

The Economic Impact of a Pilot Digital Day-Case Pathway for Knee Arthroplasty in a U.K. Setting

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Background: Knee replacements are an increasingly common procedure in the U.K. National Health Service (NHS). Importantly, the pathway for such procedures represents a prime opportunity to leverage digital technology, modernize and streamline the approach to care, and free up resources.

Methods: In this 21-patient pilot study, we assessed the impact of implementing a digital day-case pathway for knee replacement surgery at the Calderdale and Huddersfield NHS Foundation trust.

Results: Fourteen (67%) of the 21 eligible patients were treated as day cases, with an average length of stay of 8.8 hours. The pilot data were utilized to model the potential impact of implementing a digital day-case program more widely across the trust. This model showed increased efficiency over the entire episode of care, with reductions in physiotherapy appointments, preoperative visits, hospital days, and face-to-face consultations. Not only would these improvements free up capacity, but they would also result in an estimated saving of £240,540 to the trust while reducing the CO₂ footprint of knee replacements by 119,381 kg CO₂ emitted. A sensitivity analysis revealed that, even with substantial variation of several key variables within the pathway, a trust-wide digital day-case program would still be a cost-saving measure.

Conclusions: Overall, the present study supports the growing notion that digital technology can facilitate the transformation of care pathways, resulting in greater efficiency and financial savings for health-care providers while reducing the time patients spend in the hospital.

Level of Evidence: Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

Knee arthroplasty is a common procedure that is still growing in prevalence. Following the guidance of *Getting It Right First Time*¹ and as a result of the COVID-19 pandemic and the budgetary constraints on the U.K. National Health Service (NHS), there has been growing interest in reducing hospital length of stay (LOS) for patients undergoing knee arthroplasty. There is a wealth of international evidence demonstrating that the use of outpatient or “fast-tracked” recovery pathways is possible following knee arthroplasty without increasing the rates of readmission or complications²⁻⁴. Furthermore, such pathways have been shown to afford savings of up to \$6,800 per patient⁵.

Advancements in digital technology, alongside the generally increased uptake of smart devices across older adults, have led to a substantial increase in the use of technology for managing chronic diseases⁶. Indeed, the digitalization of care underpins the NHS Long-Term Plan, with knee replacement pathways providing an example where digital technology could

reduce LOS and increase at-home rehabilitation—the latter of which has also been demonstrated to be possible without clinical cost to the patient⁷.

In the present study, we described the impact of introducing a digital day-case pathway for knee arthroplasty in a U.K. setting. We report on the main alterations to the clinical process and on the potential financial impact of more widespread adoption of such a pathway, as modeled with use of data from the initial pilot program.

Materials and Methods

Enrolment

Patients undergoing knee arthroplasty were recruited for the pilot study from 2 separate sites within the Calderdale and Huddersfield NHS Foundation Trust in the U.K. Appropriate permissions to conduct the pilot were obtained via the Research and Development departments of the trust. Patients were recruited into the digital day-case pilot if they were able and willing

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (<http://links.lww.com/JBJSOA/A481>).

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to provide informed consent, were ≥ 18 years old, required knee arthroplasty, had access to either a smartphone or tablet, and had access to Wi-Fi in the home. Patients were excluded if they were unable for any reason to give informed consent, were unwilling or mentally/physically unable to adhere to study protocols, were undergoing any surgical procedure other than knee arthroplasty, had an American Society of Anesthesiologists (ASA) grade of ≥ 3 , or had any other factor or comorbidity that would make them unsuitable for discharge within 23 hours (Table I). If at any point during the day-case pathway any member of the clinical team felt that the patient was no longer suitable for the day-case approach, the patient was excluded from the study.

Standard Care Pathway

In the standard care pathway at the trust, a patient's suitability for knee arthroplasty would be assessed in an outpatient setting. Standard information regarding help with weight loss and stopping smoking, as well as details regarding what to expect from the procedure, are provided to the patient at this outpatient appointment. During the preadmission period, patient pre-assessment clinics and "joint school" are undertaken, with the latter being a training day during which patients are given preoperative information and "prehabilitation" exercise regimes. Thus, patients require a total of 3 separate preoperative visits to the hospital: 1 for outpatient assessment, 1 for the pre-assessment clinics, and 1 for joint school.

On the day of surgical procedure, most patients in the trust would receive a spinal anesthetic. Various anesthetic options are available for use, but most patients receive 0.5% heavy bupivacaine with or without intrathecal diamorphine. In certain circumstances, sedation, a peripheral nerve block, and/or general anesthesia are required.

Postoperatively, patients are transferred to a ward in which pain management and fluids are provided. Patients are expected to extend and flex their knee and to practice leg raising by the evening of postoperative day 0. Patients are prescribed blood thinners and pain medication, as necessary, for use beginning on the first postoperative day. In addition, patient blood tests and radiographic examinations are performed. The patient is encouraged to sit in a chair and walk to the bathroom with support, with a member of the therapy team assessing whether any equipment and/or support would be required post-discharge. Between postoperative days 2 and 4, analgesia is administered according to patient-reported pain scores. The patient is encouraged to stand, and physiotherapy is continued, including stair use and functional assessments of mobility. The patient is then assessed for discharge, provided with home care instructions and TE \leq D. (thrombo-embolus deterrent) stockings, and a follow-up orthopaedic clinic appointment is scheduled. Finally, once discharged, patients undergo community physiotherapy, averaging 6 appointments per patient. Both the standard and digital day-case pathways are summarized in Figure 1 and Table II.

Digital Day-Case Pathway

During the initial outpatient visit, patients were advised regarding the digital day-case pathway assessed for the study

TABLE I List of Risk Factor and Comorbidity-Related Exclusion Criteria

- History of falls
- Preoperative hemoglobin < 10 g/dL
- Cardiac disease and/or severe arrhythmia
- Sleep apnea
- Chronic obstructive pulmonary disease
- Stage-3 chronic kidney disease
- Previous pulmonary embolism
- Heavy smoking and/or alcohol addiction
- Epilepsy
- Insulin-dependent diabetes mellitus
- Clotting disorders

inclusion and exclusion criteria. If the patient was deemed suitable for inclusion, they were booked into the appropriate theater list and provided with the patient preoperative assessment smartphone application. We introduced a one-stop pre-assessment clinic in which the patient met with the physiotherapy and occupational-therapy teams to discuss their home circumstances, in order to ensure they were still eligible for the digital day-case pathway. In addition, at the one-stop clinic, the patient underwent pre-assessment by the anesthetist, advanced clinical practitioner, therapy teams, and pharmacist. Preoperative and postoperative care were also discussed with the patient. Finally, the one-stop clinic included joint school, in which the care team provided the patient with the remote-monitoring BPM pathway device (270 Vision), consisting of a wearable sensor (certified European Conformity class 1) to be worn around the lower leg. Full training on the device was provided, and patients were advised to complete a series of prehabilitation exercises over at least 2 to 3 weeks while wearing the device. The remote-monitoring device had an accompanying smartphone application and dashboard software for the patient and clinician, respectively, enabling 2-way communication. During prehabilitation, the physiotherapy team monitored patient process and range of motion and was able to remotely communicate with the patient as needed. Full details on the device, its clinical performance, and patient feedback during this pilot study have been previously reported⁸.

Preoperative medication included oxycodone MR (modified release) 5 to 10 mg and omeprazole 20 to 40 mg. Care was taken to ensure that the patient was well hydrated. In contrast to the spinal anesthesia administered in the standard pathway, all patients received a short-acting spinal anesthetic of 2% prilocaine plus intrathecal diamorphine and 8 mg of ondansetron.

Minor changes were made to the surgical approach as compared with the standard pathway (see Table II). First, the tourniquet pressure was reduced to 250 mm Hg in order to minimize patient thigh pain postoperatively. Additionally, a waterproof Dermabond Prineo Skin Closure System (Ethicon) was utilized in order to suppress wound infection while still enabling wound inspection and the ability for patients to go

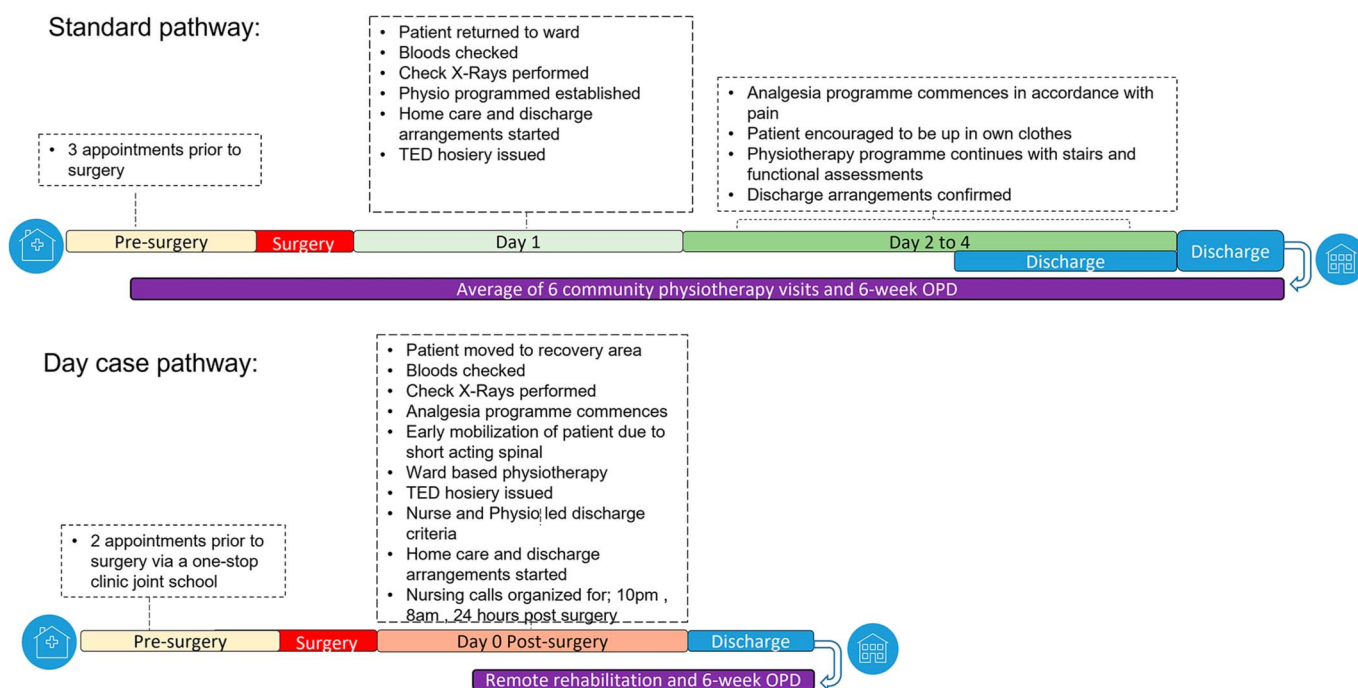


Fig. 1 A summary of the changes between the standard care pathway and the digital day-case pathway. OPD = outpatient department.

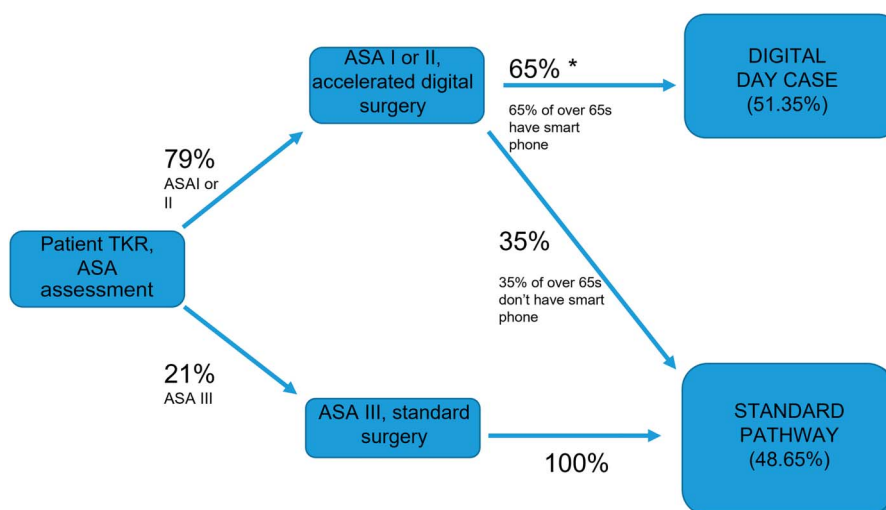
home and shower without disturbing the dressing. Surgical drains and traditional wool-and-crepe bandages were not utilized in order to psychologically steer the patient away from the concept that they had undergone major surgery, which traditionally would be followed by the use of bulky dressings. Wound infiltration was achieved with use of 60 mL of 0.25% and 0.6 mL of 1:1,000 adrenaline. The patient was supplied with intravenous (IV) fluids (with or without sedation), paracetamol 1 g, IV ondansetron 4 mg, and IV dexamethasone 6.6 mg.

Postoperative analgesia included oxycodone MR 5 to 10 mg twice daily, paracetamol 1 g 4 times daily, tramadol 50 to 100 mg 3 or 4 times daily (if an existing prescription), ondansetron 4 mg 3 times daily, and lactulose 10 to 15 mL daily. Other medication were given on an as-needed basis, including oromorphine 5 to 10 mg every 4 hours or oxycodone 5 to 10 mg

every 6 hours as well as cyclizine 50 mg every 8 hours. A rapid-mobility plan was implemented immediately postoperatively, while patients were in the recovery area where blood drawing was performed. Oral fluids were provided, and early eating and drinking were actively encouraged. Patients were then sent directly to the radiology department for postoperative radiographs. Because of the short-acting spinal anesthetic and the adequate analgesia, patients were mobilized more quickly than in the standard care pathway, undergoing 2 to 3 physiotherapy sessions prior to discharge, to the point of stair use.

There were no alterations to the discharge criteria, and patients were only discharged once the clinical team were satisfied with the movement and function of the knee. Discharge criteria included the ability for the patient to walk safely and to negotiate steps without a substantial issue. At this point, the

TABLE II Differences Between the Standard and Digital Day-Case Pathways		
	Standard Pathway	Digital Day-Case Pathway
Preoperative	<ul style="list-style-type: none"> • Majority of patients received 0.5% heavy bupivacaine with or without intrathecal diamorphine 	<ul style="list-style-type: none"> • Patients allowed to drink water up until anesthetic room • Oxycodone MR 5-10 mg; omeprazole 20 to 40 mg; ondansetron 8 mg • 2% prilocaine with or without intrathecal diamorphine
Intraoperative	<ul style="list-style-type: none"> • Wool and crepe bandages utilized 	<ul style="list-style-type: none"> • No surgical drains • No wool and crepe bandages • Dermabond Prineo Skin Closure System utilized
Postoperative	<ul style="list-style-type: none"> • Patient sent to ward for blood work and radiographs • Standard patient mobilization 	<ul style="list-style-type: none"> • Patient sent to recovery area for rapid blood work and radiographs • Early patient mobilization because of short-acting spinal anesthesia
Post-discharge rehabilitation	<ul style="list-style-type: none"> • Standard community physiotherapy and monitoring 	<ul style="list-style-type: none"> • Immediate remote rehabilitation and motoring via the BPM pathway



* 100% achievable if steps for healthcare inequalities are implemented i.e. tablets and WiFi support (not modelled)

Fig. 2 Decision tree utilized in the budget impact and sustainability model, which revealed that only 51.4% of the knee replacement patients in the trust would be eligible for the digital day-case pathway because of the requirements of an ASA grade of <III and access to a smart device. TKR = total knee replacement.

pharmacist would provide postoperative medication, including a dose of oxycodone 30 minutes before discharge. Nursing capacity was in place to ensure that patients were contacted by telephone 3 times in the first 24 hours post-discharge: once on the evening of discharge, once in the morning after, and once at 24 hours. In addition, a member of the physiotherapy team contacted the patient 48 hours post-discharge in order to again outline how to use the BPM pathway device. Over the following 6-week postoperative period, patients were continually in touch with their physiotherapy team and were monitored remotely via the BPM pathway. Follow-up appointments were arranged as needed. Scheduled follow-up appointments were performed via video call, whereas as-needed support was provided via the BPM pathway.

Budget and Sustainability Impact Model

To understand the wider budgetary impact of implementing the digital day-case program throughout the Calderdale and Huddersfield NHS Foundation Trust, a model was created with use of data from the pilot program. A decision tree was created that

showed not all patients would be suitable for the accelerated digital day-case pathway, as patients with an ASA grade of ≥III were unsuitable for discharge within 24 hours⁹ and patients without a smartphone¹⁰ were unable to utilize the remote-monitoring system (Fig. 2). Thus, only 51.4% of all possible knee arthroscopy patients in the budget-impact model were shown to be suitable for the accelerated digital day-case program, and the remaining 48.6% were budgeted according to the standard pathway.

The clinical parameters and costs utilized in the budget-impact model are described in Tables II and III. To test the robustness of the reported model, several parameters were subjected to univariate deterministic sensitivity analysis to determine the impact of variation in these parameters. Parameters were systematically varied between upper and lower bounds. Costs were varied by ±20% of the base case values (Table III), and LOS and the percentage of patients with an ASA grade of ≥III were varied by ±20%, according to guidance from the Hospital Episode Statistics database and National Joint Registry¹¹ (Table IV). Data regarding hospital LOS in the digital day-case

TABLE III Base Case and Upper and Lower Cost Parameters Utilized in the Budget Impact Model				
Parameter	Base Case	Lower Cost	Upper Cost	Reference or Other Source
Each day of bed stay	£300	£150	£450	16
Community visit	£84	£42	£126	17
Physiotherapy clinic visit	£36	£18	£54	17 and local data
Surgeon outpatient visit	£137	£68.50	£205.50	17
Surgeon teleconference	£41	£20.50	£61.50	17
BPM pathway device	£226	£177	£250	18

TABLE IV Base Case and Lower and Upper Clinical Parameters Utilized in the Impact Model*

Parameter	Base Case	Lower	Upper
Standard care pathway			
Length of stay† (days)	3.8	3	4.5
Length of stay† (hr)	90.8	72.7	109
Patients with ASA ≥III† (%)	21%	16.8%	25.2%
No. of preoperative outpatient visits	3	N/A	N/A
No. of postoperative physiotherapy community visit	6	N/A	N/A
No. of postoperative physiotherapy clinic visit	0	N/A	N/A
No. of surgeon outpatient visits	2	N/A	N/A
No. of surgeon teleconferences‡	0	N/A	N/A
Digital day-case pathway			
Length of stay (days [hr])	1.1 (26)	0.4 (9)	1.8 (43)
Patients with ASA ≥III† (%)	21%	16.8%	25.2%
Time per BPMpathway message (min)	3	1	10
No. of preoperative outpatient visits	2	N/A	N/A
No. of postoperative physiotherapy community visits†	3.3	2.6	4.0
No. of postoperative physiotherapy clinic visits	0.5	0.1	0.9
No. of surgeon outpatient visits‡	1	N/A	N/A
No. of surgeon teleconference‡	1	N/A	N/A

*Standard pathway data for length of stay were taken from Hospital Episode Statistics; for ASA grade, from the National Joint Registry; and for all remaining parameters, from local historic data. All digital day-case pathway data were taken from the present study. N/A = not applicable. †Data for the Lower and Upper columns constitute the -20% and +20% values in the model. ‡This includes visits and/or teleconferences at both the 6-week and 12-month mark.

cohort are presented as the mean and 95% confidence interval, and time spent on messaging is estimated. The underlying assumptions of the model and their justifications are provided for clinical and economic parameters in Table V and for sustainability parameters in Table VI.

Source of Funding

The BPMpathway sensors were provided free of charge courtesy of B. Braun Medical U.K., which distribute the BPMpathway. D.M.C. is employed by B. Braun, and G.W. was paid an honorarium fee by B. Braun to present this work on a B. Braun webinar.

Results

Patient Demographics

A total of 21 adult patients representing 16 total and 5 unicompartmental knee replacements were included in the study. The mean age was 57.6 years (standard deviation, 8.9 years), and there were 9 female and 12 male patients. Full patient demographics have been reported previously⁸. All patients followed the preoperative plan, attending 1 outpatient appointment prior to joint school.

Health-Care Impact of the Digital Day-Case Pathway

The digital day-case pathway resulted in no complications. The median range of motion was 109° (interquartile range, 21°) and 136° (interquartile range, 16°) at 4 and 7 weeks postop-

eratively, respectively. Patient feedback was excellent, with >94% of patients stating that they were more motivated to undertake their rehabilitation exercises because of the digital day-case pathway. Full details regarding postoperative range of motion and patient satisfaction with the digital day-case program have been published previously⁸.

The majority of patients (14 of 21) were managed as day cases, with an average hospital LOS of 8.8 hours. Five patients were managed as short-stay cases, with an average hospital LOS of 36.3 hours, and 2 patients were managed as long-stay cases, with an average LOS of >72 hours. The median LOS was 9.6 hours (interquartile range, 26 hours), with a minimum and maximum of 7 and 168 hours, respectively.

Patients were seen face-to-face by a physiotherapist only if their progression or pain required additional attention. On average, patients attended 3.9 physiotherapy visits (range, 2 to 6 visits), including 3.3 community appointments and 0.5 group clinic appointment. Patients in the standard care pathway attend an average of 6.0 appointments. In addition to face-to-face physiotherapy appointments, patients communicated with the physiotherapist team via the BPMPathway. A total of 100 messages were sent to the care team from patients, and a total of 112 messages were sent to patients from the care team, with an average of 5.3 messages received per patient. Details of messaging have been reported previously⁸. All patients received follow-up by means of a 6-week virtual review and a 12-month face-to-face review.

TABLE V Assumptions and Justifications Utilized to Build the Budget Impact Model*

Assumption	Justification	Reference or Other Source
Patients with an ASA grade of I or II are suitable for accelerated discharge	An ASA grade of \geq III represents severe systematic disease and is associated with increased rates of postoperative complications. Thus, patients with an ASA grade of \geq III are unsuitable for accelerated discharge	⁹
Only 65% of patients with an ASA grade of I or II will have a smart device and thus be eligible for the digital day-case pathway	Smart device is required for the digital day-case pathway, and only 65% of patients \geq 65 years old have a smart device	¹⁰
All ASA I or II patients with a smartphone are on the digital day-case pathway	Maximum achievable level. The actual achievable level may change	Assumption
All patients on the standard pathway attend 6 postoperative physiotherapy appointments	This is the current practice for the standard pathway	Advised clinical practice
Community visits last 1 hour	Including a 40-minute appointment and 20 minutes of travel time	Clinical expert advice
Physiotherapy outpatient appointments last 1 hour	Current standard practice	¹⁷
Consultant surgeon teleconferences last 20 minutes	Including 15 minutes for the call and 5 minutes for physician preparation	Clinical expert advice
The estimated current average length of stay following knee arthroscopy at Calderdale and Huddersfield NHS Foundation Trust is 3.78 days	Based on published 2019 HES	HES data
Responding to messages via the BPMpathway takes 3 minutes per message	A conservative estimate based on the limitation of words allowed per message	Assumption
All patients on the standard pathway patient receive 6 at-home physiotherapy visits	This is the current practice for the standard pathway	Clinical expert consensus
BPMpathway devices are bought in bulk, from 51 to 100 units per purchase	Buying 51 to 100 devices at a time represents the second most expensive buying option in the NHS supply chain—a reasonable assumption for a conservative cost analysis	Assumption
There will be 435 joint replacement patients per year per trust	This is the average according to current trust data	HES data
All patients who are suitable for the digital day-case pathway will enroll in the pathway	Maximum enrollment was assumed to highlight the potential benefit of remote monitoring. However, a lower rate of implementation is included the sensitivity analysis	Assumption

*HES = Hospital Episode Statistics.

TABLE VI Sustainability Assumptions of Impact Model

Assumption	Justification	Reference or Other Source
BPMpathway box, 105 g card and paper, recyclable	BPMpathway box materials as currently packaged	Weighed
BPMpathway USB-C charger, 16 g, reusable	Universal charger for many other devices	Weighed
BPMpathway strap, 25 g, disposed in landfill	The patient will likely throw this away	Weighed
BPMpathway device, 28 g, recyclable	Suitable for small-electrics recycling	Weighed
Patient bed day, 125 kg CO ₂ emissions	U.K., NHS emission quantification study	¹⁹
Outpatient appointment, 76 kg CO ₂ emissions	U.K., NHS emission quantification study	¹⁹
Patient distance from the hospital (as crow flies), 17.4 km	Conservative estimate	²⁰
37.6% of U.K. cars are diesel	National statistical data	https://www.gov.uk/government/statistical-data-sets/veh02-licensed-cars

TABLE VII Predicted Service Impact of Trust-Wide Implementation of the Digital Day-Case Pathway			
	Without Digital Day-Case Pathway	With Digital Day-Case Pathway	Estimated Reduction
No. of physiotherapy appointments	2,550	2,092	458
No. of preoperative visits	1,275	1,057	218
No. of patient hospital days	1,608	1,019	590
No. of face-to-face consultations	850	632	218

Economic Impact and Sustainability of the Digital Day-Case Pathway

A model was created with use of the pilot study data in order to show the potential impact of implementing the digital day-case pathway for all 435 knee arthroplasties per year at the Calderdale and Huddersfield NHS Foundation Trust, where 79% of knee replacement patients have an ASA grade of I or II¹⁰. Assuming that 65% of patients would have access to a smart device for use with the BPM pathway, a total of 218 patients (51.4%) would be enrolled in the digital day-case program. The model showed a reduction in several service parameters (Table VII), with the mean LOS improving from 3.8 to 2.4 days and with an estimated total cost savings of £240,540 (\$292,056)—even after accounting for a cost of £49,221 for the 218 remote sensors required. Furthermore, because of the reduced number of face-to-face visits,

the model predicted an incremental reduction of 119,381 kg in CO₂ emissions associated with knee replacement procedures.

Sensitivity Analysis

The univariate deterministic sensitivity analysis investigated the impact of individual parameters on the base-case savings (£240,540); the value that had the greatest influence on the total savings was the cost of the LOS, followed by the costs of surgeon outpatient appointments and community physiotherapy visits. The cost of the BPM pathway device had a minimal impact on cost savings (Fig. 3). In addition, the duration of time spent answering each message was not a strong driver of cost savings; even when varied up to 10 minutes per message, this parameter had only a minor impact on the cost-effectiveness of the model.

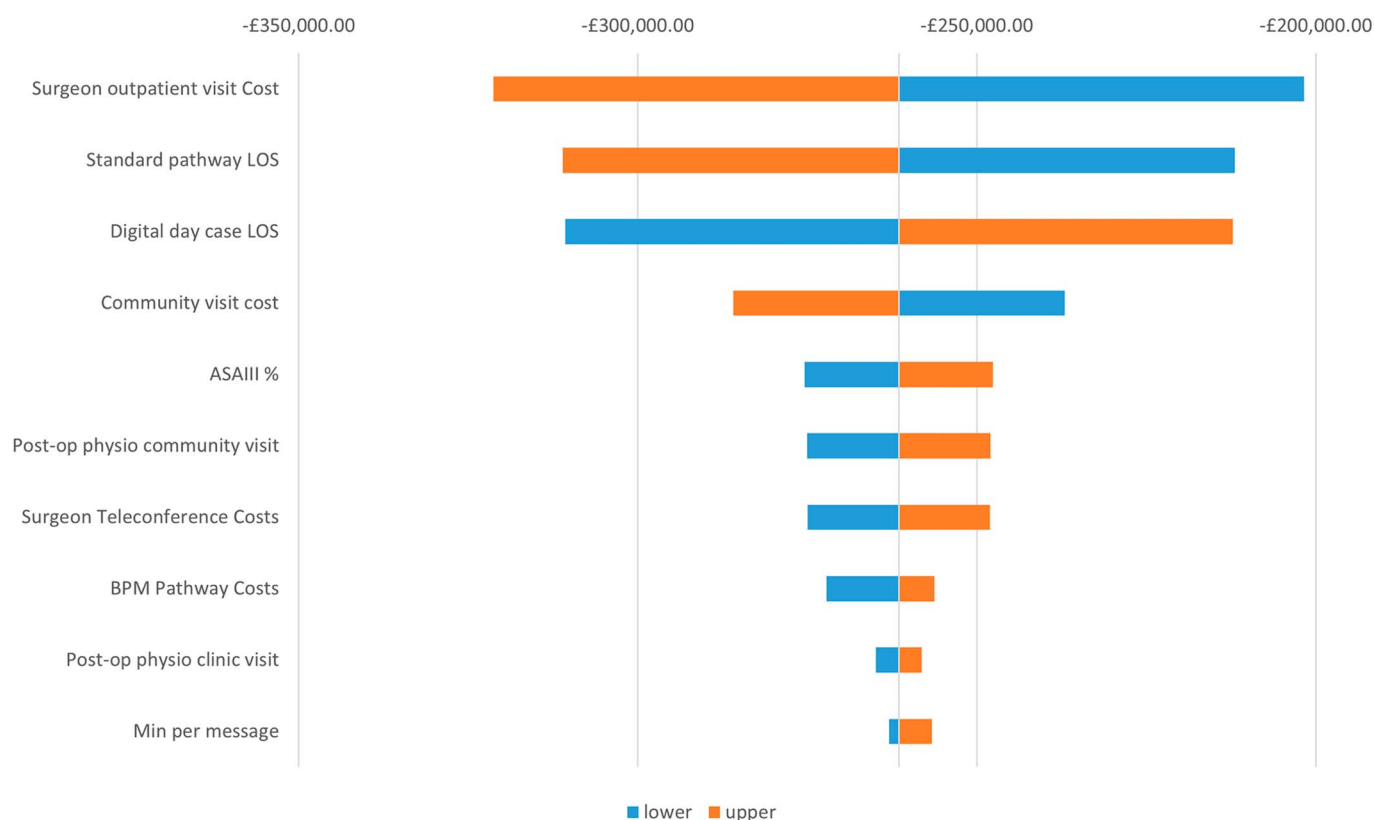


Fig. 3 Tornado plot displaying the sensitivity analysis of the budget impact model. LOS = length of stay.

Discussion

In this 21-patient pilot study, we assessed the impact of implementing a digital day-case pathway for knee replacement surgery at the Calderdale and Huddersfield NHS Foundation Trust. We found that implementing such a program resulted in several service-level improvements, including reductions in LOS and the number of preoperative and postoperative in-person visits. The present results support those of similar studies at other NHS sites, which showed reductions in LOS of up to half a day following implementation of day-case pathways¹². In the present study, the digital day-case pathway included a multifaceted set of changes to clinical care, including the use of a short-acting spinal anesthetic, early postoperative mobilization and rehabilitation, and the use of remote monitoring. Patients attended a one-stop joint school that served to educate them regarding operative and postoperative expectations; this, alongside the remote-monitoring device, allowed physicians to confidently discharge patients earlier than they would in the standard care pathway. Indeed, the use of sensor technology to digitize the rehabilitation process following joint replacement is becoming more common, with several studies reporting successful outcomes^{13,14}.

We also created a budget-impact model with use of the data from the pilot program, which revealed that a fully implemented digital day-case pathway at the Calderdale and Huddersfield NHS Foundation Trust would afford cost savings of £240,540 while at the same time freeing up resources. Importantly, these savings would not be strongly influenced by market fluctuations in the cost of the device or by the amount of time taken by physiotherapists responding to patient messages via the remote-monitoring BPM pathway device.

The most notable limitation of the present study is the small sample size on which the model was built. However,

the sample represents those patients who would be eligible for the digital day-case pathway, and the model replicates a real-world estimation, with almost half of the patients remaining on the standard pathway. In addition, the robustness of the model was tested with a high degree of variance in the parameters, and the model continued to report cost savings.

In response to the backlog of elective cases as a result of COVID-19, the NHS recently published recommendations for elective care moving forward¹⁵. The recommendation that was most pertinent to the present study was the use of digital technology to free up capacity in secondary care, including bed days and appointments, which in turn increases capacity for patients who are not suited for virtual care. Finally, the present study aligns with future NHS plans as they relate to the use of digital technology, with a government focus on the use of remote monitoring, enabling “virtual wards” that permit patients to recover in their own homes. ■

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