainty surrounding input parameters.

Results: Over a 30-day time horizon, intermittent monitoring in addition to continuous monitoring of vital signs with SensiumVitals was less costly than intermittent vital signs monitoring alone. The total cost per patient was £6,329 versus £5,863 for the comparator and intervention groups respectively and the total effectiveness per patient was 0.057 QALYs in each group. Results from the PSA showed that use of SensiumVitals in addition to intermittent monitoring has 73% probability of being cost-effective at a £20,000 willingness-to-pay threshold and 73% probability of being cost-saving compared to the comparator. Cost savings were driven by reduced costs of hospital readmissions and length of stays in hospital.

Conclusions: Use of SensiumVitals as a postoperative intervention for patients on surgical wards is a cost-saving and cost-effective strategy, yielding improvements in recovery with decreased health resource use.

KEY POINTS FOR DECISION MAKERS

- SensiumVitals has the potential to reduce the length of postoperative hospital stay, readmission rates, and associated costs in postoperative patients.
- In this study, SensiumVitals has been found to be a cost-saving (dominant) and cost-effective (dominant) intervention for monitoring the vital signs of surgical patients postoperatively.

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1. Introduction

Postoperative complications are common[1]; complications can lead to a longer length of stay (LoS) in hospital, increased risk of postoperative hospital readmission, and increased mortality rates[1]. Early detection of patient deterioration post-operatively can reduce morbidity and mortality associated with postoperative complications[2]. Surgical patients are therefore an important population in which to detect physiological decline early.

Deterioration in health can be identified through the measurement of five key vital signs: blood pressure (BP), oxygen saturation of the blood (SpO2), heart rate, respiratory rate, and body temperature[3]. Hospital policies require that

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these vital signs are measured and recorded for all patients at various frequencies throughout the day. In the UK, the National Institute for Health and Care Excellence (NICE) recommends monitoring of these vital signs at least every 12 h for each patient. More frequent monitoring is performed in cases where abnormal physiology has been identified or where the patient is at increased risk of deterioration[4].

The National Early Warning Score (NEWS) is a system for vital signs monitoring for the early detection of deterioration in patients. It is the early warning score recommended by the Royal College of Physicians and has been widely adopted throughout the UK. Patients are monitored intermittently at frequencies determined by the NEWS protocol, based on their existing physiological measurements and their likelihood of deterioration, and any evidence of physiological decline is escalated to the appropriate clinical level. A patient might show the first signs of deterioration 6 to 8 h before a cardiac or respiratory arrest; these variations in vital signs may not be detected by typical, intermittent monitoring regimes[5]. The potential for continuous measurement and monitoring of vital signs has been identified as a potential approach to ensure consistent, early identification of deterioration[6].

In their systematic review and meta-analysis, Cardona-Morrell et al.[7] assessed the benefits of continuous monitoring of vital signs for preventing adverse events on general wards. The 22 studies that were included examined diverse strategies for achieving this continuous monitoring, including manual, semi-automated, or fully automated monitoring technologies, which were either bedside, patient-worn, or clinician-portable devices. Their analysis showed no increased effectiveness for the prevention of serious adverse events or cardiac arrests, nor reduction in the frequency of Intensive Care Unit (ICU) transfers. In a systematic review and narrative synthesis, Downey et al.[6] assessed the impact of continuous versus intermittent monitoring of vital signs outside the critical care setting in hospitals. The majority of the studies included in this review showed some evidence of the superiority of continuous vital sign monitoring compared to intermittent monitoring, especially related to critical care use and LoS. A recent pilot cluster randomized control trial[8] evaluated the use of a wearable wireless patch for patients admitted to two surgical wards. Although the wide confidence intervals (CI) suggest no statistically significant findings, the results were promising; patients in the continuous monitoring group were administered antibiotics sooner after evidence of sepsis, had a shorter average LoS, and were less likely to require readmission to hospital within 30 days of discharge[8].

SensiumVitals[i] is a disposable, lightweight (15 g), ultra-low power, wireless digital patch with a battery life of five days. It is designed to monitor patients' vital signs at two-minute intervals to enable early detection of clinical deterioration. Although economic studies evaluating similar devices that have been conducted in the USA[9–11] have shown cost-savings to the healthcare system, to date no economic evaluation has been conducted in the UK setting. Given the potential benefits of these devices, this study aims to evaluate whether continuous vital signs monitoring *via* SensiumVitals is a cost-effective option for the National Health Service (NHS) compared to the current standard of practice of intermittent vital signs monitoring.

2 Methods

2.1. Model overview

A de novo decision analytic model based on the current treatment pathway and available evidence, including the impact that postoperative complications have on mortality, was developed (in MS excel) to estimate the costs and outcomes in each strategy over 30 days which is considered the time point when the majority of readmissions occur. Outcomes in the model were the total cost of each strategy, number of readmissions, LoS in hospital/ICU, deaths, quality-adjusted life-years (QALYs), and incremental cost per QALY gained. As the time horizon for this model was 30 days, no discounting was applied.

The model was based on a hypothetical cohort of patients who were admitted to surgical wards for the following reasons colorectal resections, stoma formations, stoma reversals, hernia repairs and other colorectal laparotomies including fistula exploration. The choice of patient group was based on the study by Downey et al. which was used as main source to inform the economic model. These patients were then monitored by either 1) conventional intermittent vital signs monitoring based on the National Early Warning Score (NEWS) (comparator) or 2) conventional intermittent NEWS monitoring plus continuous vital sign monitoring *via* the SensiumVitals system (intervention).

The decision tree structure of the model simulated the management of patients including the monitoring of their vital signs by either the intervention or comparator strategy. The structure of the model is illustrated in Figure 1. The number of patients in the cohort that entered our model was 2,920. This number was based on the assumption that the SensiumVitals technology was implemented in a hospital with two surgical wards, each with a capacity of 28 beds. It was further assumed that 100% patients on the ward used the SensiumVitals patch and that two patches were used per patient.

Patients in the model were stratified to one of the two monitoring strategies (i.e. intervention or comparator). Once discharged, patients remained outside the hospital or they were readmitted due to complications, which, in our model were assumed to be due to sepsis. This was based on a retrospective study of approximately 94,000 patients which showed that the most common reason of readmission was due to infection[12]. Costs and benefits were measured at 30 days, at which point some patients had survived and some had died.

2.2. Model inputs

A series of targeted searches were conducted on the NICE website and of existing clinical guidelines to identify values

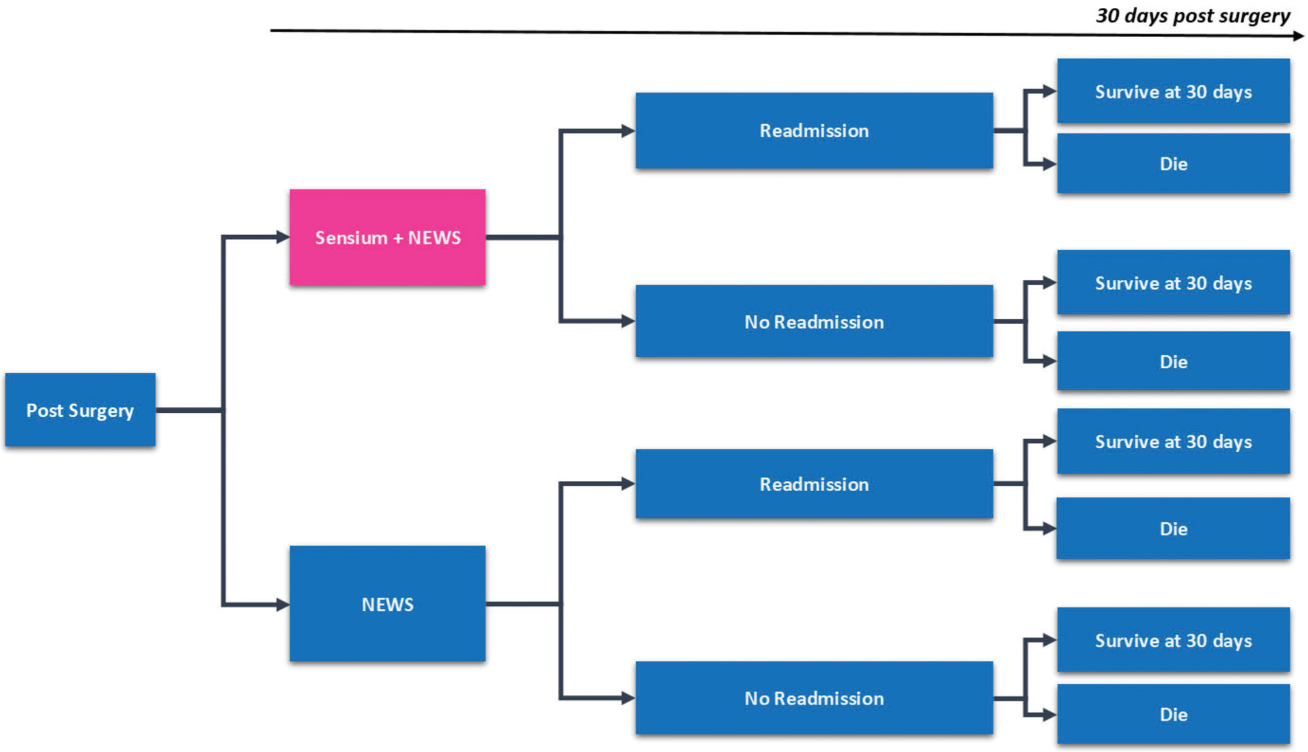

Figure 1. Model structure.

Table 1. Clinical input parameters.

Variables	Base case	Distribution	Lower limit	Upper limit	Source
With sensiumvitals plus NEWS					
Readmission rate	11.4%	Beta	6.16%	16.7%	Downey et al.[8]
Average length of stay in hospital (days)	13.3	Gamma	11.3	15.3	Downey et al.[8]
Average length of stay in ICU (days)	8.2	Gamma	4.1	12.3	Hospital Episode Statistics (HES) NHS digital 2018-19
ICU admission rate	2.1%	Beta	0%	4.54%	Downey et al.[8]
Probability of death at 30 days	5.8%	Beta	5.4%	6.4%	Morris et al.[13]
With NEWS					
Readmission rate	20.9%	Beta	12.3%	29.5%	Downey et al.[8]
Average length of stay in hospital (days)	14.6	Gamma	11.5	17.7	Downey et al.[8]
Average length of stay in ICU (days)	8.2	Gamma	4.1	12.3	Hospital Episode Statistics (HES) NHS digital 2018-19
ICU admission rate	2.3%	Beta	0%	5.51%	Downey et al.[8]
Probability of death at 30 days	5.8%	Beta	5.4%	6.4%	Morris et al.[13]
Clinical parameters in both groups					
Health Utility					
Health utility at 30 days post-colorectal surgery	0.7	Beta	0.63	0.77	Dowson et al.[14]

Abbreviation. ICU: Intensive care unit.

for the input parameters. The Cochrane pyramid of evidence was considered when selecting evidence to inform the model where possible.

2.2.1. Clinical inputs

Clinical inputs for the model were: readmission rates after discharge, ICU admission rates, average LoS in hospital and average LoS in ICU postoperatively, as well as 30-day mortality rates (Table 1). In each strategy, patients had a chance of readmission and patients in both strategies had a chance of dying during the modelled postoperative period.

Mortality rates at 30 days were obtained from a study by Morris et al.[13] that examined the 30-day mortality rate among 160,920 individuals who underwent major resection for colorectal cancer. In the base-case analysis a conservative approach was taken by assuming identical mortality rates between two groups. However this rate was changed within the sensitivity analyses. Hospital readmission rates, ICU admission rates and LoS in hospital were obtained from Downey et al.[8] while LoS in ICU was obtained from hospital episode statistics (HES) data (NHS digital 2018-19). The applicability of these studies was discussed with the clinical team; after considering the patient population, setting and intervention, a consensus was reached that the selected input values were appropriate for use in the model.

2.2.2. Health utility values

In order to estimate the QALYs gained in each strategy, it is necessary to quality-adjust the period of time the average patient is alive in the model by using an appropriate health utility weight. The utilised health utility weights were based on a study conducted by Dowson et al. on the health-related quality of life for individuals who had undergone laparoscopic colorectal surgery[14]. In this study utilities of the first 42 days after surgery were obtained with the EQ-5D questionnaire; for our analysis the mean utility value of the first 35 days was used and applied to both arms. Utilities due to readmission reasons were not applied in the model.

2.2.3. Costs

Costs were estimated from the National Health Service (NHS) and Personal Social Services (PSS) perspective. The following costs were included: cost of the initial intervention (i.e. SensiumVitals), cost of stay in the ICU, cost of additional days in hospital, as well as the cost of readmission to hospital, which was assumed to be due to sepsis. Costs were presented in UK pound sterling for the 2018 price year. We obtained the cost of hospital stays and readmissions from the NHS reference costs (Table 2)[17].

Costs of the SensiumVitals device comprised the cost of patches, costs of the system, as well as an initial setup cost that includes annual licenses, maintenance of the system, installation and test, as well as training. The estimated cost per patient, and its component parts, with the use of SensiumVitals in a hypothetical hospital with 2 surgical wards (each with 28 beds) and assuming that 100% of patients had their vitals monitored with two Sensium patches is presented in Table 2, below. The estimated total annual number of patients per hospital will be 2,920 patients.

2.3. Analysis

Cumulative estimates of costs and effectiveness were derived using Monte Carlo simulation (10,000 iterations) for both the intervention and comparator. Deterministic and probabilistic sensitivity analyses (PSA) were conducted to explore uncertainty surrounding the results. The deterministic sensitivity analysis was used to test the impact of varying the values of key parameters used in the base case analysis. This was presented as a change from the base-case value as well as absolute changes in the Net Monetary Benefit (NMB) with positive NMB values indicating that Sensium is a cost-effective intervention.

A PSA was performed to map the parameter uncertainty. To conduct the PSA, probabilistic distributions were assigned to each input variable in the model and these were used to randomly select new values within their plausible range. The distributions for each variable are included in Tables 1 and 2. Each new randomly sampled set of values was used in the model and the new results based on the randomly selected input values were recorded. This process was repeated for 10,000 iterations to produce a distribution of results from the model. The probability of being cost-saving represents the percentage of iterations within the PSA where the incremental cost was negative. Similarly, the probability of being cost-effective represents the percentage of iterations within the PSA that the incremental cost-effectiveness ratios (ICERs) fall below the willingness-to-pay (WTP) threshold per each QALY gained.

3. Results

Total and incremental costs, QALYs, ICERs, and probabilities that each strategy is cost-effective at various WTP thresholds are presented in Table 3. Probabilistic results from the Monte Carlo simulation, in the form of a cost-effectiveness scatterplot and a cost-effectiveness acceptability curve are presented in Figures 2 and 3.

Table 2. Cost input parameters.

Variable	Base case value	Distribution	Lower limit	Upper limit	Source
Cost of interventions					
Unit cost of excess bed stay after surgery	£379	Gamma	£284	£474	NHS reference costs 2017/18[15]
Unit cost of post-operative hospital stay in ICU	£1,449	Gamma	£1,087	£1,812	NHS reference costs 2017/18[15]
Unit cost of readmission with sepsis	£2,820	Gamma	£2,122	£3,537	NHS reference costs 2017/18[15]
Cost of sensiumvitals					
Installation & test (Server)	£18,000	Fixed	NA	NA	Sensium[16]
Bridge cost	£7,000	Fixed	NA	NA	Sensium[16]
Installation & Test (Bridge)	£0	Fixed	NA	NA	Sensium[16]
Training	£16,000	Fixed	NA	NA	Sensium[16]
Patch price per unit	£150	Fixed	NA	NA	Sensium[16]
Annual licences	£50,000	Fixed	NA	NA	Sensium[16]
Maintenance 10%	£0	Fixed	NA	NA	Sensium[16]
Bridge & cabling	£500	Fixed	NA	NA	Sensium[16]
Estimated average cost of SensiumVitals per patient	£320	Fixed	NA	NA	Sensium[16]

Abbreviation. ICU: Intensive care unit; NA; Not applicable.

Table 3. Base-case probabilistic results over a 30-day time horizon.

Base-case probabilistic results	NEWS		SensiumVitals & NEWS
Cost (£)	£6,329		£5,863
Incremental cost (£)		-£466	
QALYs	0.057		0.057
Incremental QALYs		0.000	
ICER (£) (ΔCost/ΔQALYs)		SensiumVitals is dominant	
Probability of being cost-effective with £20,000 WTP thresholds		73%	
Probability of being cost saving		73%	

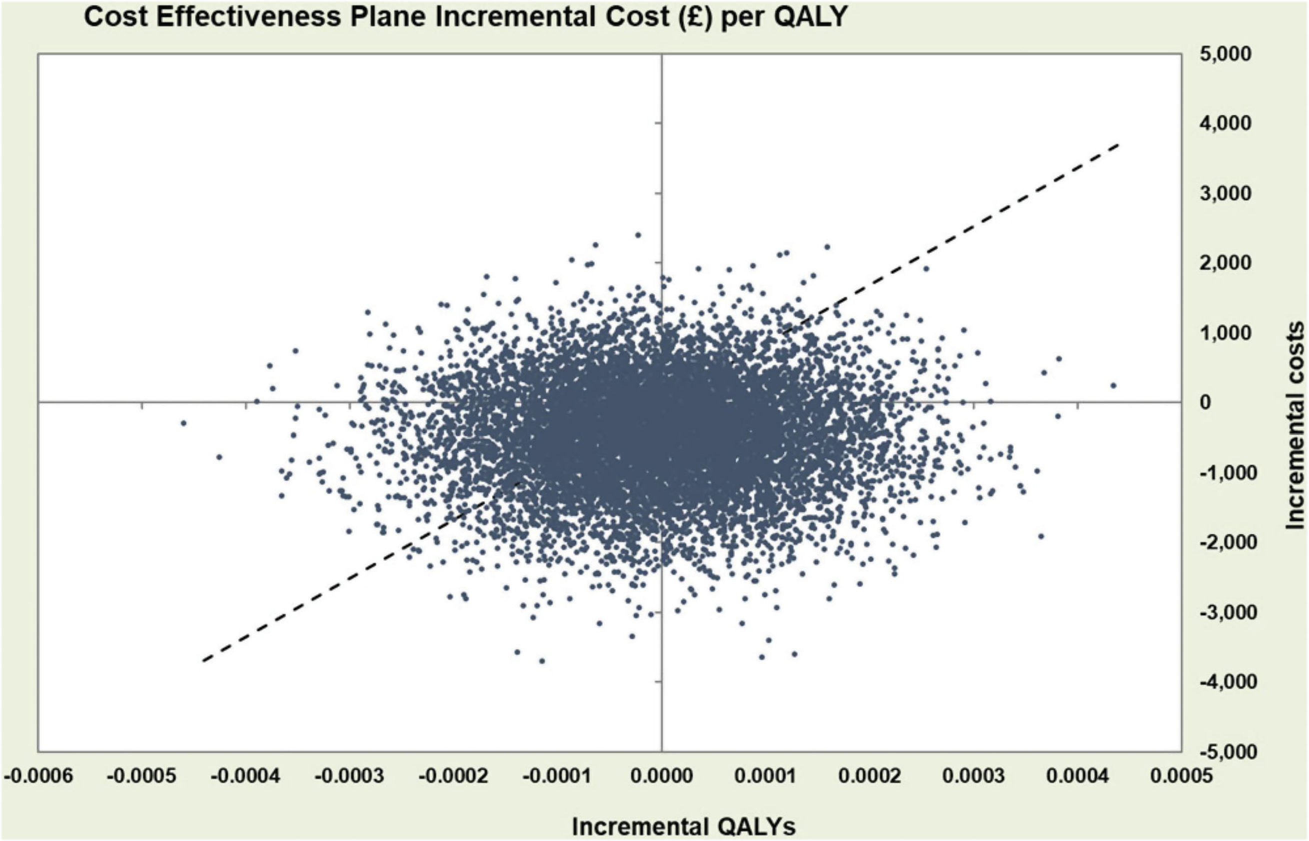

Figure 2. Scatter plot at £20,000 WTP threshold.

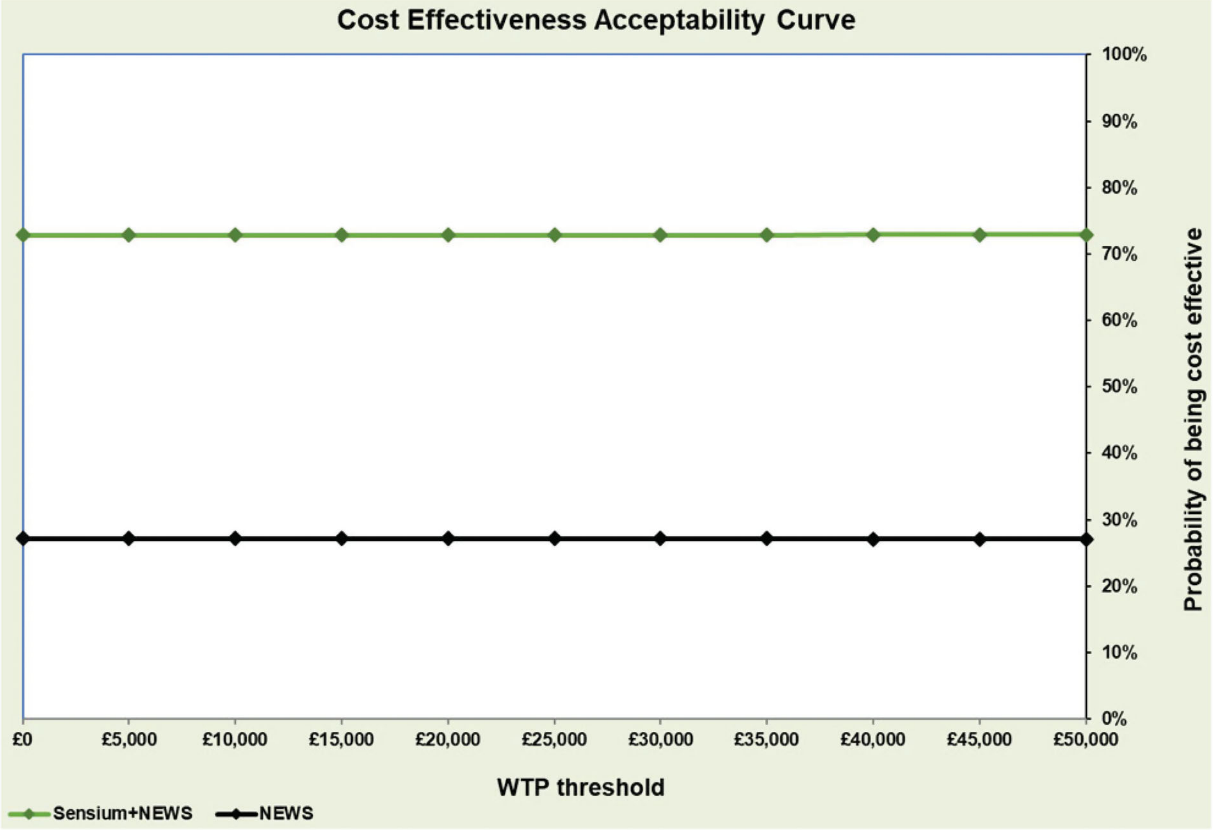

Figure 3. Cost-effectiveness acceptability curve at various WTP thresholds (£0-£50,000).

3.1. Base case analysis (30-day time horizon)

Over a 30-day time horizon, intermittent in addition to continuous monitoring of vital signs with SensiumVitals was less costly than intermittent vital sign monitoring alone. The total costs per patient were £6,329 versus £5,863 for the comparator and intervention groups respectively and the total effectiveness per patient was 0.057 QALYs in each arm. Thus, intermittent in addition to continuous monitoring of vital signs with SensiumVitals is the dominant strategy compared to the usual standard of care with intermittent vital sign monitoring only (Table 3).

The estimated annual cost saving per each hypothetical hospital is over £1.3 million (Table 4). Although the total cost of SensiumVitals for the entire cohort was substantial, with a total cost of £935,081 this intervention is still cost-saving overall. These cost-savings were driven by reduced costs of readmissions, shorter length of hospital stays and fewer ICU admissions (Table 4). The Monte Carlo simulation showed that the intervention of continuous monitoring with SensiumVitals in addition to intermittent monitoring has a 73% probability of being cost-effective at a £20,000 WTP threshold and a 73% probability of being cost-saving (Figures 2 and 3).

Table 4. Base-case deterministic results for a hypothetical hospital over a 30-day time horizon ($n = 2,920$).

Cost and outcome	NEWS	SensiumVitals & NEWS	Δ Incremental
Cost of intervention	–	935,081	935,081
Total cost of ICU stays	798,196	728,788	−69,408
Total cost of hospital stays	16,747,005	15,257,062	−1,489,943
Total cost of readmissions	1,727,092	942,050	−785,042
Total cost at 30 days	18,474,097	17,134,193	−1,339,904

3.2. Sensitivity analysis

Results from the deterministic sensitivity analyses are presented as a Tornado diagram in Figures 4 and 5; these analyses showed that ±25% changes on the average LoS in surgical wards and readmission rates as well as the cost of hospital bed days for both strategies had the most impact on the estimated cost saving (Figures 4 and 5).

4. Discussion

A review of the economic literature failed to identify any existing studies in the UK relevant to the monitoring of vital signs in patients admitted to surgical wards, either continuously or intermittently. Thus, to our knowledge, this is the first economic evaluation examining the cost-effectiveness of continuous monitoring of vital signs in the UK. Our results suggest that continuous monitoring of vital signs with SensiumVitals, in addition to intermittent vital sign monitoring based on NEWS, is a cost-saving (dominant) and cost-effective (dominant) intervention for the management of patients admitted to surgical wards when compared to NEWS alone.

Data from Hospital Episodes Statistics (HES) (NHS digital 2017-18) show that there were 53,935 admissions related to the following reasons, colorectal resections, stoma formations, stoma reversals, hernia repairs, fistula exploration, hepatobiliary, urological, appendectomy and abdominal wall repair, who were subsequently were diagnosed with sepsis. Full list of ICD and OPCS codes that were searched for in the HES database are included in the supporting materials. The same group of patients were studied in the study by Downey et al. which is the main source for informing the economic model. The estimated total cost saving in the

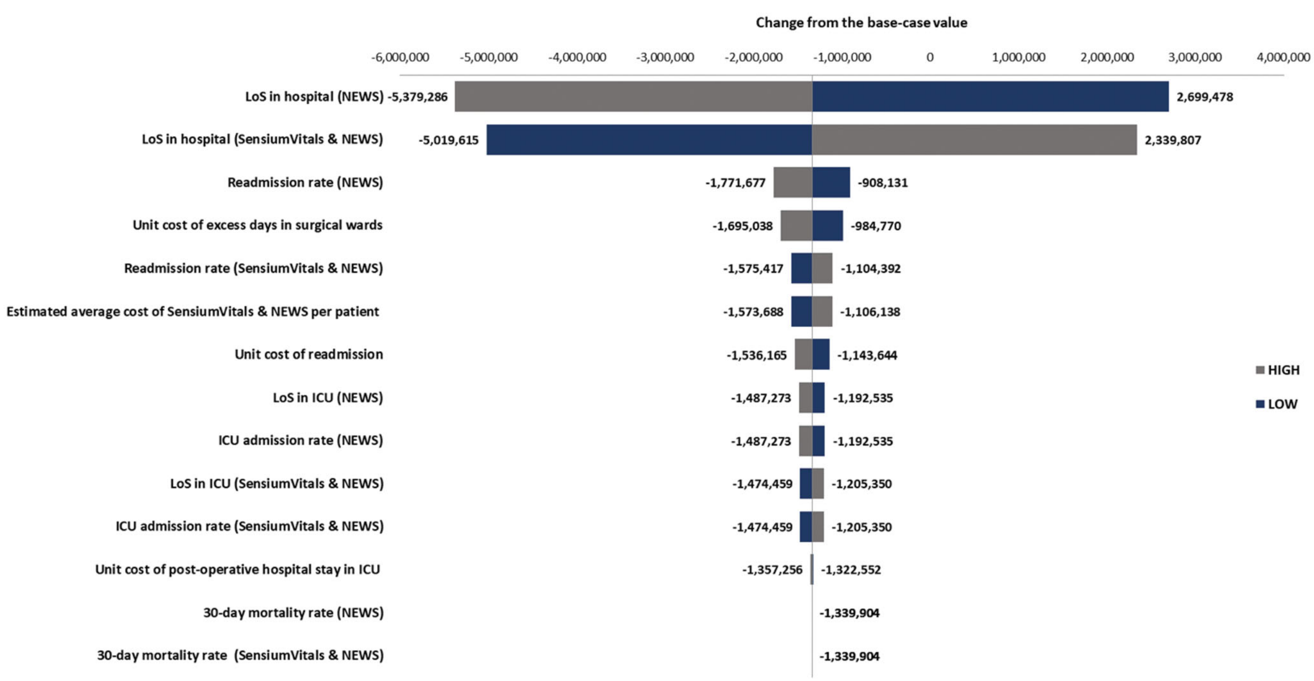

Figure 4. Impact of changing the input parameters by ± 25% on the estimated incremental cost.

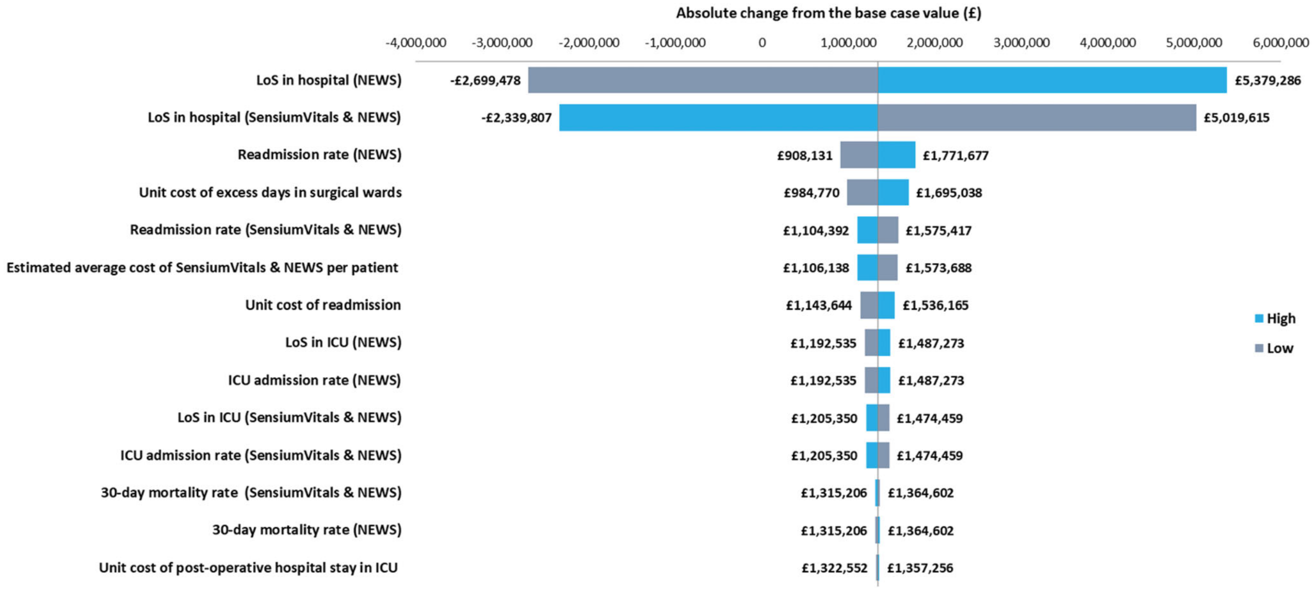

Figure 5. Impact of changing the input parameters by ± 25% on the estimated net monetary benefit (NMB) - Sensium is a cost-effective intervention as long as the estimated NMB is positive.

base-case analysis was over £1.3 million which is attributable to 2,920 patients in one hospital (2 wards) that were modelled. It is estimated that the total cost saving for NHS in England for 53,935 admissions to be £24 million per year.

A recent systematic review and narrative synthesis examining the benefits of continuous versus intermittent monitoring in hospitals identified three cost-effectiveness studies[6] evaluating single and multi-parameter monitoring devices; of these studies, one was a return on investment study[9], one was a cost analysis[10], and one was a cost-effectiveness study based in the USA[11].

Morgan et al.[11], in their cost-effectiveness study, analysing the use of a similar technology for early identification of deterioration prior to respiratory or cardiac arrest, showed that the technology was cost-saving. In that study, cost-savings were mainly due to the reduction in ICU transfers and shortened LoS in the ICU. Although the study by Morgan et al. had a similar approach as was used in our analysis, no information about clinical gains due to the intervention were reported by Morgan et al. Similar results were also observed in a study by Ochroch et al.[10]. Costs in the monitoring group were less compared to the unmonitored ($15,481 versus $18,713). These cost savings mainly accrued from fewer transfers to the ICU as well as reduced ICU LoS, despite the fact that the monitored group was older in age with more comorbidities. However, no difference in the total hospital LoS was observed. While fewer admissions to the ICU were observed for the respiratory group, this was not the case for the cardiac group. According to the authors, this likely resulted from increased vigilance of the nurses. In the return on investment study[9], which was conducted on a 316-bed community hospital with mainly medical, surgical, and trauma patients, showed savings of between $3,268,000 (conservative model) and $9,089,000 within a 5-year period. These savings were mainly driven by reduced LoS, reduced ICU LoS and reduced pressure ulcers.

Our economic analysis was largely informed by the results from a single clinical study[8] with a relatively small sample size resulting in overlapping confidence intervals and non-statistically significant results. However this was partially addressed within the Monte Carlo simulations, where the estimated ranges for the input variables were used to draw random values (10,000 iterations). Despite the lack of statistical significance the results were promising; in addition to reductions in readmission rates, shortened LoS in hospital, and fewer ICU admissions, this study also showed earlier administration of antibiotics for patients with sepsis (623 vs 1013 min). While the association between sepsis and long-term mortality is unclear in the existing literature[18], early identification of sepsis has the potential to lead to early and effective treatment, fewer complications and, consequently, fewer admissions to the ICU and a shorter LoS in hospital.

The one-way sensitivity analysis showed that LoS in hospital and hospital readmission rates were the parameter influencing most the cost-effectiveness estimates. The influence of the LoS in the ICU was also explored either by considering the different ICU LoS for both groups or by considering £0 costs for ICU stay. However, the results did not change and SensiumVitals remained a cost-effective intervention. The PSA was run with 10,000 simulations and the results suggest that Sensium has a probability of being cost-effective of 73% at a WTP threshold of 20,000. Although these are very promising results, the fact that the generated ICERs fall in all four quadrants in the CE plane, with the majority in the northeast and northwest, suggest that there is uncertainty in our model and the results should be interpreted with caution.

Our economic evaluation comes with a number of limitations which should be taken into account when interpreting the results. First, due to the lack of long-term data it was not possible to extrapolate the findings beyond the 30-day time horizon. This creates uncertainty about the long-term costs and consequences of the technology. Furthermore, in order to enhance the validity of the model a number of external sources were employed to inform the model inputs including HES and secondary publications for mortality and QALYs. Although these come from separate publications, all were derived from UK population and were deemed to be appropriate for inclusion by our clinical experts thus making our results generalizable to the UK setting. Also in our model, costs per QALY were not adjusted for the severity of the disease. However, our study used secondary sources such as the study by Morris et al.[13] as well as HES data. The inputs taken from these sources were derived from large and heterogeneous sample sizes with different levels of disease severity. Therefore we believe the results are applicable to group of patients who have had colorectal resections, stoma formations, stoma reversals, hernia repairs and other colorectal laparotomies including fistula exploration or other relevant surgeries. Furthermore, it could be argued that readmissions in the hospital due to episodes of sepsis results in productivity losses and indirect costs to the society and the patient as a whole. However, due to the fact that our analysis concerned mainly the impact of the technology on the healthcare resources no societal perspective was considered.

The potential of continuous vital sign monitoring for the early detection of deterioration is evident in the existing literature. Technologies that can be easily incorporated into existing hospital work flows to monitor vital signs can reduce patients' LoS in hospital, transfers to, and LoS in, ICUs, and readmissions, which all contribute to potential cost-effectiveness and cost-savings. This analysis contributes to the existing literature and finds similar benefits to the use of SensiumVitals to those that exist in the published literature. This model explored the likely cost-effectiveness of the use of SensiumVitals on a 30-day time horizon. The technology was found to be both less expensive and more effective than the current standard of care of intermittent vital sign monitoring.

For this economic evaluation, we adhered to the best practice guidelines recommended by NICE[19]. We conducted a range of probabilistic and deterministic sensitivity analyses to address the uncertainty of the inputs that were used in our model. This analysis represents the first evaluation of SensiumVitals and similar technologies in the UK context for the identification of early deterioration in patients admitted to surgical wards by continuous monitoring of their vital signs.

5. Conclusion

SensiumVitals is a disposable, lightweight (15 g), ultra-low power, wireless digital patch, designed to monitor patients' vital signs in surgical wards at two-minute intervals to enable early detection of clinical deterioration. While the technology yields small clinical benefits, it has the potential to be cost-saving and cost-effective compared to the usual standard practice of intermittent monitoring of vital signs. In this study, cost-savings result from reductions in LoS on the ward, hospital readmissions and ICU admission. While this analysis has some limitations, due to a lack of primary data, it suggests that SensiumVitals could aid physicians in the identification of early deterioration and consequently provide cost-savings to the health system in the UK.

Note

i. SensiumVitals is a registered trademark of Sensium, Abingdon, UK.

Transparency

Declaration of funding

This report is independent research funded by Sensium Healthcare Ltd.

Declaration of financial/other relationships

CLD, MRH, and MT have no conflicts of interest that are directly relevant to the content of this article. Device Access (MJ, AM, MBH, and JA) received funds from Sensium Healthcare during the conduct of the study.

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Author contributions

MJ, MT and MRH were responsible for developing and populating the economic model and drafting the final version of the paper. All authors provided inputs for the model, read, and approved the final draft of the manuscript.

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None.

Data availability

The authors declare that all of the data supporting the findings of this study are available within the article.

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