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Research Article

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Cost effectiveness unlocked: Redefining clinical outcomes augmented by 'Post Op' Digital Care Platform

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Abstract

Following surgery, NHS-patients are discharged from hospital with a letter to their GP, with or without a follow-up outpatient appointment. Post-operatively, they may be anxious about their recovery milestones and complications. On one hand, these issues can lead to post-operative patients seeking medical advice/care from less specialised professionals, including their GP, urgent care centres and emergency departments. On the other hand, patients may suffer complications and may delay seeking medical care, making their management more difficult. In this paper, we present a cost-effectiveness analysis to quantify the costs related to partial or ineffective post-discharge pathways for surgical patients and estimate the potential savings for NHS resources achieved by introducing an app to connect patients with the surgical team post-discharge. Considering costs from avoidable presentations to the Emergency Department, costs borne by patients, environmental costs, and costs associated with antibiotic tolerance and resistance as a result of late recognition of surgical site infections, we estimate that a digitalised postoperative care pathway can save over £60,000 per 100 patients even when accounting for the increased number of outpatient clinic follow-ups.

Keywords: Patient experience; Cost benefit; Post operative surveillance; Surgical site infection; Digital platform

Introduction

In the United Kingdom, the National Health Service (NHS) provides medical care free-of-charge to all legal UK residents (29). Over the last five years, the UK has spent around 10% of its GDP on health, totalling £181.7 billion [1]. The NHS budget varies widely, ranging from £42 per GP visit to over £400 for an Emergency Department (ED) visit and an additional £587 for each inpatient day. In a global recession and rising inflation environment [2], optimizing patient access to healthcare services and managing patient flow is crucial, aligning with recommendations [3,4].

This paper quantifies NHS and societal savings from introducing the 'Post Op' digital application, connecting post-operative patients with clinical teams for remote interactions. Piloted at a district general hospital, the app encourages patients to use it for up to sixty days post-surgery, collecting data through telephone surveys and anonymized questionnaires [5].

Patient feedback revealed that >70% believed the Post Op app prevented unnecessary healthcare visits, emphasizing reassurance as a common reason for seeking medical care [5]. Despite qualitative studies showing improved patient satisfaction and fewer complications with postoperative follow-

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up [6-8], the direct quantitative financial impact remains unexplored.

Expanding on these findings, we simulate populations with varying anxiety/complications levels, providing estimates for resource savings associated with the digital surgical follow-up app. Figure 1 identifies five domains enhancing cost-effectiveness: 1) reducing inappropriate medical care-seeking episodes, 2) preventing postoperative complication deterioration, 3) mitigating environmental costs linked to excessive hospital resource and transport use, 4) Reducing costs due to loss of productivity, and 5) alleviating patient-borne costs.

Methodology

Preliminary data from patient survey

In our previous study [5], we designed a questionnaire to assess patients' views of the Post Op app. We contacted 30 consecutive patients who had undergone a general surgical procedure and went through the questionnaire with them over the phone. Some questions asked for a rating from 1 - 6, others were binary, including questions on whether or not they felt the app had addressed concerns which otherwise would have necessitated a visit to the hospital.

The app collects data using a mobile app downloadable from Apple and Android app stores. The app is accessed through clinician invitation and the information available on the app is dictated by clinical need. The data is protected through access precautions including 2 factor authentication (FA). App development follows General Data Protection Regulation (GDPR) guidelines and is hosted on Microsoft Azure with the highest levels of data protection. The web application accessed by clinicians is protected through role-based access and 2 FA. The data is available on a web enabled dashboard, that allows for real time monitoring of patients. Integration is possible through open APIs to the tech stack which is firmly embedded in the Microsoft Azure system. Database and app is based on HL7 and latest Fast Healthcare Interoperability Resources (FHIR) recommendations and allows for safe integrations to electronic patient record systems already in the market. The app is a processor of data and control of data is held by the organisation.

The Post Op app is unique in its focus on the patient experience journey rather than on the healthcare provider. By shifting the focus of data collection towards the end user (the patient), the app endeavours to involve patients in their recovery monitoring as active participants. Traditional health visits collect information retrospectively and are designed to be 'reactionary', with poor predictive or preventive value. A patient centric app with active participation of end users involved in their own data capture is unique in the healthcare market. Cost savings are immediately realised from the reduction in the patient readmission rates, complication rates and allocation of resources more effectively. Patient outcome recording is improved through partnership with patients to transfer information in an interactive manner in real time.

The design process is human centric in that patients, clinicians and hospital administrators actively contributed to the development of the application from the start. User validation testing and workshops ensured strict adherence to user centric design processes. The effectiveness of the user interface and user experience is constantly validated through regular face to face workshops, feedback through structured and unstructured interviews of all stakeholders. This allows agile iteration of the app and leads to better engagement, retention, and experience of the app.

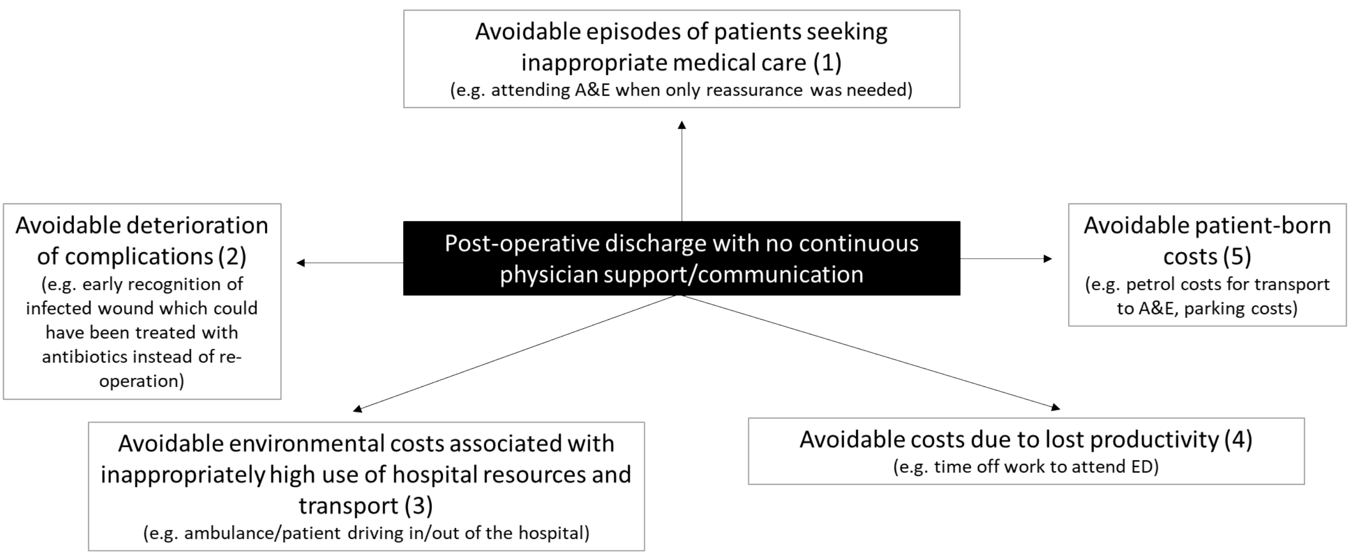

Figure 1: Schematic representation of the main classes of costs avoided by implementing a digital postoperative follow-up tool

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The app is designed by a global team located in different countries to ensure local adoption is possible. Surgical follow up is a global need that requires nuanced understanding of the local circumstances and requirements which is implemented through the use of a design and development team drawing from a rich contextual background. Since design considerations have taken into account the various differences in healthcare delivery globally, the app is more acceptable to a global market. User testing in global markets through partnership sales and pilots are core strategies that the app developers have adopted.

Estimates for NHS services cost

Our cost estimates for various levels of NHS-provided care are derived from the King's Fund latest report and the NHS Digital National schedule of reference costs [1-9]. The King's Fund, an independent charity and think tank dedicated to enhancing health and care in England, conducts impartial research on health and social care. These sources were selected for presenting unbiased and systematically reported mean nationwide costs. Table 1 provides a summary of the mean cost per event for different NHS-provided services.

Estimates for travel-associated costs

We used the HM Revenue and Customs estimate of 6.8 mi as mean distance from the patients' homes to the hospital and used this figure to calculate the mileage saved [10]. We assumed a total cost per mile of 16p, and also assumed the patients would need to pay an average cost of £1.6/h for hospital parking for an average of 3h per visit. We assumed a carbon emission of 221.4 grams per mile [11].

Table 1: Summary of mean cost per event for different NHS-provided services

Description of NHS-provided service	Mean cost per event (£)
GP visit	42
Urgent care visit	86
A&E visit with treatment	418
Ambulance visit without transport to A&E	276
General ward cost per bed day	587
Transport to A&E by ambulance	367
Hospital outpatient visit cost	201
Elective inpatient procedure	5,845

Modelling approach

We used a conservative modelling approach simulating different patient groups with varying levels of postoperative anxiety/complications. In particular, we simulated 5 groups of patients seeking 6 escalating levels of medical care as detailed in table 2. The work has been reported in line with CHEERS criteria [12].

Results

Costs associated with avoidable episodes of patients seeking inappropriate medical care

Using the framework outlined in 2.4, we simulated the costs associated with five different cohorts of patients seeking escalating levels of medical care. For each group, we simulated six increasingly expensive levels of care ranging from only ambulance call-out, to walk-in to ED with one overnight stay. Assuming a cohort of n=100 patients for each group, we estimate that the cost savings can amount to £50,000.

In particular, we note from our previous qualitative study [5] that over 70% of patients reported that using the app prevented them from otherwise seeking medical care. This finding provides preliminary evidence that the simulated patient cohort most akin to the real post-operative patient population is likely group 5 (high rates of postoperative complications/anxiety) and, thus, the most realistic savings estimates are provided by the group of bars at the far-right side of figure 2.

Costs associated with avoidable deterioration of post-operative complications

Avoidable re-operations: Surgery-related infections occur in approximately 0.5% to 3% of patients undergoing surgery as reviewed recently by Seidelman *et al*., 2023 [13], with other studies reporting significantly higher rates. In another study on a cohort of >3000 general surgical patients,

Table 2: Summary of modelling approach

Patient group	Level of post-operative anxiety/ complications	% of patients seeking medical care within the group	Type of medical care sought
1	Low	2	1. ambulance call-out with no visit
			2. GP appointment
2	Low-intermediate	20	3. walk-in to urgent care
3	Intermediate	40	4. ambulance transfer to A+E and discharged without treatment
4	Intermediate-high	60	5. walk-in to A+E, treatment and discharge without stay
5	High	70	6. walk-in to A+E, treatment and overnight stay (1 day)

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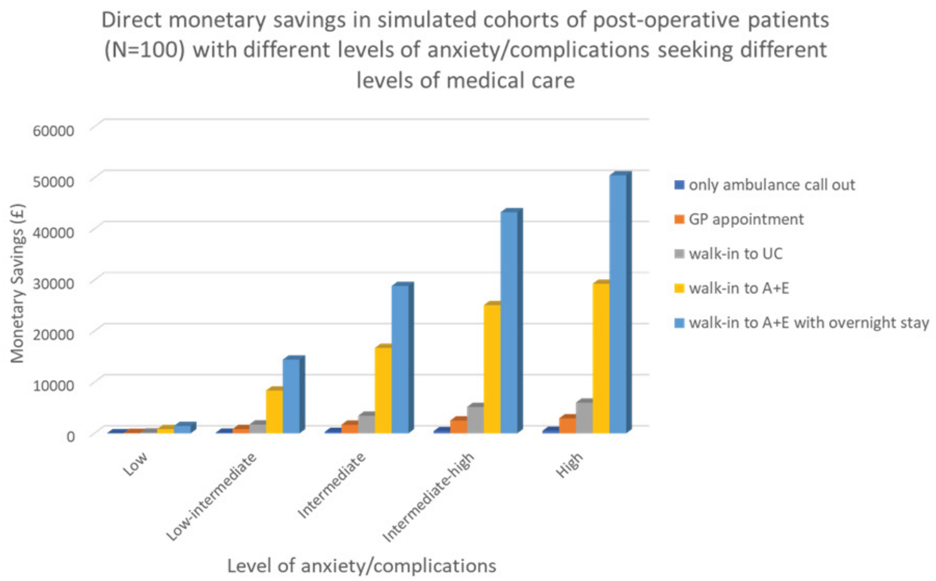

Figure 2: Graph summarising the savings associated with avoidable episodes of postoperative cohorts of patients seeking different levels of care. Monetary figures are stated per 100 patients.

3.5% experienced an unplanned return to the operating room post-discharge [14]. The mean cost per operation event at £5,845 (Table 2) and the mean re-operation rate attributable to surgical-site infections (SSI) is estimated to be 2.1% in a cohort of patients undergoing hip replacements [15]. For the purposes of our simulation, we conservatively assume that 37% of cases with SSIs will be re-operated (data from breast and general surgery using estimates from Wong *et al*., 2019 [16]) and that early detection of SSI can prevent deterioration and may be managed medically without the need for further surgical procedure. Hence, the number of avoidable re-operations per 100 patients due to avoidable SSI deterioration is equal to: % of SSIs per patients operated x %re-operation in patients with SSIs x total number of patients

Lower Limit: 0.37 x 0.005 x 100 = 0.85/100 patients

Upper Limit: 0.37 x 0.03 x 100 = 1.11/100 patients

Mean:1 further surgical procedure / 100 patients may be avoided, which equates to saving £5,845/100 patients.

Avoidable antimicrobial resistance/tolerance: Early detection of infection, sampling and antimicrobial sensitivity analyses prevents avoidable treatment with inappropriate antibiotics, extended courses of antibiotics, IV antibiotics and associated PICC line insertions and discharge-nurse visits. The estimated cost of a course of oral antibiotics is £1,488 while a course of IV antibiotics costs £3,992, a difference of £2,740 per patient [17]. Early detection of infection and treatment with narrow-spectrum antibiotics prevents costs associated with antibiotic resistance and tolerance, amounting to £1,180 per patient treated [18]. Antibiotic resistance refers to the phenomenon of bacterial populations evolving genetically in response to antibiotic treatment via a mechanism of natural selection [19], while antibiotic tolerance allows bacteria to regulate their metabolism temporarily to withstand or slow down the lethal consequences of high doses of bactericidal antibiotics but without being able to grow in their presence [20]. The relationship between antibiotic resistance and tolerance is interdependent, generating a vicious cycle [21].

If early detection of SSI can prevent 1 episode of antibiotic resistance and IV treatment in a 100-patient cohort, this would generate savings of £22,064 per 100 patients (reviewed by Poudel *et al*., 2023 [22]) giving total savings from avoidable re-operation and early detection of infection as £5,845 + £22,064 = £27,909/100 patients on average.

Costs related to avoidable environmental impact associated with inappropriately high use of hospital resources

Here, we use a previous estimate of 2 kg of CO_2 for the resources consumed per visit. For 70 patients this amounts to 2 kg x 70 = 140 kg of CO_2 per 100 patients. Next, we calculate the carbon savings for 70 patients in the UK travelling an average of 16 kilometres round trip to seek medical care. Using the UK's average emissions for cars, which is about 121.4 grams of CO_2 per km, the CO_2 emissions for one round trip would be equal to 121.4 grams/km x 16.09 km = 1,952 grams or 1.952 kg and for 100 patients = 1.952 kg x 70 = 136.64 kg of CO_2 per 100 patients.

Adding the CO_2 emissions caused by patient transport to healthcare facilities and the emissions associated with resources at the hospital gives a total of 136.64 kg (transportation) + 140 kg (resources at the hospital) = 276.64 kg or approximately 0.277 metric tons of CO_2. Thus, in the UK, by preventing 70 unnecessary hospital visits with an

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average travel distance of 10 miles each per 100 patients, we might save approximately 0.277 metric tons of CO_2, which is equal to £42 (social cost of carbon estimated at £152 per metric ton) [23].

Costs due to lost productivity

To assess the costs due to lost productivity as a result of time spent seeking unnecessary medical care, we start by looking at the age distribution of patients undergoing surgical procedures in the U.K. Data from 2015 show that 6.1% of patients are between the ages of 0 and 14 years of age, 46.4% are between 15 and 59 years of age, 26.1% are between 60 and 74 years, and 21.5% are over 75 years old [24], as summarised in the pie chart in figure 3. Given that the official state pension age in the U.K. is 66 years old [25] and that the employment rate for those in the 16-64 year-old bracket was 87.3%, we will conservatively assume that in the population of surgical patients we have: 0.873 x 0.464 x 100 = 40.5 individuals in employment/100 patients. Patients would also need to take time out to seek medical care and assuming an average hourly wage of £16.37/h (2022 data) in the UK and an average 3h per visit, the wage lost per visit is equal to £16.37 x 3 = £78.57 on average. With 40.5 individuals in employment/100 patients and a proportion of 70/100 patients visiting the hospital, that would be equal to £78.6 x 40.5 x 0.7= £2,228 per 100 patients.

Costs borne by patients associated with access to hospital

Here, we assume 70 visits per 100 patients as per self-reported findings in our study [5] and an average of 6.8 miles (10.88km) each way for East Midlands [26] to seek medical care at a price of 16p per mile [10]. This would yield a cost of: £0.16 x 13.6mi = £2.2 per trip. Assuming 70 trips per 100 patients, this would amount to £2.2 x 70 = £154 per 100 patients. Furthermore, assuming an average cost of £1.6/h for hospital parking for an average of 3h per visit, we get £1.6 x 3 = £4.8 per visit and for 70 visits: £4.8 x 70 = £336 per 100 patients. In total, the patient-borne costs per 100 patients would be equal to £(154 + 336) = £490 per 100 patients.

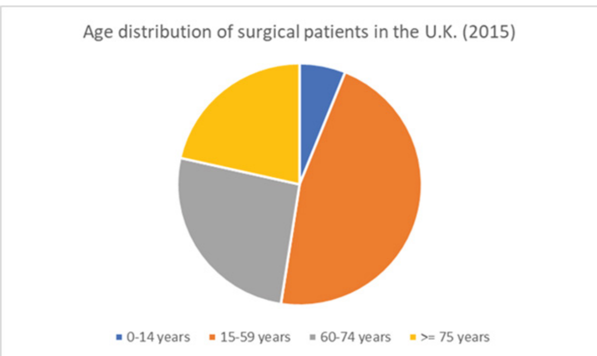

Figure 3: Pie chart summarising the age distribution of surgical patients in the U.K (data from 2015).

Discussion

Every night spent in a hospital bed adds significantly to the overall procedure costs for each patient, so over the last few years great efforts have gone into reducing the mean length of stay, and this has been accompanied by a reduction in acute hospital beds. Whilst this may be justified in health economic terms, there is a risk that patients will feel unsupported and anxious when discharged from hospital so soon after surgery. The *Post Op* application was designed to provide support for patients during this phase of their care following surgery, and patient responses in our preliminary study [5] suggests the application has succeeded in achieving this.

Obtaining an urgent visit to their GP can be challenging. It may not be the case that all our postoperative patients would have come to the hospital, some may have managed to see their GP, but on the other hand some may have ended up coming to the hospital more than once, so if these two factors balance out, taking into account the self-reported findings it seems reasonable to estimate that in a cohort of 100 patients, 70 postoperative hospital visits could be prevented, which represents a total cost saving ranging from £29,260 - £50,470.

To make our savings estimates conservative, we will also factor in the number of additional outpatient clinic visits initiated by the surgical team as part of the follow-up. Given the outpatient clinic estimate at £201, and if 50% of the patients who seek care (70/100) are called back for follow-up (and 50% will only require reassurance), the total cost will be equal to £7,035. Hence, the total cost saving from inappropriate clinical care contact episodes will be equal to £22,225 - £43,435 per 100 patients.

In addition to the potential cost saving to the service if unplanned, urgent follow-up visits are avoided, we also calculated the cost saving to the patients of these avoided hospital visits. Again, we made various assumptions; we assumed each of the 70 patients would have made one hospital visit and that they (or a relative) would have driven to and from the hospital and we cost this at 16p a mile. It is possible that patients would have used some form of public transport. It seems unlikely that a patient with a concern following surgery of sufficient severity to require a hospital visit would choose to come in on the bus, but it is possible they would have had to come by taxi. This would increase the cost, so our calculated mean cost saving to the patient may be an underestimate.

To estimate the cost of time off work, we assumed 87.3% of patients aged 16-64 years undergoing elective surgery are employed and we did not allow for patients older or younger than this being employed, so 40.5% of the total cohort would have been employed. This may be an underestimate as many older patients may still be working to supplement their pension. On the other hand, some patients may have taken

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time off work as sick leave following their surgery, and so an extra visit, while costly in other aspects might not lead to a loss of earnings.

This is only a small group of general surgical patients. Similar studies of patients in other hospitals and other specialties are needed to determine if the total economic benefits we identified are reproducible. Distances may be greater in some groups of patients and parking charges will vary between hospitals. Furthermore, we only calculated lost productivity for the 15–59-year-old bracket as this was the level of granularity in our age distribution data. However, with the state pension age being 66 years in the U.K. and individuals working past that age too, it is possible that lost productivity has been underestimated in our study, as the population of patients between 59 to 66 years old has not been included in our calculations.

Finally, we present figures for avoidable ED presentations without hospital stay (lower band) and 1-day hospital stay (higher band) separately without quantifying the proportions of each. It is likely that a large proportion of ED presentations lead to hospital stays as 12-hour waiting times have recently increased dramatically in hospitals across the country, even for patients who are not ultimately admitted [27].

Taking into account avoidable presentations to ED, costs borne by the patients, lost productivity, environmental costs, avoidable re-operations and the costs related to antibiotic tolerance/resistance, the lower boundary of total savings from a digital post-operative follow-up tool equates to £(22,225 + 490 + 2,228 + 42 + 5,845 + 27,909) = £58,739 per 100 patients and the upper boundary is £(43,435 + 490 + 2,228 + 42 + 5,845 + 27,909) = £79,949 per 100 patients. The estimates for the long-term wider and knock-on effects of antimicrobial

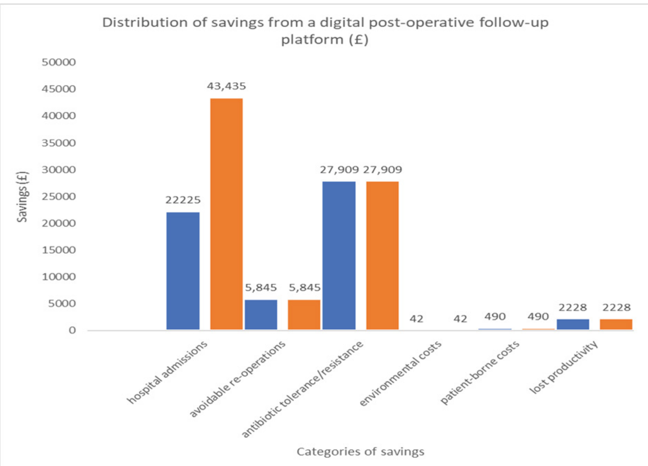

Figure 4: Bar chart illustrating the distribution of savings made by the implementation of a digital postoperative follow-up tool in a cohort of 100 patients with 70 avoidable presentations to ED either with no admission (blue) or 1-day stay (orange). Monetary figures are stated per 100 patients.

tolerance and resistance are likely to be understated and are probably higher than the conservative estimate used here [28]. Figure 4 highlights the distribution of savings for the lower boundary of £58,739 per 100 patients, showing that most savings is made from avoidable presentations to ED and prevention of antibiotic resistance/tolerance owing to early recognition and treatment of SSIs.

Conclusions

We have found that the *Post Op* application provides excellent support for most patients in the immediate postoperative period and is likely to result in a significant reduction in the number of contacts patients make with the GP or hospital, and with the Emergency Department. This results in a significant cost saving for both the service and the patients. Furthermore, earlier recognition, monitoring and appropriate treatment of SSIs provides further savings whose magnitude is likely underestimated. Finally, costs borne by the patients and environmental costs represent additional savings, which bring the total to > £60,000 per 100 patients following an operation.

Before concluding, it is important to acknowledge certain limitations within our study that future research could aim to address. Firstly, the absence of a control group composed of patients receiving standard postoperative care limits our ability to draw direct comparisons and establish causality firmly. Including a control group in future studies would offer a clearer picture of the digital tool's effectiveness over traditional care methods.

Secondly, our reliance on preliminary data from a single hospital trial and self-reported patient feedback may introduce biases and limit the generalizability of our findings. Future research could benefit from a multi-center approach and the inclusion of objective health outcome measures to validate the reported patient benefits and potential cost savings more robustly.

Furthermore, the economic analysis, while comprehensive, is based on assumptions regarding patient behaviour, healthcare utilization, and costs that may not uniformly apply across different healthcare settings or patient populations. A more detailed cost analysis that considers a wider range of variables and real-world data could provide a more accurate estimate of the potential savings.

Implementation challenges, such as varying levels of digital literacy among patients, particularly the elderly, and the need for substantial training among healthcare professionals, were not extensively discussed. Recognizing and planning for these hurdles are crucial for the successful adoption of digital health solutions across the NHS.

Incorporating these acknowledgments into our discussion, we emphasize the need for continued research and iteration on

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digital health solutions. Despite these limitations, our findings contribute valuable insights into the potential of digital tools to enhance postoperative care and generate significant savings for the healthcare system. Future studies addressing these weaknesses can build upon our work, furthering the development of efficient, patient-centered care models.

This acknowledgment serves to contextualize the study's findings, highlighting areas for future research and improvement while underscoring the value of the current research in advancing digital healthcare solutions.

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Section/item	Item No	Recommendation	Reported on page No/ line No
Title and abstract			
Title	1	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	Page 1
Abstract	2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions.	Page 1
Introduction			
Background and objectives	3	Provide an explicit statement of the broader context for the study.	Page 2
		Present the study question and its relevance for health policy or practice decisions.	Page 2
Methods			
Target population and subgroups	4	Describe characteristics of the base case population and subgroups analysed, including why they were chosen.	Pages 3-5
Setting and location	5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made.	Pages 3-5
Study perspective	6	Describe the perspective of the study and relate this to the costs being evaluated.	Pages 3-5
Comparators	7	Describe the interventions or strategies being compared and state why they were chosen.	Pages 3-5
Time horizon	8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate.	Pages 3-5
Discount rate	9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate.	Pages 3-5
Choice of health outcomes	10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed.	Pages 3-5
Measurement of effectiveness	11a	Single study-based estimates: Describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data.	Pages 3-5
	11b	Synthesis-based estimates: Describe fully the methods used for identification of included studies and synthesis of clinical effectiveness data.	Pages 3-5
Measurement and valuation of preference based outcomes	12	If applicable, describe the population and methods used to elicit preferences for outcomes.	Pages 3-5
Estimating resources and costs	13a	Single study-based economic evaluation: Describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	Pages 3-5
	13b	Model-based economic evaluation: Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	Pages 3-5
Currency, price date, and conversion	14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate.	Pages 3-5
Choice of model	15	Describe and give reasons for the specific type of decision-analytical model used. Providing a figure to show model structure is strongly recommended.	Pages 3-5
Assumptions	16	Describe all structural or other assumptions underpinning the decision-analytical model.	Pages 3-5
Analytical methods	17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty.	Pages 3-5
Results			
Study parameters	18	Report the values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended.	Page 5-8
Incremental costs and outcomes	19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost- effectiveness ratios.	Page 5-8

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Characterising uncertainty	20a	Single study-based economic evaluation: Describe the effects of sampling uncertainty for the estimated incremental cost and incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective).	Page 5-8
	20b	Model-based economic evaluation: Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	Page 5-8
Characterising heterogeneity	21	If applicable, report differences in costs, outcomes, or cost-effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information.	Page 5-8
Discussion			
Study findings, limitations, generalisability, and current knowledge	22	Summarise key study findings and describe how they support the conclusions reached. Discuss limitations and the generalisability of the findings and how the findings fit with current knowledge.	Page 8-10
Other			
Source of funding	23	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support.	Author Disclosure statement
Conflicts of interest	24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations.	Author Disclosure statement