

A Patient-Focused Technology-Enabled Program Improves Outcomes in Primary Total Hip and Knee Replacement Surgery

Prakash Jayakumar, MBBS, BSc(Hons), MRCS(Eng), MFSEM, Jianing Di, PhD, Jiayu Fu, PhD, Joyce Craig, MA, MSc, MBA, Vicki Joughin, BMedSc, Victoria Nadarajah, BSc(Physio), MSc(Rehab), Jade Cope, BSc, Marcus Bankes, BSc, FRCS(Orth), Peter Earnshaw, FRCS, FRCSC, and Zameer Shah, MBBS, MRCS, DipSMed, FRCS, MBA

Investigation performed at Guy's and St Thomas' Hospital NHS Trust, London, United Kingdom

Background: A patient-engagement and pathway-management program for patients undergoing primary total hip and knee replacement was evaluated. Health-service and multimedia features supported by technology were integrated with existing enhanced recovery after surgery (ERAS) practices. The primary objective was to demonstrate the impact on length of stay. The secondary objective was to assess the impact on clinical, patient-focused, and financial outcomes.

Methods: Two thousand and eighty consecutive patients undergoing primary total hip replacement ($n = 1,034$) and total knee replacement ($n = 1,046$) were classified into “pre-program” (retrospectively assessed [$n = 1,038$]) and “program” (prospectively assessed [$n = 1,042$]) cohorts. Patients in the program cohort were subdivided according to those who were eligible for criteria-based outreach support (OS) ($n = 401$) and those who were ineligible for this service (NOS) ($n = 641$). Clinical outcomes were assessed for all patients, and patient-focused outcomes were assessed for a subset ($n = 223$).

Results: The mean reduction in length of stay ranged from 20% (1.2 days) to 42% (2.5 days) following total hip replacement and from 9% (0.6 day) to 31% (2 days) following total knee replacement ($p < 0.001$). Clinical outcomes (readmissions, complications, emergency department re-attendance rates) were not significantly negatively impacted. The Oxford Hip Score had numerically larger improvement after total hip replacement in the OS group than in the pre-program group (4.1-point increase), and the Oxford Knee Score had numerically larger improvement after total knee replacement in the NOS group than in the pre-program group (0.8-point increase). The patients in the program cohort (either OS or NOS) rated overall health gain as higher than those in the pre-program cohort (gain in numerical rating scale, 1.4 points for patients managed with total hip replacement, 0.6 points for patients managed with total knee replacement). Older patients and those with higher comorbidity indices benefited most with respect to length of stay and multiple clinical outcomes. Patient experience was significantly improved across domains ($p < 0.001$ to $p = 0.003$). Potential savings for patients managed with total hip replacement (£401.64 [\$267.76] per patient) exceeded estimated program charges of £50 [\$33.33] to £60 [\$40] per patient, whereas the potential savings for patients managed with total knee replacement (£76.67 [\$51.11] per patient) were sufficient to achieve a reduction of total system costs.

Conclusions: Technology-enabled programs may deliver enhanced care at lower costs for patients undergoing lower-limb arthroplasty. Shorter durations of inpatient stay without a negative impact on clinical outcomes and improved patient-focused outcomes and experience can deliver substantial value that can be especially beneficial for older patients and those with greater medical complexity.

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

Disclosure: Based on the collaborative nature of program development, the health-care company provided personnel to assist in supporting the design of the study, analysis, data interpretation, data analysis, and active involvement in drafting the work. Although no direct funding source was provided for the clinical and patient outcome evaluations within this study, York Health Economics Consortium received payment from Johnson & Johnson for advising and providing health economic expertise for the costing aspects of the study only. On the **Disclosure of Potential Conflicts of Interest** forms, which are provided with the online version of the article, one or more of the authors checked “yes” to indicate that the author received payment or services from a third party (government, commercial, private foundation, etc.) for an aspect of the submitted work and “yes” to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work (<http://links.lww.com/JBJSOA/A13>).

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Primary total hip and knee replacements are 2 of the most successful and cost-effective procedures in modern medicine, with an established positive impact on quality of life¹⁻⁵. Enhanced recovery after surgery (ERAS) can further optimize outcomes through the integration of evidence-based practices with streamlined pathways of care⁶⁻¹¹. ERAS for lower-limb arthroplasty has gained popularity over the last decade, and its components can be categorized into those involving evidence-based clinical protocols, promotion of patient engagement, and optimization of care pathways^{7,9}. Clinical protocols, including standardized anesthetic and surgical procedures, preemptive multimodal pain management, perioperative regimens, and accelerated physiotherapy, have been shown to improve outcomes¹²⁻²¹. Patient engagement includes the provision of education, management of expectations, instilling confidence, and providing motivation and support for general health and particular aspects of the inpatient episode, recovery, and rehabilitation experience. The related concept of patient activation refers to how proactive patients are as well as to their propensity to engage in adaptive health behaviors^{22,23}. These components should be integrated with a care pathway that is supported by a dedicated multidisciplinary team²⁴. To our knowledge, there have been no studies in the peer-reviewed literature evaluating the integration of clinical ERAS practices for lower-limb arthroplasty with patient and pathway features supported by a technology-based interface.

This study assessed the impact of a program (Care4Today Orthopaedic Solutions) integrating health-service and multimedia components with existing ERAS clinical protocols,

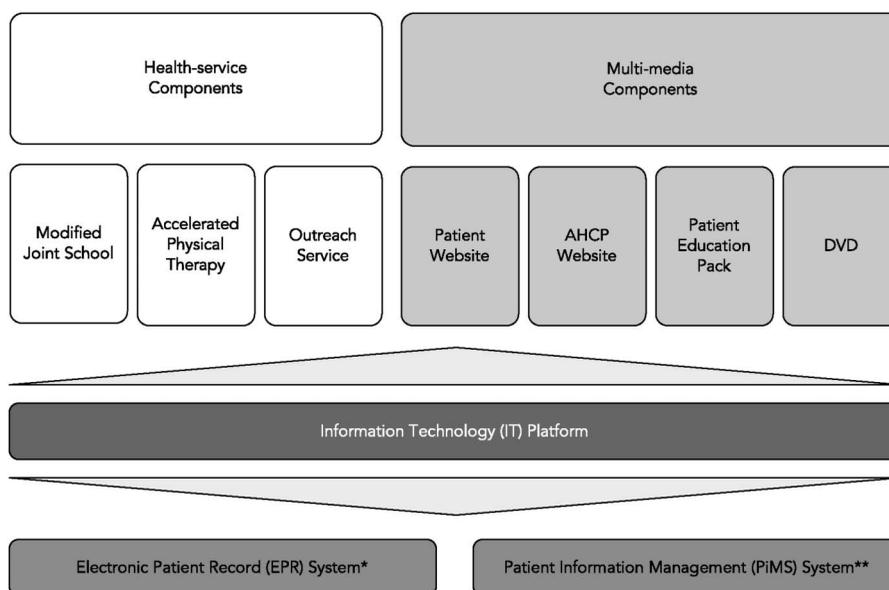
supported by a software platform. The program was developed by a health-care company (Johnson & Johnson, DePuy Synthes and Janssen Healthcare Innovation, a Division of Janssen Cilag) working in conjunction with a software-development company (Havas Lynx) in close collaboration with a university teaching hospital (Guy's and St Thomas' Hospital, NHS Trust, London, UK) (Fig. 1). Development was overseen by a core team that included key members of the orthopaedic multidisciplinary team and project leads from the health-care company. The multidisciplinary team, alongside patient champions, provided information through regular steering-committee meetings, interviews, and exercises mapping information flow through the existing care pathway. The software platform integrated with the Electronic Patient Record (EPR) system (iSOFT Clinical Manager, version 595.9, 2004) and Patient Information Management system (iSOFT Patient Manager, version 3.3.0, 2004) (Fig. 1).

All patients received the following health-service and multimedia components.

Health-Service Components

Modified Joint School

Joint schools utilizing a patient-focused video incorporating details of the program and upcoming procedure were conducted by a physiotherapist (PT) and an occupational therapist (OT). Session uptake was tracked by the Allied Healthcare Professional (AHCP) web site to maximize the delivery of preoperative education and opportunities to discuss concerns.

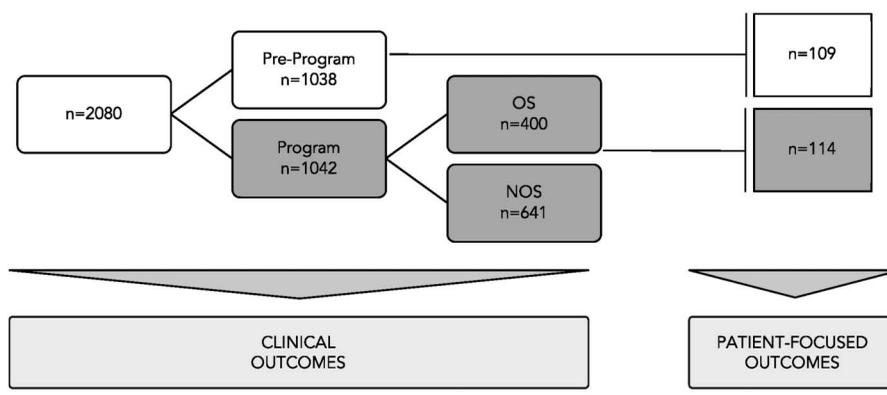


* iSOFT Clinical Manager, ver 595.9, 2004, UK

** iSOFT Patient Manager, ver 3.3.0, 2004, UK

Fig. 1

Diagram illustrating the program, which incorporated health-service and multimedia components and was supported by an information technology (IT) platform that was integrated with electronic hospital systems.



Key: OS, Outreach Support; NOS, No Outreach Support. (One TKR patient in program cohort had missing status for outreach support)

Outreach Eligibility Criteria

1. Geographical catchment
2. Satisfactory medical status
3. Satisfactory social support
4. One floor living during initial recovery period

Fig. 2 Diagram illustrating the study distribution of patients managed with total hip replacement and total knee replacement (TKR) in relation to program and outcomes.

Enhanced Accelerated Physiotherapy

Exercise information was provided preoperatively through multiple media, including online videos, with active participation being encouraged throughout. Inpatient physical therapy commenced on Day 0 and subsequently continued twice a day. Intensive early mobilization was guided by clearly visible mobility milestones within the program, taking into account the patient’s eligibility for outreach support (OS) whereby AHCPs could continue working with patients in their home setting.

Outreach Service

The work plans of the various AHCPs (nurses, OTs, and PTs) were redesigned through appraisal-based training whereby each learned key skills from the others’ disciplines (i.e., nursing staff could assess home modifications, OTs could provide exercise advice, and PTs could perform wound assessment, and vice versa). The outreach service aimed to facilitate accelerated rehabilitation and to provide home support immediately after discharge. Eligibility was based on 4 criteria: location within a specific geographic boundary from the hospital, stable medical

TABLE I Comparison of Pre-Program and Program Cohorts in Terms of Demographic Characteristics and Health Status				
	Pre-Program Cohort	Program Cohort*		
		Total	OS	NOS
Total hip replacement				
Age at admission† (yr)	58.9 ± 15.86	57.9 ± 15.94	60.2 ± 14.44	56.7 ± 16.57
Sex (% female)	62.7%	61.8%	61.8%	61.8%
CCI†	3.2 ± 2.27	3.0 ± 2.24	3.2 ± 2.21	2.9 ± 2.26
ASA grade‡ (% with ASA grade ≥3)	24.3%	24.6%	23.0%	25.4%
Total knee replacement				
Age at admission† (yr)	66.3 ± 10.23	64.8 ± 12.26	65.6 ± 10.37	64.1 ± 13.47
Sex (% female)	59.6%	61.0%	62.2%	60.0%
CCI†	4.1 ± 1.96	4.0 ± 2.07	4.0 ± 1.99	3.9 ± 2.12
ASA grade‡ (% with ASA grade ≥3)	28.1%	34.6%	33.8%	35.0%

*OS = outreach support, and NOS = no outreach support. †The values are given as the mean and the standard deviation. ‡According to National Joint Registry data⁴, 16% of the population is categorized as ASA grade 3+.

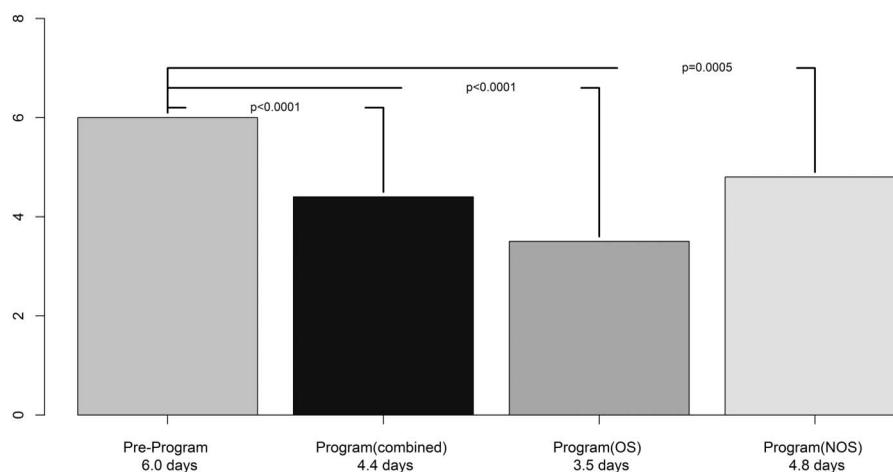


Fig. 3-A

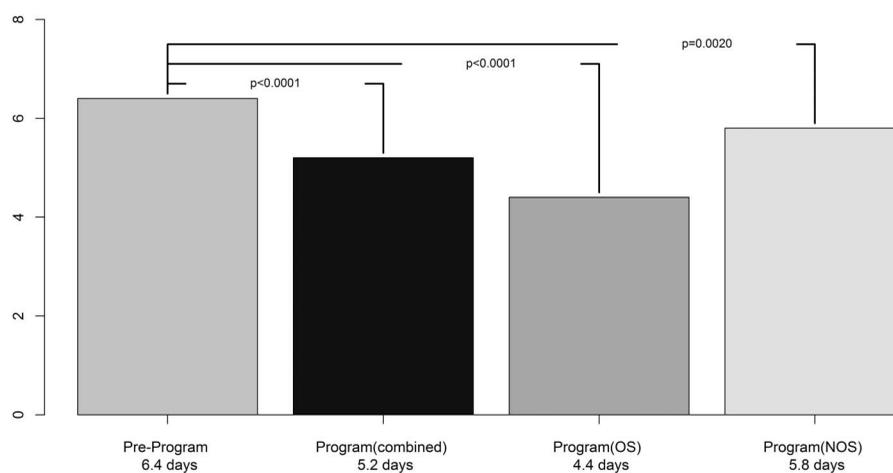


Fig. 3-B

Figs. 3-A through 3-D Length of stay and 30-day readmission by study cohort. **Fig. 3-A** Bar graph showing the mean length of stay (in days) following total hip replacement, categorized by study cohort. **Fig. 3-B** Bar graph showing the mean length of stay (in days) following total knee replacement, categorized by study cohort.

status, stable social status with support from friends and family, and the availability of ground-floor living during initial recovery. Patients who fulfilled these criteria (the OS group) experienced the entire program, including the outreach support. Patients who did not fulfill these criteria (the NOS group) experienced the remaining aspects of the program, including enhanced inpatient therapeutic input and accelerated physical therapy, but did not receive home visits.

Multimedia Components

Patient and AHCP Web Sites

The patient web site, accessible following initial registration, provided information related to general health and well-being, preparation for surgery, hospital stay and recovery at home, and a staged exercise program, along with reminders of key dates and an electronic messaging function. The AHCP web site tracked patients and managed transitions through the stages of care. It also provided a “dashboard” for key activities

(e.g., scheduling home visits, joint-school appointments) and allowed AHCPs to communicate with patients via electronic messaging. Integration with hospital electronic systems provided real-time updates.

Patient-Education Pack and DVD

Education delivered through printed packs and DVDs mirrored the online platform, accounting for patient preferences for different types of media. It also provided the information for those with less access to or proficiency with technology.

Study Objectives

The primary objective of this study was to demonstrate the impact of the program on hospital length of stay. Secondary objectives were to determine effects on clinical outcomes (30-day readmission rates, 6-month readmission rates, complication rates, and emergency department re-attendance rates, all of which accounted for demographic characteristics),

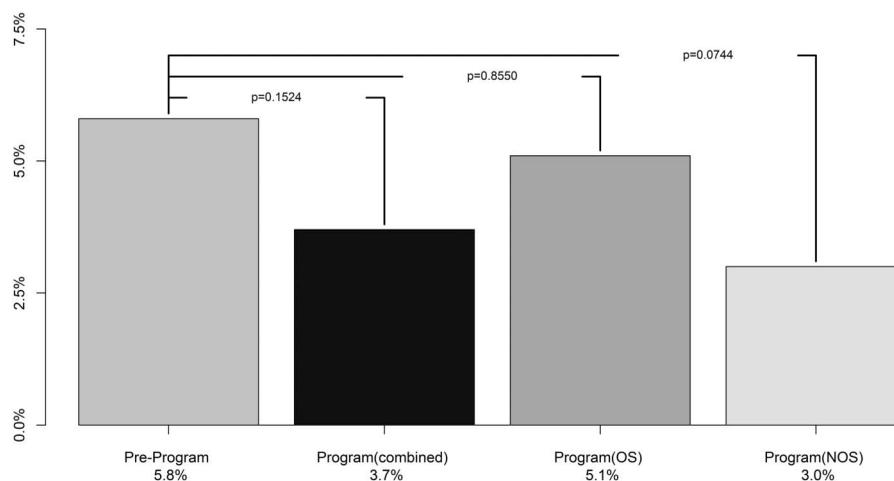


Fig. 3-C

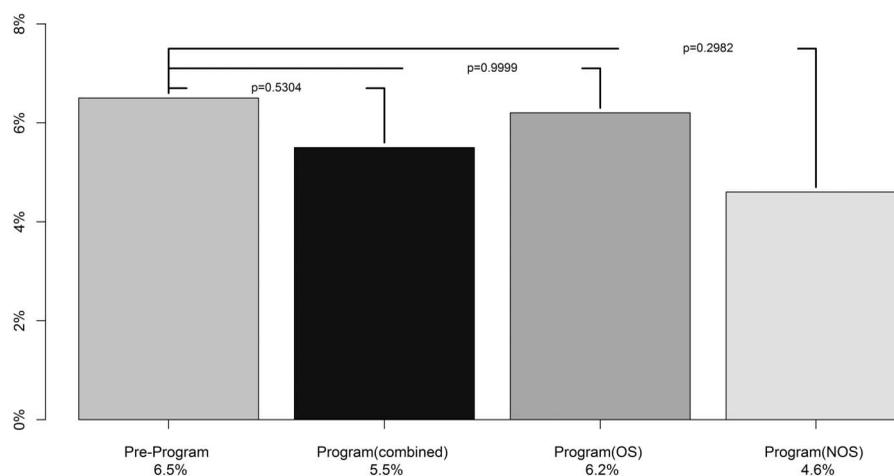


Fig. 3-D

Fig. 3-C Bar graph showing the mean 30-day readmission rate following total hip replacement, categorized by study cohort. **Fig. 3-D** Bar graph showing the mean 30-day readmission rate following total knee replacement, categorized by study cohort.

patient-focused outcomes (Oxford Hip Score [OHS], Oxford Knee Score [OKS], and general health according to a numerical rating scale [NRS]), and patient experience questionnaire. Finally, we estimated program-related costs.

Materials and Methods

A consecutive series of 2,080 adult patients (≥ 18 years of age) undergoing primary total hip ($n = 1,034$) or knee replacement ($n = 1,046$) at a United Kingdom (UK) National Health Service university teaching hospital were identified through the hospital EPR system for the period from January 1, 2012, to December 31, 2014 (Fig. 2). The initial search revealed 2,099 patients, but 19 were excluded because of procedural coding errors. Procedures were performed by 10 fellowship-trained lower-limb arthroplasty surgeons. Most patients returned to their original home setting following discharge.

The present study was approved by the local institutional review committee as a service evaluation (Institutional Review Registration No. 4,724). Patients provided informed

consent to participate in the program, and multiple measures were instituted to ensure patient confidentiality and data protection. The program commenced on June 1, 2013, and all patients undergoing primary total or knee replacement were invited to participate. Patients in the pre-program cohort were analyzed retrospectively, whereas those in the program cohort were assessed prospectively for clinical outcomes. A subset of 223 patients (132 undergoing total hip replacement and 91 undergoing total knee replacement) underwent prospective assessment of patient-focused outcomes. OHS, OKS, and NRS scores were determined preoperatively and at the 6-month follow-up visit. Patient-experience surveys were completed preoperatively, at discharge, and at the 6-month follow-up in the clinic and via post. Surveys were based on common themes found in validated health-satisfaction surveys and patient-activation measures²²⁻²⁴. Questions evaluated patient education, confidence, expectation management, and overall satisfaction (see Appendix). Only patients with scores matched over relevant time points were included in the final

TABLE II Comparison of Pre-Program and Program Cohorts in Terms of Length of Stay, Readmission Rates, Complication Rates, and Emergency Department Re-Attendance Rates

	Total Hip Replacement				Total Knee Replacement			
	Pre-Program*	Program*	% Reduction	P Value	Pre-Program*	Program*	% Reduction	P Value
Length of stay (<i>d</i>)	6.0 ± 6.8	4.4 ± 2.4	27%	<0.0001	6.4 ± 4.1	5.2 ± 3.1	19%	<0.0001
30-d readmission rate	5.8% ± 0.26%	3.7% ± 0.19%	36%	0.102	6.5% ± 0.26%	5.5% ± 0.23%	15%	0.681
6-mo readmission rate	6.2% ± 0.32%	2.7% ± 0.16%	56%	0.063	8.3% ± 0.28%	6.3% ± 0.25%	24%	0.247
Generic complication rate	9.3% ± 0.35%	7.0% ± 0.28%	25%	0.282	11.3% ± 0.38%	8.4% ± 0.28%	26%	0.211
Specific complication rate	6.4% ± 0.30%	4.1% ± 0.20%	36%	0.107	7.5% ± 0.28%	5.9% ± 0.26%	21%	0.738
Emergency department re-attendance rate	17.6% ± 0.39%	14.5% ± 0.35%	18%	0.677	19.4% ± 0.40%	15.4% ± 0.36%	21%	0.109

*The values are given as the mean and the standard deviation.

analysis. Clinical outcomes were acquired from this hospital only and were not extended to the family practice or neighboring hospitals.

Statistical Analysis

The present study was an observational cross-sectional study without randomization. Data were summarized with use of descriptive statistics for each cohort (“pre-program” and “program”) and were summarized separately for patients undergoing total hip replacement and those undergoing total knee replacement. Numerical variables were summarized as the mean and standard deviation or median and range as appropriate, and categorical values were summarized as counts and percentages. In order to account for the impact of po-

tentially unevenly balanced known or unknown subject attributes (e.g., demographic characteristics) across cohorts, and to enhance the validity of statistical inference, analyses of length of stay, readmission, and clinical outcomes were performed by controlling for the impact of baseline covariates (i.e., age, sex, Charlson Comorbidity Index [CCI], and American Society of Anesthesiologists [ASA] grade selected on the basis of the Akaike information criterion [AIC]). Exploratory adjustments were made by considering the interaction between CCI and cohort. The level of significance was set at $p < 0.05$.

On the basis of the actual data distribution, length of stay was evaluated with use of log transformation, and readmission, complication, and emergency department re-attendance data were assessed with use of Poisson regression. Subgroup analysis

TABLE III Subgroup Analysis of Reduction in Length of Stay, Readmission Rates, Complication Rates, and Emergency Department Re-Attendance Rates Following Initiation of Program, Based on CCI*

	CCI Subgroup			
	0 to 2	3 or 4	5 or 6	≥7
Total hip replacement				
Length of stay (<i>d</i>)	0.7 (<0.001)	1.0 (<0.001)	2.8 (<0.001)	6.8 (<0.001)
30-d readmission rate	1.0% (0.190)	3.5% (0.099)	2.6% (0.172)	-0.3% (0.456)
6-mo readmission rate	2.4% (0.367)	1.8% (0.067)	5.2% (0.009)	12.9% (0.011)
Generic complication rate	1.0% (0.282)	-1.4% (0.282)	7.3% (0.282)	9.9% (0.282)
Specific complication rate	1.0% (0.100)	3.6% (0.120)	1.2% (0.249)	5.0% (0.602)
Emergency department re-attendance rate	2.7% (0.676)	3.0% (0.607)	3.8% (0.802)	2.2% (0.935)
Total knee replacement				
Length of stay (<i>d</i>)	0.8 (<0.001)	0.9 (<0.001)	1.0 (<0.001)	2.6 (<0.001)
30-d readmission rate	2.7% (0.681)	0.0% (0.681)	2.8% (0.681)	-1.1% (0.681)
6-mo readmission rate	5.3% (0.247)	0.5% (0.247)	-0.5% (0.247)	7.2% (0.247)
Generic complication rate	0.2% (0.143)	2.9% (0.445)	2.0% (0.236)	6.1% (0.242)
Specific complication rate	6.7% (0.738)	2.0% (0.738)	3.8% (0.738)	2.3% (0.738)
Emergency department re-attendance rate	0.1% (0.347)	0.2% (0.123)	11.7% (0.118)	10.7% (0.236)

*The p values calculated from the multivariate regression model are shown in parentheses. Results are not adjusted by covariates (i.e. age, sex, ASA) and are directly summarized from data.

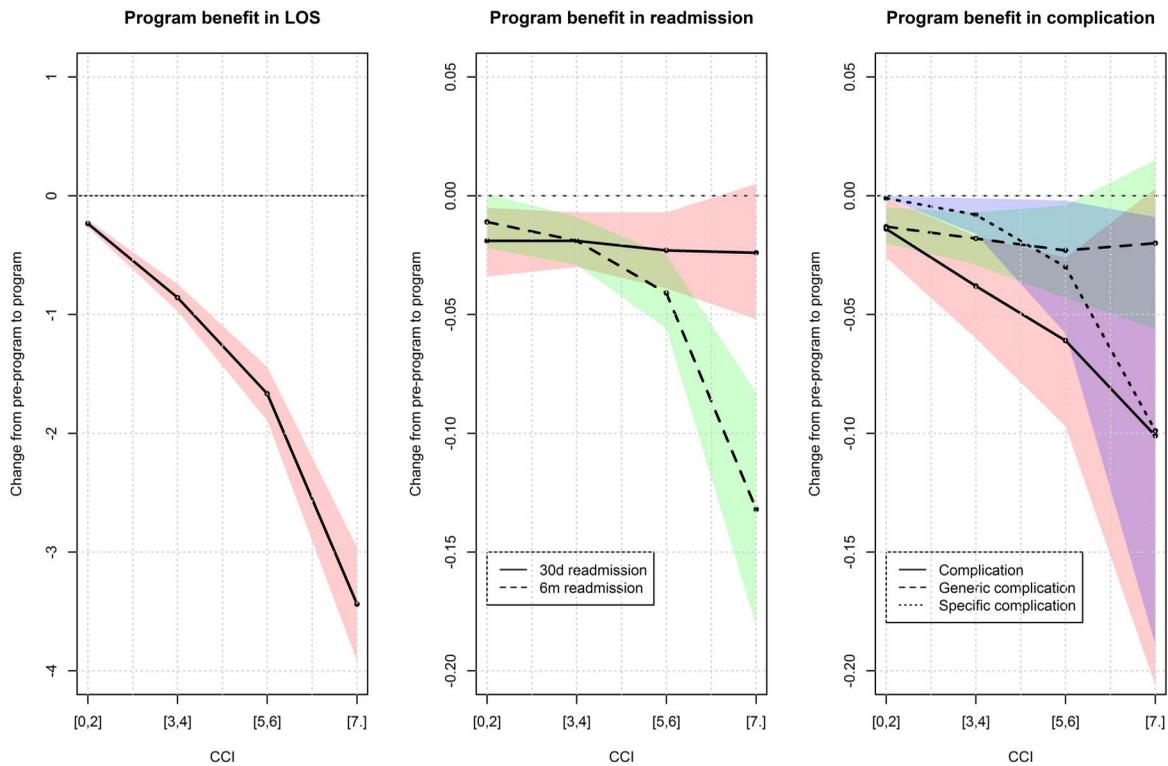


Fig. 4-A

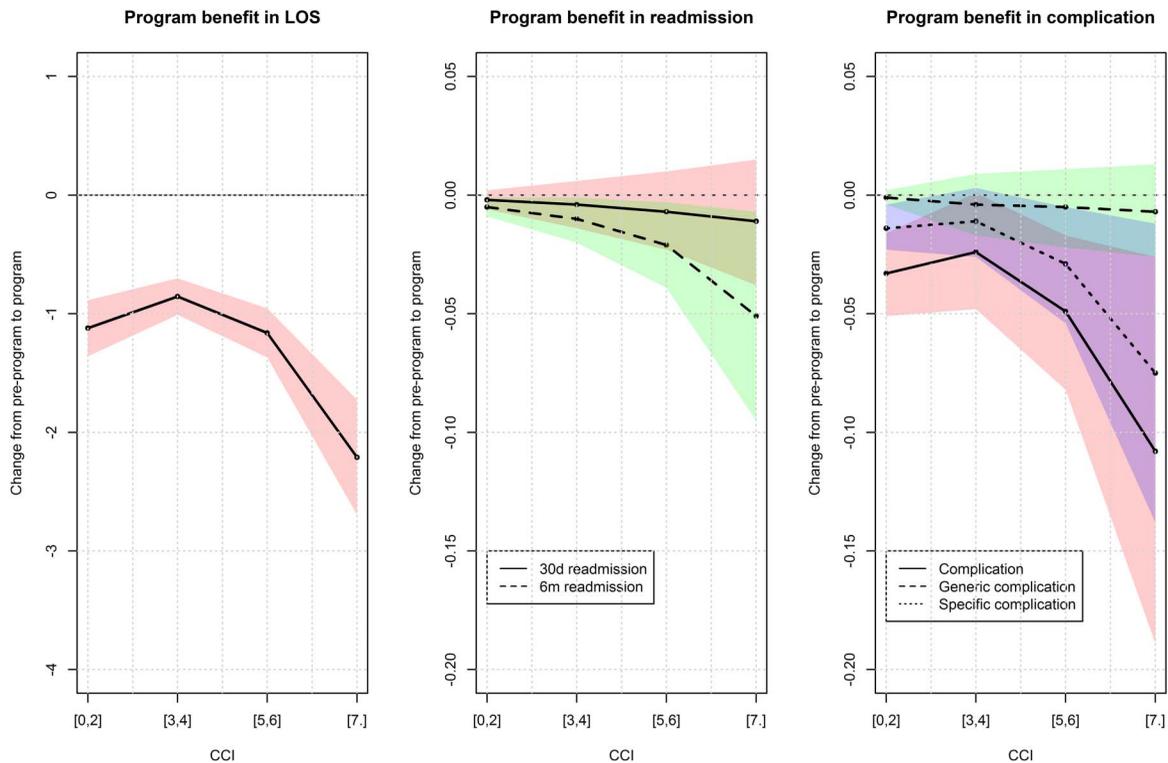


Fig. 4-B

Figs. 4-A and 4-B Outcomes by CCI. The shading represents the 95% confidence interval. Model-based results are adjusted by covariates (i.e. age, sex, ASA) for pre-program and program cohorts in different CCI subgroups. **Fig. 4-A** Illustration depicting the program-related reductions in length of stay (LOS), readmission rates, and complication rates following total hip replacement for subgroups of patients according to CCI. **Fig. 4-B** Illustration depicting the program-related reductions in length of stay (LOS), readmission rates, and complication rates following total knee replacement for subgroups of patients according to CCI.

TABLE IV Subgroup Analysis of Reduction in Length of Stay, Readmission Rates, Complication Rates, and Emergency Department Re-Attendance Rates Following Initiation of Program, Based on Age*

	Age Subgroup		
	0 to 64 Yr	65 to 74 Yr	≥75 Yr
Total hip replacement			
Length of stay (d)	0.7 (<0.001)	1.9 (<0.001)	4.2 (<0.001)
30-d readmission rate	2.1% (0.063)	1.2% (0.483)	3.2% (0.644)
6-mo readmission rate	3.1% (0.009)	3.6% (0.007)	4.3% (0.004)
Generic complication rate	0.2% (0.036)	4.1% (0.182)	6.2% (0.121)
Specific complication rate	1.2% (0.119)	5.3% (0.231)	2.0% (0.146)
Emergency department re-attendance rate	5.1% (0.293)	4.9% (0.633)	7.4% (0.482)
Total knee replacement			
Length of stay (d)	1.4 (<0.001)	0.7 (<0.001)	1.0 (0.003)
30-d readmission rate	1.9% (0.418)	3.6% (0.65)	5.7% (0.703)
6-mo readmission rate	2.5% (0.283)	1.2% (0.464)	2.4% (0.273)
Generic complication rate	3.2% (0.021)	0.7% (0.813)	6.7% (0.995)
Specific complication rate	2.5% (0.133)	0.6% (0.417)	1.7% (0.436)
Emergency department re-attendance rate	4.4% (0.051)	7.6% (0.105)	11.9% (0.26)

*The p values calculated from the multivariate regression model are shown in parentheses.

was performed on the basis of CCI score (0 to 2, 3 or 4, 5 or 6, 7+) and age (≤64 years, 65 to 74 years, ≥75 years). Patient-reported outcomes were summarized with use of descriptive statistics. Health gains from preoperatively to 6 months postoperatively were listed according to cohort and eligibility for OS. Patient-experience scores were summarized for the cohorts preoperatively, at discharge, and at 6 months postoperatively with scoring rules applied (see Appendix).

Cost Analysis

Clinical and service-performance data were combined with hospital financial data to calculate the net cost savings per patient and in total for the program. Program-related costs were deducted from total potential cost savings pertaining to the episode of care (hospital-derived costs per bed day) and the

reduction in mean inpatient length of stay. Program-related costs combined fixed and variable costs.

Fixed costs included the cost of program implementation, annual joint school, and annual staff training. Staff-related costs were derived from multiplying the cost per minute of resource (personnel) utilized (i.e., project manager, OT, PT, nurses, clinical staff trainer) by the additional time each was required to implement and operate the program. Implementation costs were allocated to use of the service over 3 years.

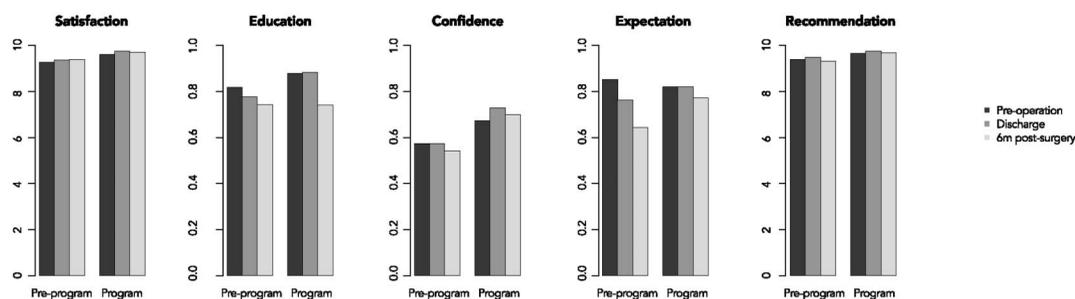
Variable costs per patient were determined on the basis of the additional time spent during pre-assessment, postoperative, and post-discharge activity combined with the salary of each involved AHCP. OTs spent additional time in the pre-assessment clinics to enroll patients; PTs spent additional time postoperatively on the ward to conduct accelerated physiotherapy

TABLE V Health Gains in Terms of OHS or OKS Score and General Health Numerical Rating Scale (NRS) Following Total Hip or Knee Replacement*

	Total Hip Replacement				Total Knee Replacement			
	Pre-Program Cohort	Program Cohort†			Pre-Program Cohort	Program Cohort†		
		Overall	OS	NOS		Overall	OS	NOS
OHS or OKS score (points)	20.1 ± 10.9	20.4 ± 11.0	24.2 ± 9.8	18.6 ± 11.3	16 ± 11.1	13.2 ± 9.3	10.8 ± 8.0	16.8 ± 10.3
General health score‡ (points)	1.424 ± 2.424	1.930 ± 3.173	2.286 ± 2.431	1.759 ± 3.502	0.577 ± 2.452	1.467 ± 2.556	1.167 ± 2.618	1.917 ± 2.503

*The values are given as the mean and the standard deviation. Health gains represent the change from pre-surgery to 6-month post-surgery for OHS, OKS and NRS. A positive value means improvement in OHS, OKS, or NRS 6 months after surgery. A larger positive value represents larger improvement. †OS = outreach support, and NOS = no outreach support. ‡Assessed with a numerical rating scale (NRS).

THR	Pre-program					Program				
	Pre-operation	Discharge	6 month post-surgery	Change from pre-operation to D/C	Change from pre-operation to 6-month post-surgery	Pre-operation	Discharge	6 month post-surgery	Change from pre-operation to D/C	Change from pre-operation to 6-month post-surgery
General satisfaction* (SD)	9.290 (1.510)	9.387 (0.844)	9.419 (0.807)	0.097 (1.491)	0.129 (1.586)	9.649 (0.889)	9.784 (0.534)	9.730 (0.652)	0.135 (0.918)	0.081 (1.038)
Education** (SD)	0.821 (0.235)	0.780 (0.217)	0.745 (0.217)	-0.041 (0.280)	-0.076 (0.259)	0.883 (0.221)	0.887 (0.195)	0.744 (0.273)	0.004 (0.211)	-0.139 (0.309)
Confidence* (SD)	0.576 (0.502)	0.576 (0.502)	0.545 (0.506)	0.000 (0.354)	-0.031 (0.467)	0.676 (0.475)	0.730 (0.450)	0.703 (0.463)	0.054 (0.524)	0.027 (0.600)
Expectation** (SD)	0.853 (0.359)	0.765 (0.431)	0.647 (0.485)	-0.088 (0.452)	-0.206 (0.479)	0.825 (0.385)	0.825 (0.385)	0.775 (0.423)	0.000 (0.453)	-0.050 (0.504)
Recommendation* (SD)	9.424 (1.062)	9.515 (1.121)	9.364 (0.962)	0.091 (1.011)	-0.061 (0.899)	9.684 (0.904)	9.789 (0.528)	9.711 (0.654)	0.105 (1.034)	0.026 (1.026)



TKR	Pre-program					Program				
	Pre-operation	Discharge	6 month post-surgery	Change from pre-operation to D/C	Change from pre-operation to 6-month post-surgery	Pre-operation	Discharge	6 month post-surgery	Change from pre-operation to D/C	Change from pre-operation to 6-month post-surgery
General satisfaction* (SD)	9.417 (1.139)	9.125 (1.513)	8.750 (2.192)	-0.292 (0.908)	-0.667 (1.786)	9.692 (0.884)	9.269 (1.402)	9.538 (0.811)	-0.423 (1.554)	-0.154 (1.190)
Education** (SD)	0.816 (0.282)	0.803 (0.262)	0.800 (0.252)	-0.013 (0.185)	-0.016 (0.341)	0.921 (0.147)	0.830 (0.248)	0.779 (0.233)	-0.091 (0.299)	-0.143 (0.299)
Confidence* (SD)	0.600 (0.498)	0.533 (0.507)	0.600 (0.498)	-0.067 (0.450)	0.000 (0.643)	0.774 (0.425)	0.677 (0.475)	0.774 (0.425)	-0.097 (0.597)	0.000 (0.577)
Expectation** (SD)	0.774 (0.425)	0.548 (0.506)	0.516 (0.508)	-0.226 (0.497)	-0.258 (0.514)	0.889 (0.320)	0.741 (0.447)	0.778 (0.424)	-0.148 (0.456)	-0.111 (0.424)
Recommendation* (SD)	9.400 (0.968)	9.400 (1.163)	9.200 (1.375)	0.000 (1.259)	-0.200 (1.562)	9.800 (0.610)	9.400 (1.329)	9.433 (1.223)	-0.400 (1.404)	-0.367 (1.450)

* Satisfaction and recommendation domains: scores were estimated by the actual points patients scored.

** Education, confidence & expectation domains: scores were estimated by the average of item scores contributing to the domain.

Highlighted in bold – Higher pre-program scores versus program scores

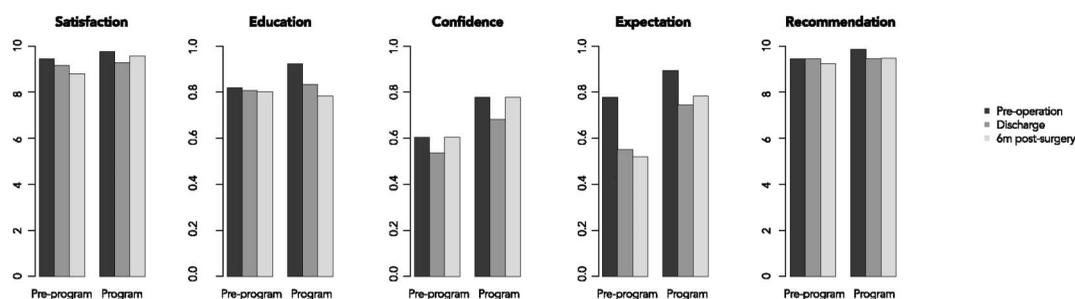


Fig. 5 Experience scores for the total hip replacement (THR) and total knee replacement (TKR) groups preoperatively, at discharge, and at 6 months postoperatively. SD = standard deviation, and D/C = discharge.

TABLE VI Fixed and Variable Costs per Patient Related to Program

	Total Hip Replacement	Total Knee Replacement
Fixed costs		
Program implementation	£11.41 (\$7.61)	£11.41 (\$7.61)
Joint school	£13.21 (\$8.81)	£13.21 (\$8.81)
Staff training	£6.86 (\$4.57)	£6.86 (\$4.57)
Total fixed costs	£31.48 (\$20.99)	£31.48 (\$20.99)
Variable costs		
Pre-assessment clinic	£42.00 (\$28)	£42.00 (\$28)
Postoperative AHCP activity	£42.00 (\$28)	£42.00 (\$28)
Home visits	£1.97 (\$1.31)	£7.28 (\$4.85)
Travel costs	£0.64 (\$0.43)	£2.33 (\$1.55)
Post-discharge AHCP activity	£8.27 (\$5.51)	£8.24 (\$5.49)
Total variable costs	£94.88 (\$63.25)	£101.85 (\$67.90)
Total cost per patient	£126.36 (\$84.24)	£133.33 (\$88.89)

TABLE VII Reduction in Cost per Patient Related to Program

Cost Per Patient	Total Hip Replacement	Total Knee Replacement
Cost of program	£126.36 (\$84.24)	£133.33 (\$88.89)
Total cost per episode of care*	-£528 (-\$352)	-£210 (-\$140)
Change in cost	-£401.64 (-\$267.76)	-£76.67 (-\$51.11)

*Cost difference based on cost per bed day and mean change in length of stay per patient.

sessions, to monitor the web site, and to perform check-up phone calls; and the OS team spent additional time after discharge to conduct home visits and to travel. Staff costs included

hospital-derived estimates that factored in the added financial burden for workers employed in the capital city (entitled London weighting) national insurance, and superannuation costs. Mean travel costs per journey were multiplied by the total number of journeys to provide travel costs.

Results

Ninety-nine percent of patients who were scheduled to undergo primary total hip or knee replacement enrolled in the program following its commencement. The pre-program (n = 1,038) and program (n = 1,042) cohorts were comparable in terms of demographic characteristics and levels of medical comorbidity (Table I). The reduction in mean length of stay ranged from 20% (1.2 days) to 42% (2.5 days) after total hip replacement and from 9% (0.6 day) to 31% (2.0 days) after total knee replacement (p < 0.0001) (Figs. 3-A and 3-B). The reduction in 30-day readmission rates was not significant (Figs. 3-C and 3-D).

Thirty-day and 6-month readmission rates, generic and specific complication rates, and emergency department re-attendance rates improved in association with the program (Table II). Subgroup analyses of comorbidity according to CCI group demonstrated that patients with higher CCI values had greater reductions in mean length of stay in association with the program after both total hip replacement and total knee replacement (Table III and Figs. 4-A and 4-B). No increases in subsequent readmissions, re-attendances, or complications were observed in any subgroup. Further subgroup analysis by age demonstrated greater reductions in length of stay, readmission rates, generic complication rates, and emergency department re-attendance rates following the program among patients who underwent total hip replacement at an age of ≥75 years and in 30-day readmission rates, generic complication rates, and emergency department re-attendance rates among patients who underwent total knee replacement at an age of ≥75 years (Table IV).

Patients in the OS group had greater health gains in terms of the OHS following total hip replacement, and patients in the NOS group had greater health gains in terms of the OKS after total knee replacement (Table V). Patients in the NOS group who underwent total hip replacement and patients in the OS group who underwent total knee replacement had lower health

TABLE VIII Overall Cost Reduction Related to Program

	Total Hip Replacement	Total Knee Replacement
Overall program costs		
Fixed costs	£16,403 (\$10,935.33)	£16,781 (\$11,187.33)
Variable costs	£49,428 (\$32,952)	£54,286 (\$36,190.67)
Total costs	£65,831 (\$43,887.33)	£71,067 (\$47,378)
Overall cost difference*	-£275,123 (-\$183,415.33)	-£112,106 (-\$74,737.33)
Total change in costs	-£209,292 (-\$139,528)	-£41,039 (-\$27,359.33)
Overall total cost reduction	-£250,331 (-\$166,887.33)	

*Based on cost per bed stay and mean change in length of stay for all episodes of care.

gains compared with the pre-program cohort. In contrast, both the OS and NOS groups within the program cohort had greater gains in terms of the NRS for general health and well-being in comparison with the pre-program cohort following both hip and knee replacement. Almost all patient-experience scores were greater across all time points across domains for the program cohort as compared with the pre-program cohort (Fig. 5).

Total program costs were £126.36 (\$84.24) (total hip replacement) and £133.33 (\$88.89) (total knee replacement) per patient (Table VI). Cost-savings following the length-of-stay reduction were £401.64 (\$267.76) (total hip replacement) and £76.67 (\$51.11) (total knee replacement) per patient. Deducting the total program costs from the total savings resulted in net savings of £250,331 (\$166,887) over 18 months (Table VII and Table VIII).

The costs and savings in the present study are specific to this pilot hospital site. Sites that acquired the program following its commercialization were determined to have incurred a program fee estimated to be £50 (\$33.33) to £60 (\$40) per patient. The savings identified for patients undergoing total hip replacement (£401.64 [\$267.76]) comfortably exceeded that range, whereas the savings of £76.67 (\$51.11) for those undergoing total knee replacement were sufficient to enable sites to reduce total system costs with the program.

Discussion

Established ERAS programs for total hip and knee replacement have demonstrated reductions in postoperative length of stay, readmission rates, complication rates, and perioperative morbidity rates; lower blood transfusion rates; earlier mobilization; and higher patient-reported outcomes and satisfaction ratings compared with conventional care^{11,25-32}. The program described in the present report focused on patient activation and pathway optimization alongside established clinical ERAS practices, supported by technology, and demonstrated positive clinical, patient-focused, and financial outcomes overall.

Our findings must be considered in light of the limitations of the study. First, multiple components are involved in the program, making it challenging to systematically identify the most influential factors while accounting for confounding variables. The positive influence of organizational change management was also crucial but was difficult to quantify.

Second, although all patients were invited to participate in the program in order to limit the risk of selection bias, demographic factors such as socioeconomic status and education level may have influenced outcomes but were not assessed. Notably, however, both the pre-program and program cohorts were comparable with the general population according to demographic data from the UK National Joint Registry⁴.

Third, ERAS pain, anesthetic, and surgical protocols were difficult to define and varied among the surgeons. Overall, however, protocols were well-established prior to the study and did not change during the study period.

Fourth, clinical outcomes were captured in our center only, and it is possible that patients presented with problems to family practices or other hospitals. However, the rate of this

occurrence is likely to be relatively low given that most patients in the study were within the geographic catchment.

Fifth, the software, technology, and content-development costs were largely borne by the company and were not charged to the project as the hospital was a pilot research and development site. Program development and implementation costs shared between the hospital and company were difficult to quantify, not least because of variation at different phases of the project. In addition, no information technology-related operating costs (e.g., re-entry of data during system failure or maintenance) were included in the analysis once the program was established. Although such costs also were difficult to quantify, they also were extremely rare. The current estimate of charges accounts for these factors, such that any future site initiating the program should still achieve net savings. Finally, psychological factors have been shown to have a significant influence on clinically important functional improvement in patients managed with lower-limb arthroplasty^{25,33}. Although knee and hip-specific disability and general health were assessed, mental and emotional health were not.

This program demonstrated significant reductions in length of stay after both primary total hip replacement and primary total knee replacement. Although shorter lengths of stay may be reported in many arthroplasty units⁴, the observed reductions were considered to be substantial in the context of a service within a universal health-care system serving a range of patients, including those with multiple medical problems. Furthermore, most patients returned to their home setting following OT clearance, and ambulatory care was not routinely available. The savings achieved through reduced length of stay exceeded the costs generated by increased patient contact, longer pre-admission assessments, program registration, training, and home visits. It is recognized that a key component of reducing length of stay and achieving safe, early discharge within arthroplasty care involves early attention to patient expectations, discharge planning, and the management of staff mindsets. Length of stay and multiple clinical outcomes appeared to be further improved in older patients and those with higher comorbidity indices. The increase in medical complexity and gradual reduction in adaptive capacity in the aging adult is well recognized³². Thus, the program may provide additional benefit to those in greater need and supports the consideration that older, more medically complex patients may have the most to gain from orthopaedic enhanced recovery³⁴.

The demands of transferring rehabilitation efforts to the community and providing resources for outreach physical therapy services have been highlighted¹⁶. However, outreach support of this nature involving service redesign and cross-discipline training has not been well described. The outreach support service was utilized more frequently after total knee replacement than after total hip replacement, and the associated health gains were mixed. Patients in the OS group who underwent total knee replacement and patients in the NOS group who underwent total hip replacement had lower health gains in terms of the OKS or OHS than those in the pre-program cohort, respectively,

whereas general health and well-being was improved in all groups in both the OS and NOS groups within the program cohort. As previously stated, other factors such as psychosocial status in these groups may have explained the variations in knee and hip-specific disability. This possibility requires further assessment.

Systematic reviews have highlighted the lack of evidence on patient experience in orthopaedic ERAS programs alongside the need to standardize its measurement^{11,35}. Optimizing patient experience and managing their expectations around length of stay is especially important in order to avoid triggering anxiety, fear, ineffective coping, and avoidance behaviors³⁵. There is increased interest in quantifying patient activation with the development of contemporary patient-activation measures (PAMs)^{22,23}. Early work utilizing PAMs in lower-limb arthroplasty has demonstrated a direct correlation with satisfaction and improved pain relief, mental health, and physical function³⁶. Future studies involving patient engagement-related interventions may be well placed to utilize these measures.

Program integration with existing clinical services and electronic platforms alongside resource-related costs naturally provides some challenges. However, the present study demonstrates the substantial benefits achievable through collaborative development, implementation, and application of a program that augments joint-replacement surgery. This patient-centered program appeared to drive efficiencies in the real-time management of patients undergoing total hip and knee replacement while demonstrating a positive impact on clinical effectiveness, cost-effectiveness, and patient-focused outcomes throughout the pathway of care.

Appendix

Scoring and Scaling Criteria for Patient-Experience Questionnaire

Education, Confidence, and Expectation Domains

One point was scored for patients answering “Completely,” “Yes, completely,” “The right amount of information,” or

“Very confident” in response to the relevant questions for each of these domains. One point was also scored for those responding with ≥ 6 on the 11-point ordinal scale. All other answers were scored with 0 points for each question. A final total domain score (DS) was calculated on the basis of the average of the item scores contributing to each domain (i.e., $DS = [Q1 + Q2 + \dots + Qn]/n$).

Satisfaction and Recommendation Domains

Each of these domains involved only 1 question, and responses were scaled from 0 to 10 points. ■

Prakash Jayakumar, MBBS, BSc(Hons), MRCS(Eng), MFSEM¹
 Jianing Di, PhD²
 Jiayu Fu, PhD²
 Joyce Craig, MA, MSc, MBA³
 Vicki Joughin, BMedSc⁴
 Victoria Nadarajah, BSc(Physio), MSc(Rehab)⁵
 Jade Cope, BSc⁵
 Marcus Bankes, BSc, FRCS(Orth)⁵
 Peter Earnshaw, FRCS, FRCSC⁵
 Zameer Shah, MBBS, MRCS, DipSMed, FRCS, MBA⁵

¹Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, University of Oxford, Nuffield Orthopaedic Centre, Oxford, United Kingdom

²Janssen Healthcare Innovation, a Division of Janssen Cilag Ltd., High Wycombe, United Kingdom

³York Health Economics Consortium, Heslington, York, United Kingdom

⁴Johnson & Johnson Medical Devices, Beeston, Leeds, United Kingdom

⁵Department of Trauma and Orthopaedics, Guy's and St Thomas' Hospital NHS Trust, London, United Kingdom

ORCID iD for P. Jayakumar: [0000-0003-2598-2509](https://orcid.org/0000-0003-2598-2509)

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