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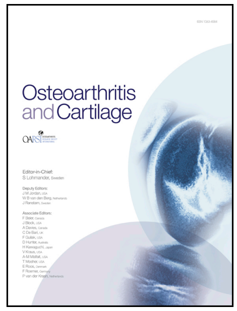

Impact of a National Enhanced Recovery After Surgery Programme on Patient Outcomes of Primary total Knee Replacement: an Interrupted Time Series Analysis from "The National Joint Registry of England, Wales, Northern Ireland and the Isle of Man"

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Impact of a National Enhanced Recovery After Surgery Programme on Patient Outcomes of Primary total Knee Replacement: an Interrupted Time Series Analysis from "The National Joint Registry of England, Wales, Northern Ireland and the Isle of Man".

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ABSTRACT

Objective: We aimed to test whether a national Enhanced Recovery After Surgery (ERAS) Programme in total knee replacement (TKR) had an impact on patient outcomes.

Design: Natural-experiment (April 2008-December 2016). Interrupted time-series regression assessed impact on trends before-during-after ERAS implementation.

Setting: Primary operations from the UK National Joint Registry were linked with Hospital Episode Statistics data which contains inpatient episodes undertaken in NHS trusts in England, and PROMs.

Participants: Patients undergoing primary planned TKR aged ≥18 years.

Intervention: ERAS implementation (April 2009-March 2011).

Outcomes: Regression coefficients of monthly means of LOS, bed day costs, change in Oxford knee scores (OKS) 6-months after surgery, complications (at 6 months), and rates of revision surgeries (at 5 years).

Results: 486,579 primary TKRs were identified. Overall LOS and bed-day costs decreased from 5.8 days to 3.7 and from £7607 to £5276, from April 2008 to December 2016. OKS change improved from 15.1 points in April 2008 to 17.1 points in December 2016. Complications decreased from 4.1 % in April 2008 to 1.7 % March 2016. 5-year revision rates remained stable at 4.8 per 1000 implants years in April 2008 and December 2011. After ERAS, declining trends in LOS and bed costs slowed down; OKS improved, complications remained stable, and revisions slightly increased**.**

Conclusions: Different secular trends in outcomes for patients having TKR have been observed over the last decade. Although patient outcomes are better than a decade ago ERAS did not improve them at national level.

INTRODUCTION

Between April 2009 and March 2011 the UK Department of Health implemented an Enhanced Recovery After Surgery (ERAS) Partnership Programme[1] to improve recovery in colorectal, musculoskeletal, gynaecology and urology surgical pathways. The first year of the programme focussed on learning best practice from pioneer units of ERAS practice in the NHS. It collected information about principles of enhanced recovery, clinical elements of the patient pathway, metrics and success factors. It established a website to share information and resources, generated a financial and equality impact evaluation, published an implementation guide, and developed an online reporting tool to support implementation. A lead for enhanced recovery was named in each local health authority to prepare for a programme of spread and adoption across the NHS during the ERAS implementation in the second year of the programme.

Hip and knee replacement were the focus of ERAS in musculoskeletal care. ERAS is a complex intervention[2, 3] that focuses on several areas of care across patients' pathways through surgery: pre-operatively (for the patient to be in the best possible condition for surgery); peri-operatively[4] (the patient has the best possible management during and after their operation); post-operatively (the patient experiences the best rehabilitation). The intervention includes provision of information before and after surgery, comprising elements such as making changes around the home, strengthening exercises, and changes to nutrition. For patients in whom it is suitable, ERAS aims to enable earlier return home from hospital with tailored discharge. A greater number of frail older people with complex co-morbid conditions now receive hip/knee replacement surgery. The new ERAS pathways' could specifically benefit these patient groups[5].

There is limited evidence concerning the effectiveness of ERAS programmes[6], particularly when applied nationwide across a healthcare system with variation in the way hospitals organise enhanced recovery services and it is unclear which way is best. Length of stay (LOS) has been declining prior to the intervention, and we hypothesised that after the implementation of ERAS, this downward secular trend would decline faster. For the outcomes of complications, revision, pain and function, we did not have a specific a-prior hypothesis as it is unclear what impact ERAS would have on these outcomes. Our aim is to see if introduction of the ERAS programme for knee replacement has led to improved patient outcomes: less knee pain and better knee function, fewer surgical complications, fewer revision operations and reduced LOS.

METHODS

Study design

We used a natural experimental study design[19]. We evaluated the impact of ERAS on trends before (April 2008 to March 2009), during (April 2009 to March 2011) and after the intervention (April 2011 to December 2016) [20, 21] (Supplementary Figure S1). The timing of implementation of ERAS varied by trust and was assumed to span the 2 years of the implementation period (April 2009 to March 2011).

Participants and inclusion criteria

We included only patients receiving elective surgery (Fig. 1) between 1 April 2008, and 31 December 2016. We excluded patients without a concordant date of surgery between the UK National Joint Registry (NJR) and Hospital Episode Statistics (HES) databases.

Further exclusions were made specific to the outcome being analysed. For LOS we excluded patients staying more than 15 days at hospital. Patients with missing data for LOS were excluded. We excluded patients without information on baseline and/or 6-months follow-up for the analysis of change in OKS. However, we used all patients in a sensitivity analysis after imputing missing values. For complications we excluded patients with surgery after June 2016 to guarantee all patients had at least 6-months of follow up. For revision at 5 years we excluded patients receiving surgery after 2011 to ensure all patients had at least 5-years follow up.

[Fig. 1. near here]

Data source

We used the NJR to obtain data on primary knee replacements. NJR contains data on knee replacement surgeries from 149 UK National Health Service (NHS) trusts. NJR includes 2 million patients since 2003, covering 96% and 90% of primary knee replacements and knee revisions, respectively[7].

Data linkages

Primary operations were linked with HES data which contains records of all inpatient episodes undertaken in NHS trusts in England (125 million each year). Knee replacements were linked to Patient Reported Outcome Measures (PROMs). A cohort of patients undergoing primary total knee replacement (TKR) in England, UK, was retrieved for the period April 2008 to December 2016.

Outcome measures

We evaluated trends for LOS at hospital for patients undergoing primary TKR. LOS was calculated as the number of days between hospital admission and discharge date. Time points for the trends were monthly mean LOS. We estimated the inpatient cost relating to the index episode using NHS reference costs from 2015/16[8]. We estimated the mean cost per bed day based on the healthcare resource use (HRG) for each patient and their LOS (Appendix 1). Monthly mean bed-day costs were the unit of analysis for costs trends.

We assessed absolute change in OKS. Patients complete the same questionnaire about their knee pain and function before and 6 months after surgery[9]. Each question is scored between 0 (worse symptoms) and 4 (least symptoms). Scores from these 12 questions are added getting a total score spanning from 0 (worst possible) and 48 (best possible score). We calculated the absolute difference (change) between baseline and 6-month follow-up scores. Higher positive values for OKS change measure represented greater improvement. OKS trends were obtained by calculating the monthly mean OKS change scores.

We estimated mean 6-month complication proportions aggregated by month. We defined post-operative complications as one or more events from the following list: stroke (excluding transient ischaemic attack), respiratory infection, acute myocardial infarction, pulmonary embolism/deep vein thrombosis, urinary tract infection, wound disruption, surgical site infection, fracture after implant, complication of prosthesis, neurovascular injury, acute renal failure and blood transfusion (Appendixes 2 and 3).

We evaluated the rate of revision at 5 years by month of primary TKR. We included revisions declared to the NJR registry by the surgeons[10] and revisions reported to HES using codes from Appendix 4. We specified our analysis time in years reporting the rate as number of revisions per 1000 implant-years.

Intervention

The period of the national ERAS implementation (April 2009 to March 2011). During the first year the programme focused on identifying best practice, determining clinical elements of the patient pathway, publishing an implementation guide, supporting early adopters of the programme to better understand key factors for implementation and sustainability[11]. During the second year ERAS supported local health areas for delivering and commissioning implementation of ERAS.

Potential modifiers

Whether trends in LOS and OKS differed by age (18-59, 60-69, 70-79, 80-84, ≥85 years) and presence of co-morbidities according to the Charlson classification[12] (none versus one or more comorbidities) (Appendix 5).

Missing data

We used Pearson's χ^2 statistic to evaluate missingness for OKS across categories of study period (before, during, and after ERAS), age and presence of co-morbidities. OKS at baseline and 6 months was imputed as a sensitivity analysis. We generated a single imputed dataset using a chained equation across 50 iterations to reach a stationary distribution.

Statistical analysis

We described the trends by calculating monthly outcomes, being means (LOS, bed costs, OKS), proportions (complications), rates (revision), together with their 95% confidence intervals (CI). We estimated a fractional polynomial over the study period and plotted the resulting curve along with the confidence interval of the mean.

We used an interrupted time series approach to estimate changes in outcomes during and immediately following the intervention period while controlling for baseline levels and trends. We modelled aggregated data points of each outcome of interest by month using segmented linear regression[13].

$Y_t = \beta_0 + (\beta_1 * \text{time}_{\ t}) + (\beta_2 * \text{ERAS}_0) + (\beta_3 * \text{time after ERAS}_0) + (\beta_4 * \text{ERAS}_{\ end}) + (\beta_5 * \text{time after ERAS}_{\ end}) + e_t$.

Yt is the mean number of days at hospital in month t for LOS outcome; mean OKS change in month t for the PROMs outcome; mean proportion of complications in month t for the 6-month complications outcome; and mean rate of revisions in month t for the 5-year revision outcome. “time” is a continuous variable representing number of months from the start of observation period at time t. Each phase of the study has two parameters: baseline level and trend:

- Pre-intervention period. β_0 estimates the baseline level of the outcome at the beginning of the time series (i.e., April 2008). β_1 estimates the trend before ERAS implementation (i.e., before April 2009).
- Intervention period. β_2 is the change in level immediately following the intervention ($ERAS_0$ = April 2009). β_3 estimates the change in the trend in the monthly mean

(number or rate depending of outcome) after ERAS started (i.e., ERAS implementation trend).

- Post-intervention period. β_4 is the change in level immediately following the end of the intervention ($ERAS_{end}$ = March 2011). β_5 estimates the change in the trend in the mean monthly number or rate (depending of outcome) after ERAS ended (i.e., ERAS post-implementation trend).

In preliminary analysis we checked the autocorrelation with the previous month, two months… until the previous 12 months using Durbin's alternative test[14]. We estimated linear regression models with Newey-West standard errors[15].

All analyses were conducted using Stata version 13.1 (StataCorp, College Station, Texas). We followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guideline[16].

RESULTS

Between April 2008 and December 2016 there were 486,579 planned primary TKR (Fig. 1). 57% of patients were women, the average age was 70 years (SD ±9 years). Mean body mass index (BMI) pointed to a nutritional status of obesity class I 31.0 kg/m^2 (SD ±5.5 kg/m^2)[17]. The physical status[18] of patients was mild or fit for 83% according to the American Society of Anesthesiologists (ASA grade).

LOS

479,353 patients were used for the analysis of LOS (Fig. 1). LOS decreased from 5.8 days (95% CI: 5.7 to 5.9) in April 2008 to 3.7 (95% CI: 3.7 to 3.8) in December 2016 (Fig. 2A). Prior to ERAS LOS was already decreasing significantly by -0.032% every month (95% CI: -

0.035% to -0.028%) (Table 1). The rate of reduction in mean LOS declined at a slower rate (-0.016%, i.e. baseline trend - trend change after ERAS) after the intervention period (April 2011 to December 2016).

[Fig. 2 and Table 1 near here]

Although older patients had a longer LOS, the secular trends in decreasing LOS were seen across all age groups (e.g. 5.1 days (95% CI: 4.9 to 5.4) to 3.3 days (95% CI: 3.1 to 3.4) in those age 18-59 and 7.7 days (95% CI: 7.2 to 8.2) to 5.4 days (95% CI: 5.1 to 5.8) in age ≥85) (Fig. 3, Supplementary Table S1). Secular trends also decreased in patients with and without pre-existing co-morbidity (Fig. 4). Cost data were estimated for a total of 479,353 patients. The results for mean inpatient bed day cost over time shows a similar trend to that observed for LOS. Overall mean cost of the index hospital episode decreased from £7607 (95% CI: £7511 to £7704) in April 2008 to £5276 (95% CI: £5213 to £5339) in December 2016 (Fig 5).

[Figs 3-5 near here]

OKS change

We excluded 48% of patients with missing information for OKS in the analysis of change in PROMs (Figure 1). We found more missing data for OKS change prior to ERAS (88.6%) than in the implementation period or after ERAS (43.0% and 45.0%, respectively) (Supplementary Table S2). Supplementary Table S3 shows more patients without data for OKS change than with data in the period prior to ERAS (15.7% and 1.9%, respectively).

Over the study period there was an improvement in OKS change 6 months after surgery of 15.1 points (95% CI: 14.1 to 16.2) in April 2008, to 17.1 points (95% CI: 16.2 to 18.1) in December 2016 (Fig. 2B). The improvement in the secular trends was observed across all age categories and patients with and without co-morbidity (Figs. 6 and 7, Supplementary Table S4). For the sensitivity analysis imputing OKS change we observed similar results (Supplementary Figs. S2 and S3, Supplementary Tables S5 and S6)

[Fig. 6 and Fig. 7 near here]

The interrupted time-series model for OKS change shows that prior to ERAS OKS change increased by 0.052% (95% CI: -0.044% to 0.148%) every month (Table 1) and in the imputed dataset by 0.053% (95% CI: 0.042% to 0.064%) (Supplementary Table S5). During ERAS implementation (April 2009 to March 2011) the secular trend slowed down by 0.009 and increased significantly again after ERAS by 0.071.

Complication at 6-months

6,884 (1.6%) patients had one or more complications 6 months after TKR. The proportion of complications decreased from 4.1% (95% CI: 3.5 to 4.8) to 1.7% (95% CI: 1.3 to 2.0) (Fig. 2C). The interrupted time-series model for complications at 6 months shows that prior to ERAS complication proportion decreased by -0.058% every month (95% CI: -0.071% to -0.045%) (Table 1). The period after the ERAS intervention remained stable.

5-year revision rates

3,917 (2.2%) patients had a knee revision in the following 5 years according to the NJR registry. We found 30 more 5-year revisions using HES giving a total of 3,947 (2.2%). Rates of 5-year knee revision per 1000 implant year remained unchanged with a rate of 4.8 per 1000 implants years (95% CI: 3.9 to 6.0) at risk in April 2008 and 4.8 (95% CI: 3.9 to 5.9) in December 2011 (Fig. 2D).

The model for 5-year knee-revision rates shows a significant downward trend of -0.031 per 1000 implants years (95% CI: -0.058 to -0.003) during ERAS implementation (April 2009 to March 2011) (Table 1). The trend changed direction by increasing during the post-intervention period (April 2011 to December 2016) in 0.040 per 1000 implants years (95% CI: 0.021 to 0.060).

DISCUSSION

Prior to the introduction of ERAS LOS and inpatient bed-day cost was declining. Although LOS and inpatient bed-day cost continued to decrease after ERAS implementation, this was at half the rate of decline. The absolute change in OKS was higher following ERAS implementation, but although significant, it did not reach clinical significance. There was no change in complications, while the 5-year revision trend slightly increases after ERAS. LOS and OKS trends were seen across all age groups, and in those with and without co-morbidity. Reductions in LOS have been achieved without adversely impacting on patient outcomes. However, implementation of ERAS either slowed down or maintained pre-existing secular trends.

We know from other UK studies that length of stay has been in gradual decline in the years prior to 2008, where Burn et al found that in 1997 mean LOS for TKR was 18.89 days, and in 2008, before the ERAS intervention, 7.49 days [19]. We expected to observe a steeper trend in the decrease in length of stay after the intervention period (2009-2011). Although we did not a-priori know what pattern would be expected prior to ERAS for the other outcomes, we hypothesized that following the intervention, outcomes of patient reported pain and function, complications, and revision surgery should improve.

Our assumptions, for this "natural experiment" of the implementation of ERAS, were that this large scale intervention was implemented homogenously across all England NHS trusts spanning this 2-year period. There was already an encouraging trend towards reduction in LOS and improved outcomes that had begun prior to the official EPR programme. This is likely to reflect early adoption of elements of ERAS methods in some Trusts, prior to the start of the Department of Health led programme in 2009. Not all hospitals had implemented ERAS at the end of the implementation period (March 2011)[11]. The survey on the spread and adoption of ERAS carried out close to the end of the implementation (February 2011) by the Department of Health reported full implementation in 81 consultant teams, while about 20 had partially implemented ERAS, and about 30 still planned to implement ERAS. A limitation is the variation in interpretation and adoption across centres because what constitutes ERAS was not clearly established after the expected identification of best practices in the first year of the ERAS programme[20].

Dates of implementation of ERAS were different among hospitals. How long that implementation could span or actually spanned are not provided in the Department of Health guideline or in the subsequent report[11, 20]. Because of the complexity of the intervention and stakeholders involved this could vary between hospitals. Therefore, our quasi-experimental approach smoothed dissimilarities in times used to adopt the ERAS intervention.

External influencing factors

Our results show trends in outcomes that has been achieved in the context of an increasing strain on NHS funding and hospital budgets. NHS funding growth is much slower than the historical long term trend[21]. There are fewer hospital beds and wards have been closed. For example, the average daily number of occupied beds open overnight for trauma and orthopaedics for England between April and June 2010 was 10,015 while in October to December 2016 was 8,770[22]. Conversely, the number of primary knee replacements increased from 74,277 in 2008 to 98,147 in 2016[23] in England. It has been estimated that 118,666 TKRs will take place by the year 2035[24]. Further to this, the complexity of patients has changed over time, with more patients with co-morbidities now receiving surgery. Efficiencies need to be made to meet this demand within existing or lower capacity. An important issue is the high variation in services and practices across hospitals in England. The Getting It Right First Time (GIRFT) programme aims to reduce discrepancies between hospitals showing diversity in activity volumes, implant choice, and guidelines follow-up[25]. The first GIRFT report was published in 2012, while the improving trends in outcomes in our study are detected since 2008. Although our results of a positive national trend are encouraging, there still remains substantial variation in outcomes between hospital trusts. In 2016, mean LOS varied between a low of 2.2 days to a high of 5.6, and OKS between 12.8 and 22.3 points. Hence although the national picture has improved for patients as a whole, there is still work to be done to reduce and understand unwarranted variations in outcome between individual hospitals.

Many studies supporting the implementation of ERAS pathways have been placed in single institutions or rather small trials[26]. Thus, they may not be generalizable to the wider population. Reductions in LOS prior to the official implementation of ERAS may reflect a commitment to improving the cost-effectiveness of this surgery which represents an important expenditure for the NHS [19, 27, 28]. Reduction in LOS has been reported in systematic reviews and randomised clinical trials comparing patients following an ERAS programme for colorectal and other planned surgeries against those under conventional care[6]. There is variation in the type of ERAS intervention for knee replacement that has been evaluated among previous studies[29][30, 31][32][33][34][29-35] that preclude us to make generalizations at a nationwide level. Additionally, these studies were limited to only one hospital or trust. Moreover, they were focused on the comparison of the intervention with traditional management. Our study investigates whether the ERAS pathway has been successfully implemented comparing with a previous period without ERAS, as has been done in other studies[30-32], but also, and for first time, comparing with the post-intervention period.

The decreasing trend in LOS over time was also reflected in the change in estimated average inpatient bed day cost. We found that the majority of episodes in the data had a LOS less than the trim point for the relevant cost HRG. This meant that (assigning the same unit cost to all patients with the same HRG who had a LOS below the trim point) the reduction in LOS within the trim point would not be reflected by a change in the estimated average episode costs. We therefore estimated the true reduction in NHS expenditure by estimating a cost per bed day reflecting the LOS for each patient.

OKS change scores increased across the study period. However, the change of ~2-3 points using complete and imputed cases does not reaching the clinically meaningful difference of 5 points suggested within the literature[36]. A review on ERAS in total hip replacement shows that better improvement in pain and function scores could be related to making patients active participants in their recovery and to help them to manage their expectations[28]. A Cochrane review on preoperative education for hip or knee replacement did not find additional benefits over usual care[37]. However, non-significant reduction of pain and better function were reported to be associated with preoperative education.

The 6-month complications were decreasing until the implementation took place. Subsequently, the trend remained steady during the ERAS period and slightly increased following the intervention. Potentially, discharging patients too soon after surgery could increase complications. However, a meta-analysis in colorectal surgery on several ERAS programmes did not find evidence of an increased risk of surgical complications[38], and found that cardiovascular, pulmonary, and infectious medical complications decreased. Patients with diabetes undergoing hip and knee replacement under ERAS protocols reduce the additional risk for complications otherwise associated with operating patients with diabetes[39]. A limitation is that manipulation under anaesthesia was not considered among the list of 6-month complications. Werner et al. found 4.24% requiring manipulation under anaesthesia by 6 months in a large cohort of patients undergoing TKR (n=141,016). 4.8% of them had a revision within the following 7 years[40].

5-year revision rates diminished across the study. It has been an important effort to reduce revision rates because the procedure is more complicated to perform[41]. Surveillance of knee replacement revisions, using joint registries, have long been the main measure of primary surgical success/failure until PROMs were also used to assess outcomes[42]. Revision rates could have declined as a consequence of patient selection for primary surgery[43].

To inform the list of important outcomes for this study, we conducted a forum with the University of Bristol's Musculoskeletal Research Unit's patient involvement group. Mortality was ranked low by the group in respect of its importance to them, and hence has not been included and remains a limitation of the analysis. We did not included BMI as a potential modifier for trends in LOS and OKS. A slightly higher proportion of obese patients (≥35 Kg/m^2) between 2008 and 2016 (21.4% and 25.3%, respectively) might influence trends for LOS and OKS, respectively.

Conclusion

Our study shows that trends of improved outcomes of planned TKR slowed down after ERAS. LOS, OKS, complications and revisions are currently better than 10 years ago. LOS has declined substantially over the study period, consistent across all age groups and in people with and without co-morbidity. Nevertheless, declines in LOS were half the initial decline following ERAS implementation. Reductions in LOS have been achieved without adversely impacting on patient outcomes. Patient reported outcomes in respect of pain and function have improved, but did not reach clinical significance. Complication rates remain stable and revision rates decline less than before ERAS implementation. These trends in outcomes have been achieved in the context of reductions in the numbers of available beds/wards/operating theatres, with increasing absolute numbers of patients undergoing TKR year on year and sicker patients over the study time.

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CONTRIBUTIONS

All authors contributed to study design, data analysis, interpretation of results and writing the manuscript. All authors had full access to all statistical reports and tables in the study. CG had full access to all of the study data and takes responsibility for the integrity of the data and the accuracy of the data analysis. All authors contributed to the interpretation of results and critical revision of the manuscript and approved the final manuscript. AJ is the guarantor. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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COMPETING INTERESTS STATEMENT

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf and declare: AJ has received consultancy fees from Freshfields Bruckhaus Deringer, and has held advisory board positions (which involved receipt of fees) from Anthera Pharmaceuticals, INC. AP reports personal fees from Zimmer Biomet, outside the submitted work. AR reports grants from DePuy Ltd outside the submitted work. CC received personal fees from: Alliance for Better Bone Health; Amgen; Eli Lilly; GSK; Medtronic; Merck; Novartis; Pfizer; Roche; Servier; Takeda; UCB, outside the submitted work. NKA received grants and personal fees outside the submitted work from: Bioberica; Merck; Flexion; Regeneron; Freshfields Bruckhaus Deringer. DPA received grants from: Amgen; UCB Biopharma; Servier; Astellas; Novartis, outside the submitted work. All other authors declare no conflicts of interest.

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FIGURE LEGENDS

Fig. 1. Flow diagram on selection of patients.

Fig. 2. Trends in outcomes following primary TKR in England, UK, 2008- 2016, by month.

2A, length of stay at hospital; 2B, change in self-reported pain and function, measured using Oxford knee score (OKS) at baseline and 6 months after the surgery; 2C, any complication in the following 6 months after primary TKR; 2D, knee revision in the following 5 years; enhanced recovery after surgery programme implemented in England from April 2009 to March 2011, ERAS.

Fig. 3. Trends of length of stay at hospital following primary TKR according to age categories in England, UK, 2008 –2016, by month.

Total knee replacement, TKR; enhanced recovery after surgery programme implemented in England from April 2009 to March 2011, ERAS.

Fig. 4. Trends of length of stay at hospital following primary TKR by patients with/without comorbidities in England, UK, 2008 –2016, by month.

Total knee replacement, TKR; enhanced recovery after surgery programme implemented in England from April 2009 to March 2011, ERAS.

Fig. 5. Trends of cost per bed day following primary TKR in England, UK, 2008 – 2016, by month.

Total knee replacement, TKR; enhanced recovery after surgery programme implemented in England from April 2009 to March 2011, ERAS.

Fig. 6. Trends of OKS change following primary TKR according to age categories in England, UK, 2008 – 2016, by month.

Oxford knee score, OKS; total knee replacement, TKR; enhanced recovery after surgery programme implemented in England from April 2009 to March 2011, ERAS.

Fig. 7. Trends of OKS change following primary TKR by patients with/without comorbidities in England, UK, 2008 –2016, by month.

Oxford knee score, OKS; total knee replacement, TKR; enhanced recovery after surgery programme implemented in England from April 2009 to March 2011, ERAS.

MANUSCRIPT TITLE:

Impact of a National Enhanced Recovery Programme on Patient Outcomes of Primary total Knee Replacement: an Interrupted Time Series Analysis from "The National Joint Registry of England, Wales, Northern Ireland and the Isle of Man".

APPENDIXES

Appendix 1. Cost methods.

Objective

We aimed to estimate the trend in National Health Service (NHS) expenditure over time, reflecting the change in length of stay (LOS) observed.

Grouper and reference cost methods

Using Hospital Episode Statistics (HES) data for the same group of patients as for LOS (i.e. excluding those with length of stay above 15 days), we generated healthcare resource use group (HRG) classifications for the index episode for each patient using the 2015/16 NHS reference costs grouper [1], which were subsequently used to estimate inpatient costs per patient using NHS reference costs from 2015/16 [2].

A reduction in LOS within the trim point is therefore not reflected in the cost of the episode, despite there being a true reduction in NHS costs. In order to estimate the mean change in NHS expenditure we therefore estimated an adjusted average bed day cost.

Estimating the adjusted average bed day cost

For each HRG we estimated the average cost per bed day (defined as any part of a day spent in hospital) by dividing the total cost of the index episodes for that HRG by the total number of bed days for that HRG. This generated a single average bed day cost per HRG.

For each patient we estimated the adjusted episode cost by multiplying their length of stay (bed days) by the average bed day cost for the HRG that they had been assigned by the NHS reference costs grouper [1]. Therefore, instead of assigning the same unit cost to all patients with the same HRG who had a LOS below the trim point, the adjusted cost differed according to a patient's LOS, even if that LOS was below the trim point for the HRG. Using this method we were able to estimate the average difference in true NHS expenditure as a result of the reduction in length of stay over time even when the LOS was below the trim point.

The 2015/16 grouper and reference costs [1,2] were used to estimate costs for all patients in all years, as there are differences in the methodologies used for HRG classification in different cost years [3]. This prevents a like-for-like comparison between years if different groupers and/or costs are used.

Costs were estimated for a total of 517,798 patients.

<u>References for Appendix 1</u>

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2. Department of Health. NHS reference costs 2015 to 2016. https://www.gov.uk/government/publications/nhs-reference-costs-2015-to-2016
3. Reference Costs 2015-16. Department of Health. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/577083/Reference_Costs_2015-16.pdf.

Appendix 2. Codes defined in the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) that we used to identify complications in the Hospital Episode Statistics (HES) registry.

<u>Stroke</u>: I60.X, "Subarachnoid haemorrhage"; I61.0, "Intracerebral haemorrhage in hemisphere, subcortical"; I61.1, "Intracerebral haemorrhage in hemisphere, cortical"; I61.2, "Intracerebral haemorrhage in hemisphere, unspecified"; I61.3, "Intracerebral haemorrhage in brain stem"; I61.4, "Intracerebral haemorrhage in cerebellum"; I61.5, "Intracerebral haemorrhage, intraventricular"; I61.6, "Intracerebral haemorrhage, multiple localized"; I61.8, "Other intracerebral haemorrhage"; I61.9, "Intracerebral haemorrhage, unspecified"; I63.0, "Cerebral infarction due to thrombosis of precerebral arteries"; I63.1, "Cerebral infarction due to embolism of precerebral arteries"; I63.2, "Cerebral infarction due to unspecified occlusion or stenosis of precerebral arteries"; I63.3, "Cerebral infarction due to thrombosis of cerebral arteries"; I63.4, "Cerebral infarction due to embolism of cerebral arteries"; I63.5, "Cerebral infarction due to unspecified occlusion or stenosis of cerebral arteries"; I63.6, "Cerebral infarction due to cerebral venous thrombosis, nonpyogenic"; I63.8, "Other cerebral infarction"; I63.9, "Cerebral infarction, unspecified"; and I64.X, "Stroke, not specified as haemorrhage or infarction".

<u>Respiratory infection</u>: J12.X, "Viral pneumonia, not elsewhere classified: bronchopneumonia due to viruses other than influenza viruses"; J13, "Pneumonia due to *Streptococcus pneumoniae*"; J14, "Pneumonia due to *Haemophilus influenzae*"; J15.X, "Bacterial pneumonia, not elsewhere classified: bronchopneumonia due to bacteria other than *S. pneumoniae* and *H. influenzae*"; J18.0, "Bronchopneumonia, unspecified. Excluding bronchiolitis"; J18.1, "Lobar pneumonia, unspecified"; J18.2, "Hypostatic pneumonia, unspecified"; J18.8, "Other pneumonia, organism unspecified"; J18.9, "Pneumonia, unspecified"; J22, "Unspecified acute lower respiratory infection"; J44.0, "Chronic

obstructive pulmonary disease with acute lower respiratory infection. Excluding with influenza"; J44.1, "Chronic obstructive pulmonary disease with acute exacerbation, unspecified"; J69.0, "Pneumonitis due to food and vomit. Excluding Mendelson syndrome"; J69.1, "Pneumonitis due to oils and essences"; J69.8, "Pneumonitis due to other solids and liquids. Pneumonitis due to aspiration of blood"; and J85.1, "Abscess of lung with pneumonia. Excluding with pneumonia due to specified organism".

Acute myocardial infarction: I21.0, "Acute transmural myocardial infarction of anterior wall"; I21.1, "Acute transmural myocardial infarction of inferior wall"; I21.2, "Acute transmural myocardial infarction of other sites"; I21.3, "Acute transmural myocardial infarction of unspecified site"; I21.4, "Acute subendocardial myocardial infarction"; and I21.9, "Acute myocardial infarction, unspecified".

Pulmonary embolism/deep vein thrombosis: I80.1, "Phlebitis and thrombophlebitis of superficial vessels of lower extremities"; I80.1, "Phlebitis and thrombophlebitis of femoral vein"; I80.3, "Phlebitis and thrombophlebitis of other deep vessels of lower extremities"; I26.0, "Pulmonary embolism with mention of acute cor pulmonale"; and I26.9, "Pulmonary embolism without mention of acute cor pulmonale".

Urinary tract infection: N30.0, "Acute cystitis. Excluding irradiation cystitis and trigonitis"; and N39.0, "Urinary tract infection, site not specified".

Wound disruption: T81.3, "Disruption of operation wound, not elsewhere classified".

Surgical site infection: T81.4, "Infection following a procedure, not elsewhere classified".

Fracture after implant: M96.6, "Fracture of bone following insertion of orthopaedic implant, joint prosthesis, or bone plate. Excluding complication of internal orthopaedic devices, implants or grafts".

Complication of prosthesis: T84.0, “Mechanical complication of internal joint prosthesis”.

Neurovascular injury: T81.2, “Accidental puncture and laceration during a procedure, not elsewhere classified. Accidental perforation of: blood vessel, nerve or organ by: catheter, endoscope, instrument or probe during a procedure”.

Acute renal failure: N17.0, “Acute renal failure with tubular necrosis”; N17.1, “Acute renal failure with acute cortical necrosis”; N17.2, “Acute renal failure with medullary necrosis”; N17.8, “Other acute renal failure”; and N17.9, “Acute renal failure, unspecified”.

Appendix 3. Operative procedure codes (OPCS 4.8) that we used to identify blood-transfusion complication in the Hospital Episode Statistics (HES) registry.

X33.2, "Intravenous blood transfusion of packed cells"; X33.3, "Intravenous blood transfusion of platelets"; X33.8, "Other specified other blood transfusion"; X33.9, "Unspecified other blood transfusion"; X33.1, "Intra-arterial blood transfusion"; X33.7, "Autologous transfusion of red blood cells"; X34.1, "Transfusion of coagulation factor"; X34.2, "Transfusion of plasma not elsewhere classified"; X34.3, "Transfusion of serum not elsewhere classified"; and X34.4, "Transfusion of blood expander".

Appendix 4. Operative procedure codes (OPCS 4.8) that we used to identify knee revision in the Hospital Episode Statistics (HES) registry.

Code	Procedure
Procedure type 1	
W40.0	Conversion from previous cemented total prosthetic replacement of knee joint
W40.2	Conversion to total prosthetic replacement of knee joint using cement
W40.3	Revision of total prosthetic replacement of knee joint using cement
W40.4	Revision of one component of total prosthetic replacement of knee joint using cement
W41.0	Conversion from previous uncemented total prosthetic replacement of knee joint
W41.2	Conversion to total prosthetic replacement of knee joint not using cement
W41.3	Revision of total prosthetic replacement of knee joint not using cement
W41.4	Revision of one component of total prosthetic replacement of knee joint not using cement
W42.0	Conversion from previous total prosthetic replacement of knee joint NEC
W42.2	Conversion to total prosthetic replacement of knee joint NEC
W42.3	Revision of total prosthetic replacement of knee joint NEC
W42.4	Attention to total prosthetic replacement of knee joint NEC
W42.5	Revision of one component of total prosthetic replacement of knee joint NEC
W42.6	Arthrolysis of total prosthetic replacement of knee joint

W58.0 Conversion from previous resurfacing arthroplasty of joint

O18.0 Conversion from previous hybrid prosthetic replacement of knee joint using cement

O18.2 Conversion to hybrid prosthetic replacement of knee joint using cement

O18.3 Revision of hybrid prosthetic replacement of knee joint using cement

O18.4 Attention to hybrid prosthetic replacement of knee joint using cement

Procedure type 2

W52.0 Conversion from previous cemented prosthetic replacement of articulation of bone NEC

W52.2 Conversion to prosthetic replacement of articulation of bone using cement NEC

W52.3 Revision of prosthetic replacement of articulation of bone using cement NEC

W53.0 Conversion from previous uncemented prosthetic replacement of articulation of bone NEC

W53.2 Conversion to prosthetic replacement of articulation of bone not using cement NEC

W53.3 Revision of prosthetic replacement of articulation of bone not using cement NEC

W54.0 Conversion from previous prosthetic replacement of articulation of bone NEC

W54.2 Conversion to prosthetic replacement of articulation of bone NEC

W54.3 Revision of prosthetic replacement of articulation of bone NEC

W54.4 Attention to prosthetic replacement of articulation of bone NEC

W55.3 Conversion to prosthetic interposition arthroplasty of joint

W56.4 Conversion to interposition arthroplasty of joint NEC

W57.4 Conversion to excision arthroplasty of joint

W60.3 Conversion to arthrodesis and extra-articular bone graft NEC

W61.3 Conversion to arthrodesis and articular bone graft NEC

W64.1 Conversion to arthrodesis and internal fixation NEC

W64.2 Conversion to arthrodesis and external fixation NEC

Site for revision

Z76.5 Lower end of femur NEC

Z77.4 Upper end of tibia NEC

Z78.7 Patella

Z84.4 Patellofemoral joint

Z84.5 Tibiofemoral joint

Z84.6 Knee joint

Procedure type 3

W40.1 Primary total prosthetic replacement of knee joint using cement

W40.8 Other specified total prosthetic replacement of knee joint using cement

W40.9 Unspecified total prosthetic replacement of knee joint using cement

W41.1 Primary total prosthetic replacement of knee joint not using cement

W41.8 Other specified total prosthetic replacement of knee joint not using cement

W41.9 Unspecified total prosthetic replacement of knee joint not using cement

W42.1 Primary total prosthetic replacement of knee joint NEC

W42.8 Other specified other total prosthetic replacement of knee joint

W42.9 Unspecified other total prosthetic replacement of knee joint

O18.1 Primary hybrid prosthetic replacement of knee joint using cement

O18.8 Other specified hybrid prosthetic replacement of knee joint using cement

O18.9 Unspecified hybrid prosthetic replacement of knee joint using cement

Algorithm: One code from procedure type 1 or a combination of one code from procedure type 2 and site for revision were used to identify knee revision. Combination of codes from procedures type 3 and type 1 or procedure type 3, type 2 and site of surgery identified knee revision after a primary knee unicompartmental replacement (UKR).

Appendix 5. Codes defined in the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) that we used to identify comorbidities in the Hospital Episode Statistics (HES) registry.

Disease	**Codes**
Myocardial infarction	I21, I22
Congestive heart failure	I50.0
Peripheral vascular disease	I70- I73
Cerebrovascular disease	I60-I67
Dementia	F00-F03
Chronic obstructive pulmonary disease	J41-J47
Connective tissue disease	M05, M06, M08, M15-M19, M35, M36
Peptic ulcer disease	K25-K28
Mild liver disease	K70.0, K76.0, K76.1
Mild diabetes (without end organ damage - include ketoacidosis and coma)	E10.X, E10.0, E10.1, E10.9, E11.X, E11.0, E11.1, E11.9, E12.X, E12.0, E12.1, E12.9, E13.X, E13.0, E13.1, E13.9, E14.X, E14.0, E14.1, and E14.9
Hemiplegia	G81
Moderate/severe renal disease	N17-N19

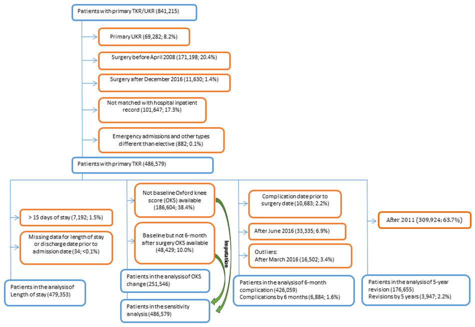
Severe diabetes (i.e. with organ damage)	E10-E12, E13, or E14 complicated with .2-.8, N083
Tumour	C00-C76, C80, C88, C90.0, C90.2, C96, C97, D00-D48
Leukaemia	C90.1, C91-C95
Lymphoma	C81- C85
Moderate/severe liver disease	K70-K76. Excluding codes for mild liver disease K70.0, K76.0 and K76.1
AIDS	B20-B23
Metastatic solid tumour	C77-C79

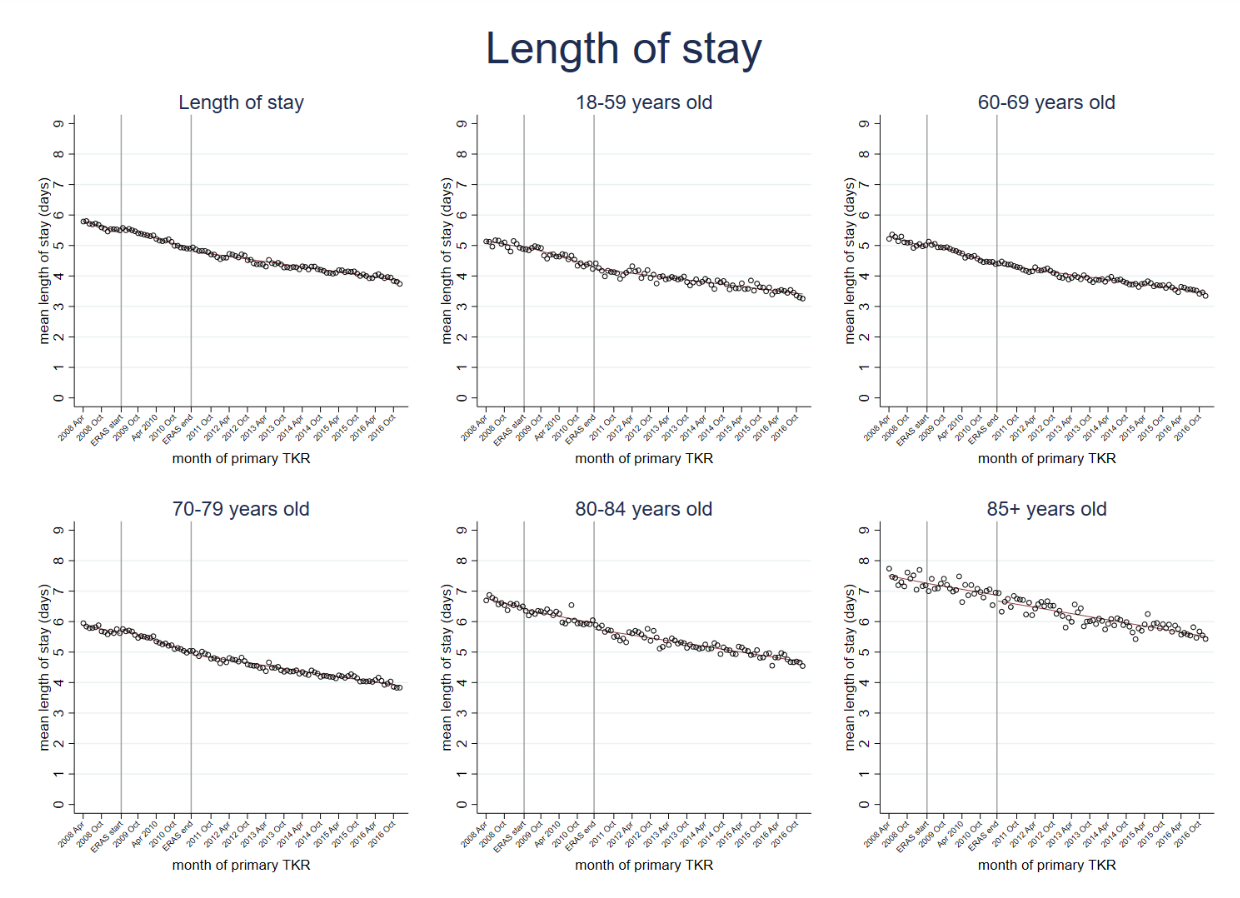
Table 1. Temporal trends in patients underwent planned primary TKR from April 2008 to December 2016. Full models with Newey-West standard errors.

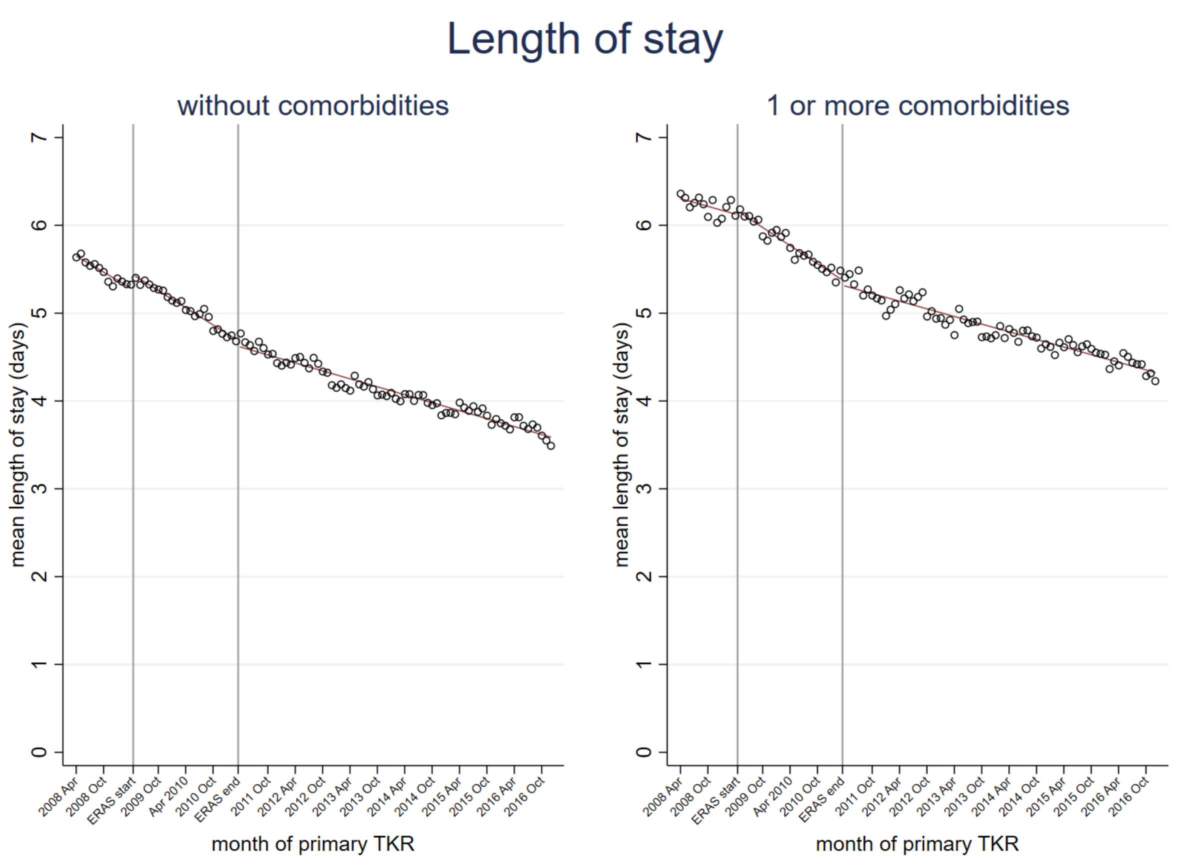
Parameter	**Coefficient**	**Lower 95% CI**	**Upper 95% CI**	***P*-value**
LOS				
Intercept	5.871	5.852	5.890	<0.001
Monthly trend	-0.032	-0.035	-0.028	<0.001
Level change $ERAS_0$	0.158	0.106	0.210	<0.001
Trend change after $ERAS_0$	0.002	-0.002	0.006	0.395
Level change $ERAS_{end}$	-0.091	-0.171	-0.012	0.025
Trend change after $ERAS_{end}$	0.016	0.013	0.018	<0.001
OKS 6 months – OKS baseline				
Intercept	14.020	13.376	14.664	<0.001
Monthly trend	0.052	-0.044	0.148	0.285
Level change $ERAS_0$	0.261	-0.286	0.808	0.346
Trend change after $ERAS_0$	-0.043	-0.146	0.059	0.404
Level change $ERAS_{end}$	0.325	0.003	0.647	0.048
Trend change after $ERAS_{end}$	0.019	0.003	0.036	0.024
Complication by 6 months				
Intercept	4.049	3.936	4.162	<0.001
Monthly trend	-0.058	-0.071	-0.045	<0.001

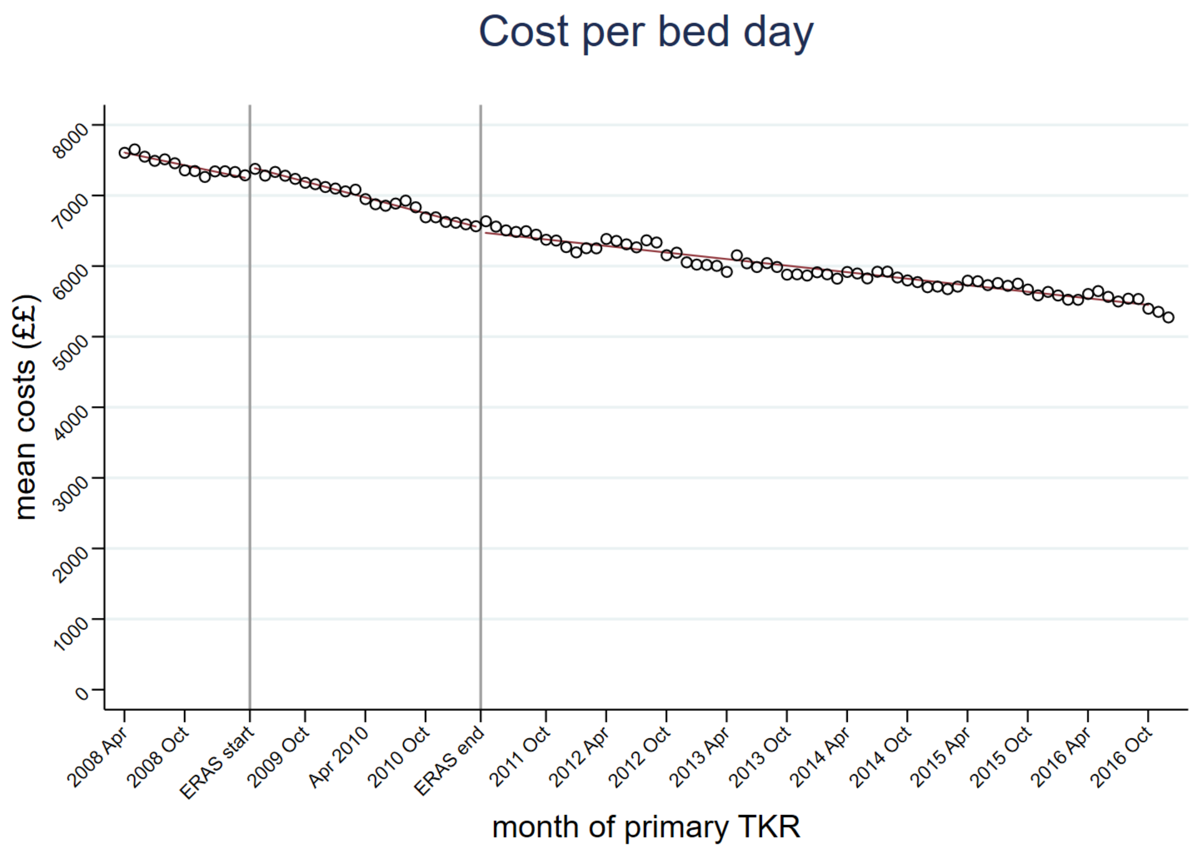
Level change $ERAS_0$	-0.807	-1.363	-0.250	0.005
Trend change after $ERAS_0$	-0.003	-0.044	0.039	0.899
Level change $ERAS_{end}$	0.314	-0.074	0.702	0.112
Trend change after $ERAS_{end}$	0.058	0.021	0.095	0.002
Revision rates by 5 years				
Intercept	4.833	4.597	5.068	<0.001
Monthly trend	0.014	-0.011	0.039	0.255
Level change $ERAS_0$	-0.090	-0.313	0.133	0.418
Trend change after $ERAS_0$	-0.031	-0.058	-0.003	0.031
Level change $ERAS_{end}$	-0.095	-0.323	0.132	0.402
Trend change after $ERAS_{end}$	0.040	0.021	0.060	<0.001

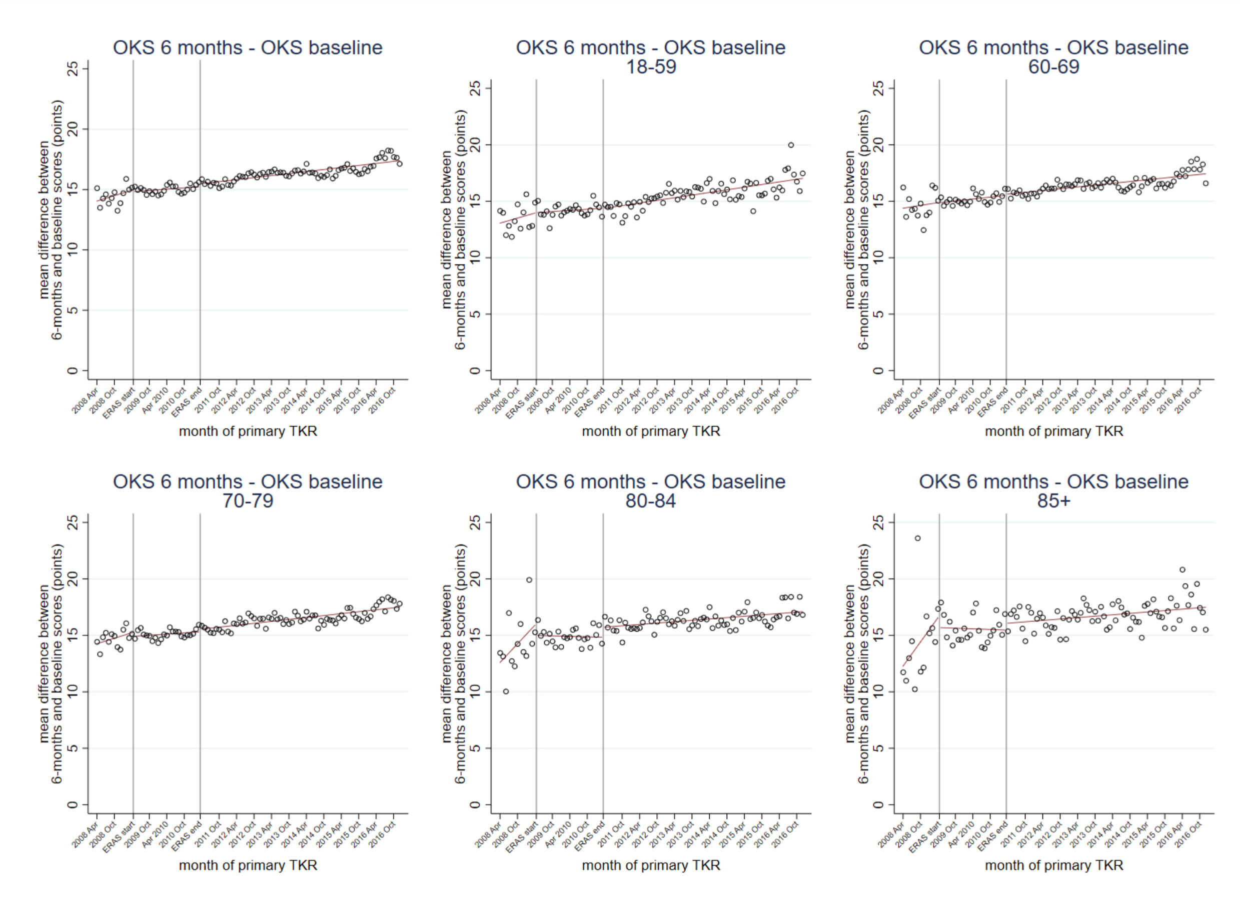
Total knee replacement, TKR; confidence intervals, CI; length of stay at hospital, LOS; Oxford knee score, OKS; Enhanced Recovery Pathway, ERAS; start point of ERAS intervention in April 2009, $ERAS_0$; end point of ERAS intervention in March 2011, $ERAS_{end}$.

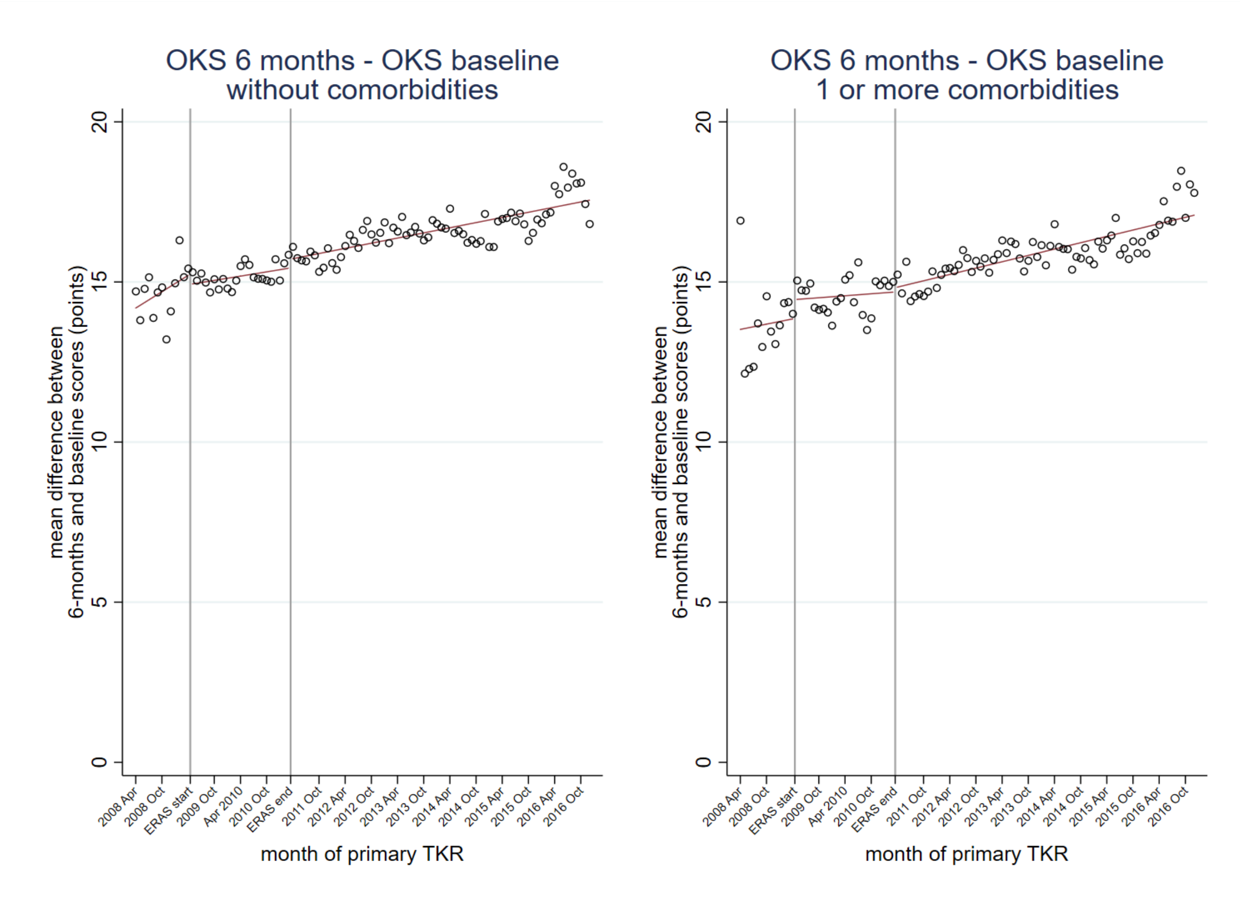

Patients with primary TKR/UKR (841,215)
Primary UKR (69,282; 8.2%)
Surgery before April 2008 (171,198; 20.4%)
Surgery after December 2016 (11,630; 1.4%)
Not matched with hospital inpatient record (101,647; 17.3%)
Emergency admissions and other types different than elective (882; 0.1%)
Patients with primary TKR (486,579)
> 15 days of stay (7,192; 1.5%)
Missing data for length of stay or discharge date prior to admission date (34; <0.1%)
Patients in the analysis of Length of stay (479,353)
Not baseline Oxford knee score (OKS) available (186,604; 38.4%)
Baseline but not 6-month after surgery OKS available (48,429; 10.0%)
Imputation
Patients in the analysis of OKS change (251,546)
Patients in the sensitivity analysis (486,579)
Complication date prior to surgery date (10,683; 2.2%)
After June 2016 (33,335; 6.9%)
Outliers:
After March 2016 (16,502; 3.4%)
Patients in the analysis of 6-month complication (426,059)
Complications by 6 months (6,884; 1.6%)
After 2011 (309,924; 63.7%)
Patients in the analysis of 5-year revision (176,655)
Revisions by 5 years (3,947; 2.2%)

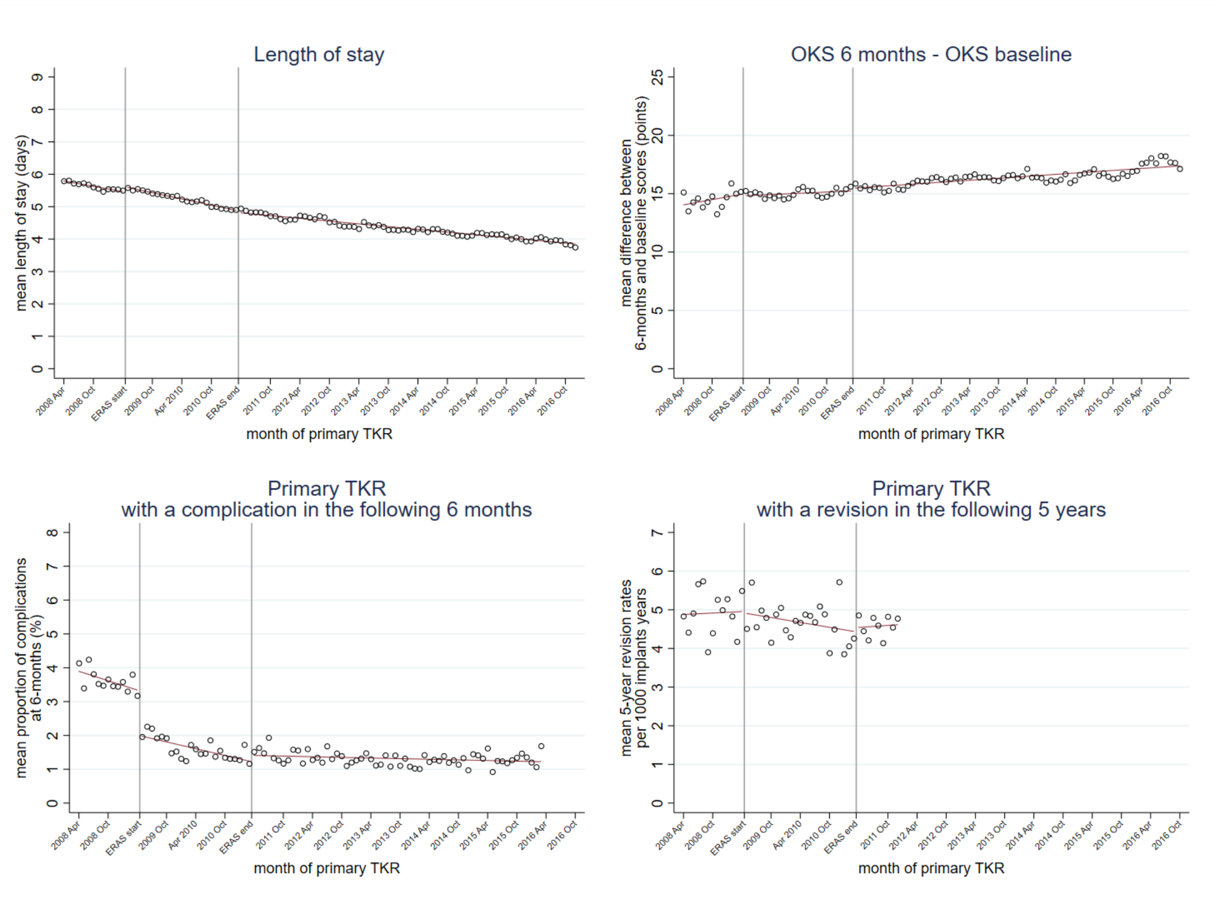

Length of stay
Length of stay
18-59 years old
60-69 years old
70-79 years old
80-84 years old
85+ years old
mean length of stay (days)
month of primary TKR
ERAS start
ERAS end


Length of stay
without comorbidities
1 or more comorbidities
mean length of stay (days)
0
1
2
3
4
5
6
7
2008 Apr
2008 Oct
ERAS start
2009 Oct
Apr 2010
2010 Oct
ERAS end
2011 Oct
2012 Apr
2012 Oct
2013 Apr
2013 Oct
2014 Apr
2014 Oct
2015 Apr
2015 Oct
2016 Apr
2016 Oct
month of primary TKR


Cost per bed day
mean costs (££)
0
1000
2000
3000
4000
5000
6000
7000
8000
2008 Apr
2008 Oct
ERAS start
2009 Oct
Apr 2010
2010 Oct
ERAS end
2011 Oct
2012 Apr
2012 Oct
2013 Apr
2013 Oct
2014 Apr
2014 Oct
2015 Apr
2015 Oct
2016 Apr
2016 Oct
month of primary TKR


OKS 6 months - OKS baseline
OKS 6 months - OKS baseline 18-59
OKS 6 months - OKS baseline 60-69
OKS 6 months - OKS baseline 70-79
OKS 6 months - OKS baseline 80-84
OKS 6 months - OKS baseline 85+
mean difference between 6-months and baseline scores (points)
0 5 10 15 20 25
2008 Apr
2008 Oct
ERAS start
2009 Oct
Apr 2010
2010 Oct
ERAS end
2011 Oct
2012 Apr
2012 Oct
2013 Apr
2013 Oct
2014 Apr
2014 Oct
2015 Apr
2015 Oct
2016 Apr
2016 Oct
month of primary TKR


OKS 6 months - OKS baseline
without comorbidities
mean difference between
6-months and baseline scores (points)
20
15
10
5
0
2008 Apr
2008 Oct
ERAS start
2009 Oct
Apr 2010
2010 Oct
ERAS end
2011 Oct
2012 Apr
2012 Oct
2013 Apr
2013 Oct
2014 Apr
2014 Oct
2015 Apr
2015 Oct
2016 Apr
2016 Oct
month of primary TKR
OKS 6 months - OKS baseline
1 or more comorbidities
mean difference between
6-months and baseline scores (points)
20
15
10
5
0
2008 Apr
2008 Oct
ERAS start
2009 Oct
Apr 2010
2010 Oct
ERAS end
2011 Oct
2012 Apr
2012 Oct
2013 Apr
2013 Oct
2014 Apr
2014 Oct
2015 Apr
2015 Oct
2016 Apr
2016 Oct
month of primary TKR


Length of stay
mean length of stay (days)
month of primary TKR
OKS 6 months - OKS baseline
mean difference between
6-months and baseline scores (points)
month of primary TKR
Primary TKR
with a complication in the following 6 months
mean proportion of complications
at 6-months (%)
month of primary TKR
Primary TKR
with a revision in the following 5 years
mean 5-year revision rates
per 1000 implants years
month of primary TKR
ERAS start
ERAS end

DATA STATEMENT

Access to data is available from the National Joint Registry for England and Wales, Northern Ireland and the Isle of Man, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data access applications can be made to the National Joint Registry Research Committee. Access to linked HES and PROMs data is available through data applications to NHS Digital.