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The impact of pausing elective hip and knee replacement surgery during winter 2017 on subsequent service provision at a major NHS Trust: a natural experiment

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Complete List of Authors:	<p>Jones, Tim; University Hospitals Bristol and Weston NHS Foundation Trust, NIHR ARC West; University of Bristol, Department of Population Health Sciences</p> <p>Penfold, Chris; University Hospitals Bristol and Weston NHS Foundation Trust, NIHR ARC West; University of Bristol, Musculoskeletal Research Unit</p> <p>Redaniel, Maria Theresa; University Hospitals Bristol and Weston NHS Foundation Trust, NIHR ARC West; University of Bristol, Population Health Sciences, Bristol Medical School</p> <p>Eyles, Emily; University Hospitals Bristol and Weston NHS Foundation Trust, NIHR ARC West; University of Bristol, Population Health Sciences, Bristol Medical School</p> <p>Keen, Tim; North Bristol NHS Trust</p> <p>Elliott, Andrew; North Bristol NHS Trust</p> <p>Blom, AW; University of Bristol, Translational Health Sciences, Bristol Medical School</p> <p>Judge, Andrew; University of Bristol, Musculoskeletal Research Unit</p>
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2
3 1 **Title:** The impact of pausing elective hip and knee replacement surgery during winter 2017 on
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5 2 subsequent service provision at a major NHS Trust: a natural experiment
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11 4 **Authors:** Tim Jones^{1,2}, Christopher Penfold^{1,2,3}, Maria Theresa Redaniel^{1,2}, Emily Eyles^{1,2}, Tim Keen⁴,
12
13 5 Andrew Elliott⁴, Ashley Blom^{2,3}, Andrew Judge^{3,5}
14
15
16 6
17
18

19 7 ¹ NIHR ARC West, University Hospitals Bristol NHS Foundation Trust, Bristol, BS1 2NT, UK
20
21

22 8 ² Department of Population Health Sciences, Bristol Medical School, University of Bristol, BS8 2PS,
23
24 9 UK
25
26

27 10 ³ Musculoskeletal Research Unit, Translational Health Sciences, Bristol Medical School, University of
28
29 11 Bristol, Learning and Research Building, Level 1, Southmead Hospital, Bristol, BS10 5NB, UK
30
31

32 12 ⁴ North Bristol NHS Trust, Southmead Hospital, Westbury-on-Trym, Bristol, BS10 5NB, UK
33
34

35 13 ⁵ National Institute for Health Research Bristol Biomedical Research Centre, University Hospitals
36
37 14 Bristol and Weston NHS Foundation Trust and University of Bristol, Bristol, UK
38
39
40
41
42

43 16 **Corresponding author:**

44 17 Tim Jones
45 18 Research Fellow
46 19 NIHR ARC West,
47 20 9th Floor Whitefriars,
48 21 Lewin's Mead
49 22 Bristol, BS1 2NT
50 23 United Kingdom
51
52
53

54 25 Tel: ++44 (0)117 342 1265

55 26 Timothy.Jones@bristol.ac.uk
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57

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ABSTRACT

Objectives: To explore the impact of a temporary cancellation of elective surgery in winter 2017 on trends in primary hip and knee replacement at a major NHS Trust, and whether lessons can be learnt about efficient surgery provision.

Design and Setting: Observational interrupted time series analysis using hospital records to explore trends in primary hip and knee replacement surgery at a major NHS Trust, as well as patient characteristics, 2016-2019.

Intervention: A temporary cancellation of elective services for two months in winter 2017

Outcomes: NHS-funded hospital admissions for primary hip or knee replacement, length of stay and bed occupancy. Additionally, we explored the ratio of elective to emergency admissions at the Trust as a measure of elective capacity, and the ratio of public to private provision of NHS-funded hip and knee surgery.

Results: After winter 2017 there was a sustained reduction in the number of knee replacements, a decrease in the proportion of most deprived people having knee replacements, and an increase in average age for knee replacement and comorbidity for both types of surgery. The ratio of public to private provision dropped after winter 2017, and elective capacity generally has reduced over time. There was clear seasonality in provision of elective surgery, with less-complex patients admitted during winter.

Conclusions: Declining elective capacity and seasonality has a marked effect on the provision of joint replacement, despite efficiency improvements in hospital treatment. The Trust has outsourced less complex patients to independent providers, and/or treated them during winter when capacity is most limited. There is a need to explore whether these are strategies that could be used explicitly to maximise the use of limited elective capacity, provide benefit to patients, and value for money for taxpayers.

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3 55 **STRENGTH AND LIMITATIONS OF THIS STUDY**
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- 6 56 • Trends analyses using data obtained from the electronic health records of a local hospital
7
8 NHS Trust are informative for clinicians and service managers in monitoring changes in
9 57
10 planning and delivery of elective surgery, and could be regularly updated in near real time
11 58
12 for monitoring.
13 59
14
15 60 • The inclusion of wider hospital admissions data beyond the NHS Trust allows us to estimate
16
17 the proportion of people within the Trust catchment area having NHS-funded treatment at
18 61
19 independent providers.
20 62
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22 63 • We report the experience of one NHS Trust that is one of the larger elective orthopaedic
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24 centres - the findings may not be generalisable to or reflect the experience of other trusts.
25 64
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27 65 • Our study does not include privately funded, privately provided hip and knee surgery which
28
29 may also have been changing over time.
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76 INTRODUCTION

77 Primary hip and knee replacement operations are common planned elective surgical procedures.

78 They are highly clinically effective for improving symptoms of pain and functional limitations, and

79 have been shown to be safe and cost-effective.¹⁻⁴ Around 100,000 hip⁴ and over 100,000 knee

80 operations³ are carried out each year in the UK. Demand for these operations has been increasing

81 substantially in recent decades⁵ with an ageing population, rising levels of obesity, and widening

82 indications for surgery in younger patient groups.^{3 4}

83 Orthopaedic services have become more efficient over time, with length of hospital stay for primary

84 hip and knee replacements reducing from around 15 days in 1997 to roughly 5.5 days in 2014.⁶ This is

85 largely due to the introduction of 'fast track' surgery and enhanced recovery services,⁷ which reduce

86 length of stay whilst maintaining patient safety and outcomes of surgery.⁶ However, over the past

87 decade there has also been a reduction in the numbers of hospital beds and operating theatres

88 available for hip and knee replacement patients.⁸ Waiting lists for orthopaedic procedures have been

89 growing over time, and the average time people wait for treatment once on the waiting list has also

90 increased.⁹

91 Pressures on elective surgery are exacerbated during winter, when resources for planned surgery are

92 often displaced by more acute, unplanned hospital admissions.⁸ At the end of 2017, this led to all

93 planned elective hip and knee replacement operations in England being cancelled for the whole of

94 January.¹⁰ Even before the COVID-19 pandemic, over half a million people were already on the waiting

95 list.¹¹ Patients are having to wait longer with deteriorating severe pain and functional limitation,

96 affecting their health and quality of life. The COVID-19 pandemic has had an even greater impact on

97 cancelling planned elective surgery, with over 635,000 people waiting for hip and knee replacements

98 in April 2021, more than 10% of these waiting over a year, and over a third waiting longer than the 18

99 week target.¹¹

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3 100 The winter of 2017 provides a form of 'natural experiment', where elective capacity was intentionally
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5 101 reduced close to zero. A natural experimental design is a valid methodological approach to evaluate
6
7 102 the impact of a range of events, policies and interventions which are not under the control of
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9
10 103 researchers.¹² Researchers can use the variation in exposure that natural experiments generate to
11
12 104 analyse their impact on health outcomes. This provides a form of quasi-experimental study, where we
13
14 105 can explore trends in provision of elective surgery before and after Winter 2017, which is a robust
15
16 106 approach to explore real-world impact when randomisation is not possible.^{13 14}
17
18
19 107 Our aim was to understand what happens after common, planned elective surgery is temporarily
20
21 108 cancelled, and how this might inform optimum planning of elective surgery when capacity is limited,
22
23 109 such as following the COVID-19 pandemic. We used interrupted time series analysis to model trends
24
25 110 in elective hip and knee replacement surgery for a major NHS Trust from 2016 to 2019 and see how
26
27 111 these were impacted by the withdrawal of elective surgery in winter 2017. We explored these trends
28
29 112 by patient factors (age, sex, deprivation, number of comorbidities) and seasonality to see when
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31 113 demand was highest for different patient groups.
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37 115 **METHODS**

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41 116 This study is a longitudinal observational study using routinely collected administrative information
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43 117 about patients admitted to a major NHS Trust for elective hip and knee replacements, 2016 to 2019.
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45 118 It was developed and reported according to the RECORD extension¹⁵ to STROBE guidelines for
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47 119 observational studies using routinely collected data.
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51 120 **Data Sources**

52
53 121 We used two data sources for our analyses. The first was an extract of elective primary hip and knee
54
55 122 replacement inpatient admissions identified from the Trust's electronic medical records (EMR)
56
57 123 between 1st January 2016 and 31st December 2019. Up to 29 diagnoses were provided per entry using
58
59 124 the International Classification of Diseases version 10 (ICD-10), and up to 11 procedures were provided

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2
3 125 per entry using the Office of Population Censuses and Surveys Classification of Interventions and
4
5 126 Procedures version 4 (OPCS-4). The extract included patient demographics such as age, sex,
6
7 127 deprivation quintile, and comorbidities; and other characteristics of the hospital admissions such as
8
9
10 128 length of stay. This data source was used for all analyses of hip and knee replacements at the Trust,
11
12 129 including those relating to patient demographics, length of stay, and bed occupancy.
13
14

15 130 The second data source was pseudonymised national admitted patient care Hospital Episode
16
17 131 Statistics (HES-APC) between 1st January 2016 and 31st December 2019. HES-APC is a routinely
18
19 132 collected dataset that records all episodes of admitted (day case or inpatient) care provided to
20
21 133 patients at NHS hospitals in England and to NHS-funded patients treated in independent hospitals.¹⁶
22
23 134 Each episode represents a period of care under one consultant team. Up to 20 diagnoses and 24
24
25 135 clinical procedures are recorded per episode using ICD-10 codes and OPCS-4 codes, respectively. HES
26
27 136 also includes the Lower Super Output Area (LSOA; an area of around 1,500 people) of residence for
28
29 137 each patient, which can be linked to CCG of residence. This data source was used to estimate
30
31 138 elective capacity overall at the Trust, and the ratio of public/private provision of hip and knee
32
33 139 replacements in the catchment area for the Trust (see details below), which could not be gathered
34
35 140 from the extract provided from the Trust EMR.
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41 **Hospital admissions for hip and knee replacements**

42
43 142 Hospital admissions for elective hip and knee replacements were identified by entries with a primary
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45 143 procedure code representing primary hip or knee replacement (Supplementary Table T1) using the
46
47 144 Trust EMR. We used this information to explore summary characteristics of the hospital admissions
48
49 145 over time (overall counts of admissions, average age, proportion of women, proportion with 2+
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51 146 comorbidities, proportion in the two most deprived quintiles) stratified by primary hip or knee
52
53 147 replacements.
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57 **Length of stay and bed occupancy**

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3 149 We used the average number of overnight stays in hospital (days) for length of stay, trimmed at 30
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5 150 days to exclude a small number of outliers (n=32, 0.6%). Trimming allowed us to model averages
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7 151 assuming a roughly normal distribution which we felt was more easily interpretable. Bed occupancy
8
9 152 was the total number of beds used overnight for hip and knee replacement patients.
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13 153 **Comorbidity of Admissions**

14
15 154 For each admission, we counted the number of conditions from the Charlson comorbidity index¹⁷
16
17 155 recorded in the diagnosis fields. The Charlson index provides a summary of weighted scores relating
18
19 156 to different comorbidities and has been shown to be associated with mortality. Admissions were
20
21 157 categorised into those with zero, one, and two or more Charlson comorbidities.
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25 158 **Ratio of Elective to Emergency Admissions**

26
27 159 To estimate the ratio of elective to emergency admissions for all purposes at the Trust (as a proxy for
28
29 160 elective capacity), we extracted all hospital admissions from HES-APC with the Trust as a provider
30
31 161 and categorised them into elective and emergency (admission method beginning with '1' or '2',
32
33 162 respectively).
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37 163 **Ratio of Public to Private Provision of Hip and Knee Replacements**

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39 164 To estimate the ratio of public to private provision of NHS-funded elective hip and knee surgery for
40
41 165 the Trust catchment area, we extracted all hospital admissions for primary hip and knee
42
43 166 replacements (codes in Supplementary Table T1) for residents of the major local clinical
44
45 167 commissioning groups (CCGs) from HES-APC (using 2021 CCG boundaries after local CCGs had
46
47 168 merged into one CCG¹⁸), and categorised providers into public and private (provider code beginning
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49 169 with 'R' or 'N', respectively).
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53 170 **Statistical Analysis**

54
55 171 For each of our outcomes, we conducted interrupted time series (ITS) analyses using segmented
56
57 172 regression models comparing hospital admissions in the 'before' period (January 2016 to November
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1
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3 173 2017) to the 'after' period (February 2018 to December 2019). We excluded the winter 2017 period
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5 174 when admissions were very low (December 2017 and January 2018). The ITS analyses explored the
6
7 175 trend before winter 2017, and how this trend changed after winter 2017^{12 19}, allowing for an
8
9 176 immediate step change in February 2018 and a change in slope afterwards. We explored seasonality
10
11 177 in the data by including indicator variables for spring, summer, and autumn¹⁹ compared to winter as
12
13 178 a baseline, and adjusted for serial autocorrelation using Newey-West standard errors with a maximum
14
15 179 lag of two²⁰⁻²². For count or proportion outcomes (number of admissions, proportion women,
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17 180 proportion with 2+ comorbidities, proportion in top two deprivation quintiles, bed occupancy)
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19 181 segmented Poisson regression models were fit to the data, whilst for averages/ratios (average age,
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21 182 average length of stay, ratio of elective to emergency admissions, ratio of public to private provision)
22
23 183 segmented linear regression models were fit, using the 'glm' command in Stata. Sensitivity analyses
24
25 184 were conducted adjusting the maximum lag for serial autocorrelation to zero and five; this would not
26
27 185 affect point estimates but could alter standard errors, confidence intervals, and p-values.

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29
30 186 All statistical analyses were conducted using Stata/MP version 16.1. Smoothed trends were fit to the
31
32 187 data on all plots using the 'lowess' command with bandwidth 0.3. Stata code is available at:
33
34 188 https://github.com/jonestim2002/hdr_uk_hospital_efficiency

189 **Patient and public involvement**

190 Initial research ideas for the grant application of which this work is part were presented to the public
191 in a workshop and suggestions and comments were incorporated in the protocol. Feedback during
192 the workshop was positive, with participants agreeing with the research objectives and the
193 identified need.

194

195 **RESULTS**

196 *Descriptive information and demographics*

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3 197 A total of 2,623 patients had a hip replacement and 2,674 had a knee replacement at the Trust in the
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5 198 4 years between 2016 and 2019. The mean age of patients was 67 years and 60% were women for
6
7 199 both types of operations.
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10 200 *Trends in hip and knee elective hospital admissions over time*

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12
13 201 The overall numbers of elective primary hip and knee replacement operations gradually declined
14
15 202 over the study period from 63 hip and 65 knee replacements per month in 2016 to 49 hip and 51
16
17 203 knee replacements per month in 2019. Whilst there was a drop off in winter 2017, after elective
18
19 204 surgery was re-started hip replacements resumed at similar numbers and continued to decline along
20
21 205 a similar trajectory. Numbers of knee replacements dropped by 16% after winter 2017 (RR=0.843,
22
23 206 95% CI: 0.728 to 0.976, p=0.022), and the slope appeared to level off, although there was little
24
25 207 evidence for this in the regression model (RR=1.005, 95% CI: 0.996 to 1.014, p=0.256); see Figure 1
26
27 208 and Supplementary Table T2. Hip and knee operations were clearly seasonal, with higher admissions
28
29 209 in non-winter months compared to winter; 21% higher in the highest season (summer) for hips
30
31 210 (RR=1.207, 95% CI: 1.094 to 1.332, p<0.001), and 31% higher in the highest season (spring) for knee
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33 211 replacements (RR=1.308, 95% CI: 1.157 to 1.479, p<0.001), excluding winter 2017.
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43 213 *Age on Admission*

44 214 There was evidence of seasonality in average age on admission for hip admissions, where the mean
45
46 215 age of patients was 66 in winter compared to 68 in summer (+2.09; 95% CI: 0.81 to 3.37, p = 0.001),
47
48 216 suggesting that older patients might be more likely to receive surgery in the summer months. There
49
50 217 was a change in the trend in average age for knee replacements after winter 2017 (+0.21, 95% CI:
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52 218 0.12 to 0.31, p < 0.001) towards treating older patients (+1.59 years of age per year); see Figure 2.
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57 220 *Proportion Women*

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3 221 A higher proportion of hip replacements were performed on women in the summer (64%) compared
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5 222 to winter (58%) months (RR=1.088, 95% CI: 1.001 to 1.183, p=0.048). There were no clear patterns
6
7 223 for knee replacements.
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11 225 *Comorbidity of Admissions*

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13
14 226 There was seasonality in the comorbidity of people having hip replacements, with a higher
15
16 227 proportion of people having 2+ comorbidities in the summer (15.9%) compared to winter (12.3%)
17
18 228 months (RR=1.306, 95% CI: 1.096 to 1.557, p=0.003). There was also a step change up in the
19
20 229 proportion having hip replacements with 2+ comorbidities after winter 2017 (RR=1.411, 95% CI:
21
22 230 1.064 to 1.873, p=0.017), and an upward slope change for knee replacements (RR=1.042, 95% CI:
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24 231 1.017 to 1.067, p=0.001); see Figure 3.
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28 232

29 233 *Deprivation*

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31
32 234 There was a higher proportion of more deprived people (quintiles 4 and 5) having knee
33
34 235 replacements in the spring (37.6%) compared to the winter (30.2%) months (RR=1.224, 95% CI:
35
36 236 1.077 to 1.49, p=0.002). Additionally, there was evidence of a reducing proportion of the most
37
38 237 deprived people having knee replacements after winter 2017 (RR=0.986, 95% CI: 0.974 to 0.998,
39
40 238 p=0.021).
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43 239

44 240 *Ratio of elective admissions to emergency admissions at the Trust*

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48 241 There was an overall downward trend in the ratio of elective to emergency admissions at the Trust,
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50 242 from an average of 2.91 (SD: 0.17) electives for every emergency in 2016 to 2.16 (SD: 0.06) in 2019;
51
52 243 see Supplementary Figure F1. There was no indication of seasonality, but the ratio reduced after
53
54 244 winter 2017 (RR=0.725, 95% CI: 0.64 to 0.821, p<0.001), and started to decrease more rapidly
55
56 245 afterwards (RR=0.984, 95% CI: 0.974 to 0.995, p=0.003).
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56 247 *Ratio of public to private provision of hip/knee elective surgery at the Trust*
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9 248 The ratio of public to private provision was higher in the summer (1.56 for hips and 1.28 for knees)
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11 249 compared to winter (1.22 and 0.99, respectively) months (hips RR=1.361, 95% CI 1.166 to 1.589,
12
13 250 $p<0.001$; knees RR=1.318, 95% CI: 1.035 to 1.678, $p=0.025$). There was also evidence of a step
14
15 251 change downwards in public provision compared to private provision after winter 2017 for both
16
17 252 types of surgery, but particularly for hip replacements (hips RR=0.477, 95% CI: 0.29 to 0.782,
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19 253 $p=0.003$; knees RR=0.621, 95% CI: 0.358 to 1.077, $p=0.09$); see Figure 4.
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23 254
24
2526 255 *Bed Occupancy*
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28
29 256 Bed occupancy for hip and knee replacements at the Trust was very seasonal, with lower occupancy
30
31 257 in the winter months compared to all other seasons; e.g. summer bed occupancy was 324 beds for
32
33 258 hips and 291 beds for knees on average compared to winter bed occupancy of 225 beds for hips and
34
35 259 199 beds for knees on average. In both cases bed occupancy has reduced over time, although there
36
37 260 wasn't evidence of this in the regression model for hip replacements, and there was a step change
38
39 261 downwards (RR=0.834, 95% CI: 0.704 to 0.989, $p=0.037$) for knee surgery after winter 2017; see
40
41 262 Figure 5.
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45 263
46
4748 264 *Length of Stay*
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50
51 265 The average length of hospital stay was 5.5 days (SD: 5.9 days) for hip replacements and 5.2 days
52
53 266 (SD: 5.0 days) for knee replacements in 2016, compared to 5.1 days (SD: 4.1 days) and 4.3 days (SD:
54
55 267 3.4 days) respectively in 2019 (see Supplementary Figure F2). Length of stay was longer in spring
56
57 268 than winter for hip replacements (0.502 days, 95% CI: 0.214 to 0.79, $p=0.001$), and longer in spring
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59
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269 (0.422, 95% CI: 0.073 to 0.771, p=0.018) and autumn (0.396, 95% CI: 0.015 to 0.777, p=0.042)

270 compared to winter for knee replacements.

271

272 **DISCUSSION**

273 *Principle findings*

274 The temporary cancellation of elective services during winter 2017 does appear to have had some
275 impact on service provision at the Trust after that time. There was an immediate and sustained
276 reduction in the number of knee replacements being done at the Trust and this was also reflected in
277 the drop in bed occupancy for knee surgery. The average age for knee replacement and comorbidity
278 of hip and knee surgery patients increased after winter 2017, whilst the proportion of more deprived
279 people having knee replacements decreased, and the ratio of public to private provision of hip and
280 knee replacements in the local area dropped after winter 2017. This suggests an NHS-funded
281 outsourcing of less comorbid hip and knee replacement surgery to independent providers, and
282 therefore on average the patients being treated at the Trust became older and more comorbid.
283 There was a general decrease in capacity for elective surgery at the Trust (ratio of elective to
284 emergency admissions), mostly driven by increasing non-elective admissions even before the COVID-
285 19 pandemic. The winter 2017 cancellation may have been just one symptom of this overall pressure
286 on elective surgery that underlies some of the longer-term changes in provision.

287 There was also some seasonality in service provision. It is no surprise that elective admissions and
288 bed occupancy are lower in winter when the hospital requires capacity for an increase in unplanned
289 admissions. There were also indications that people being admitted in winter were younger, less
290 comorbid, and less deprived (particularly for knee surgery). Length of stay for hip and knee
291 replacements was lower in winter compared to spring. This suggests the admission of younger, less

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3 292 comorbid patients during the winter months given the reduced elective capacity and delaying
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5 293 surgery for more comorbid patients to when capacity is higher in the following months.
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9 294 *Strengths and limitations*

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11 295 Trends analyses such as these, using data obtained from the EHR of a local hospital NHS Trust, are
12
13 296 informative for clinicians and service managers in monitoring changes in planning and delivery of
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15 297 elective surgery, and could be regularly updated in near real time for monitoring. This concept might
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17 298 be informative for other commissioning groups / Trusts to adopt for monitoring of their own elective
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19 299 surgery and capacity. We report the experience of just one trust that is one of the larger elective
20
21 300 orthopaedic centres, and hence the findings may not be generalisable to or reflect the experience of
22
23 301 other trusts. We should be aware that some results may reflect chance findings due to multiple
24
25 302 testing and type 1 error. The trends in the data as plotted do not change substantially in sensitivity
26
27 303 analyses accounting for different autocorrelation lags (Supplementary Tables T3-T4). The catchment
28
29 304 area of the Trust is not exactly the same as the major local CCG and is difficult to define exactly.
30
31 305 However, 89.4% of admissions at the Trust were for residents of the local CCG and we felt this was a
32
33 306 reasonable approximation to estimate the ratio of public to private provision in the Trust catchment
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35 307 area. Our analyses only include NHS-funded surgery and not privately-funded, privately-provided
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37 308 surgery.
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43 309 *Comparison to other studies*

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45
46 310 A previous study²³ using data for England from Hospital Episode Statistics found increasing private
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48 311 provision of elective hip arthroplasties nationally from 2007/8 to 2012/13, particularly for less
49
50 312 deprived people, which echoes our findings. More recent news stories have suggested that 20% of
51
52 313 NHS-funded hip replacements and 29% of NHS-funded knee replacements were carried out by
53
54 314 independent providers in 2016/17²⁴, and that independently-provided hip and knee replacement
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56 315 surgery (privately or NHS-funded) has now overtaken NHS provision.²⁵ A UK-wide study⁶ using
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3 316 primary care data (CPRD) linked to hospital admissions found similar effects of patient
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5 317 characteristics (age, sex, comorbidity, and deprivation) on length of stay for primary hip and knee
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7 318 replacements, although they did not explore seasonality. A recent qualitative study²⁶ highlighted the
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9 319 negative financial and emotional impact of winter elective cancellations on patients and their
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11 320 families and recommended better advanced planning of elective operations to reduce these
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13
14 321 impacts.

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17 322 *Implications for clinicians and policy makers*

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20 323 Outsourcing of less complex hip and knee replacements to take advantage of spare capacity in non-
21
22 324 NHS hospitals may be a good strategy to reduce waiting times and waiting lists for surgery and get
23
24 325 the best results for patients given the evident capacity limitations. However, this would leave the
25
26 326 NHS Trust to cope with more complex cases and has training implications because trainee surgeons
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28 327 are usually trained by first undertaking less-complex cases on healthier patients. There are also
29
30 328 potential equity implications, if less complex cases have the option of surgery with shorter waiting
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32 329 times at independent providers, whilst more complex (and potentially more deprived) cases do not.
33
34 330 We would need to consider the acceptability of this outsourcing to patients and practitioners.

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39 331 There is an indication that some selection of patients for elective surgery depending on available
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41 332 capacity already takes place at the Trust. It is possible that this could become a more explicit
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43 333 strategy, based on evidence, to optimise the use of limited capacity in hospitals at different times of
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45 334 the year. However, this could mean that people placed earlier on the waiting list for surgery might
46
47 335 get their surgery later due to such scheduling strategies, so acceptability to patients would need to
48
49 336 be explored. We need to understand how the scheduling and possible outsourcing of elective
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51 337 surgery for different types of patients, depending on capacity, may impact on throughput of
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53 338 patients, waiting times, waiting lists, outcomes of surgery, costs, and equity of access to surgery.
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55 339 Inevitably outsourcing simpler patients to the independent sector will leave more complex patients
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57 340 being treated by NHS Trusts, which could have a detrimental impact on their service. An appropriate
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3 341 balance would need to be achieved to maximise the benefits for patients, and research is needed to
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5 342 understand what that balance is. Additionally, we need to understand whether this type of
6
7 343 scheduling and outsourcing is acceptable to people waiting for hip and knee surgery as well as
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9 344 clinicians. These issues of optimising limited elective resources are in even sharper focus due to the
10
11 345 backlog in waiting lists caused by the COVID-19 pandemic.
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15 346 *Unanswered questions and future research*

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18 347 We need to understand how the scheduling and possible outsourcing of elective surgery for
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20 348 different types of patients, depending on capacity, may impact on throughput of patients, waiting
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22 349 times, waiting lists, outcomes of surgery, costs, and equity of access to surgery. Inevitably
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24 350 outsourcing simpler patients to the independent sector will leave more complex patients being
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26 351 treated by NHS Trusts, which could have a detrimental impact on their service. An appropriate
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28 352 balance would need to be achieved to maximise the benefits for patients, and research is needed to
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30 353 understand what that balance is. Additionally, we need to understand whether this type of
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32 354 scheduling and outsourcing is acceptable to people waiting for hip and knee surgery as well as
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34 355 clinicians.
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39 356 *Conclusions*

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42 357 Declining elective capacity and seasonality has a marked effect on the provision of joint
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44 358 replacement, despite efficiency improvements in hospital treatment. The Trust has outsourced less
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46 359 complex patients to independent providers, and/or treated them during winter when capacity is
47
48 360 most limited. There is a need to explore whether these are strategies that could be used explicitly to
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50 361 maximise the use of limited elective capacity, provide benefit to patients, and value for money for
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52 362 taxpayers.
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56 363

59 364 **Author Contributions**

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3 365 This publication is the work of the authors, who serve as guarantors for the contents of this paper. TJ
4
5 366 contributed to study design, data cleaning, data analysis, interpretation of results and writing the
6
7 367 manuscript. MTR contributed to study conceptualisation, supervision, interpretation of results and
8
9 368 reviewing the manuscript. TK contributed to data curation, supervision, interpretation of results and
10
11 369 reviewing the manuscript. AE contributed to data curation, interpretation of results and reviewing
12
13 370 the manuscript. CP and EE contributed to interpretation of results and reviewing the manuscript. AB
14
15 371 contributed to study conceptualisation, supervision, interpretation of results and reviewing the
16
17 372 manuscript. AJ contributed to study conceptualisation and design, supervision, and writing the
18
19 373 manuscript. TJ had full access to the data in the study and takes responsibility for the integrity of the
20
21 374 data and the accuracy of the data analysis.
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31
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34 378 Trust, and the use of their hospital admissions data via the NIHR ARC West Partnership Agreement.
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37 379

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41
42
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44
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46
47 383 Collaboration West (NIHR ARC West). The views expressed in this article are those of the author(s)
48
49 384 and not necessarily those of the NHS, the NIHR, the Department of Health and Social Care or HDR
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51 385 UK.
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56 57 58 387 **Ethical Approval**

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3 388 We were provided with pseudonymised hospital admissions data from the NHS Trust under the NIHR
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5 389 ARC West Partnership Agreement. The project received ethical approval from the University of
6
7 390 Bristol Faculty of Health Sciences ethical review board on 3rd November 2020 (ref# 109024).
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9

10 391 We were provided with routinely-collected Hospital Episode Statistics data under licence from NHS
11
12 392 Digital (DARS-NIC-17875-X7K1V). The licence allows us to use the information under Section 261 of
13
14 393 the Health and Social Care Act 2012, 2(b)(ii): “after taking into account the public interest as well as
15
16 394 the interests of the relevant person, considers that it is appropriate for the information to be
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18 395 disseminated”.
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25 397 **Data Sharing**

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28 398 The data from the NHS Trust was obtained under the NIHR ARC West Partnership Agreement. The
29
30 399 agreement precludes us from sharing the raw data but it can be published and shared once
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32 400 aggregated to a non-identifiable level.
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35 401 The data from Hospital Episode Statistics (HES) was obtained under licence (DARS-NIC-17875-X7K1V)
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37 402 from NHS Digital (previously the Health and Social Care Information Centre); *Copyright © 2022, re-*
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39 403 *used with the permission of The Health & Social Care Information Centre. All rights reserved.* The
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41 404 data are provided by patients and collected by the NHS as part of their care and support. HES data
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43 405 can be accessed via NHS Digital: <https://digital.nhs.uk/services/data-access-request-service-dars>
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50 407 **Transparency**

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53 408 The manuscript’s guarantor (TJ) affirms that the manuscript is an honest, accurate, and transparent
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55 409 account of the study being reported; that no important aspects of the study have been omitted; and
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57 410 that any discrepancies from the study as originally planned have been explained.
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412 **Competing Interests**

413 All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf
 414 and declare: TJ, EE, and TR had financial support from NIHR ARC West for the submitted work; AJ has
 415 had financial support in the previous three years through institutional grants from NIHR, HDR UK,
 416 Versus Arthritis, Healthcare Quality Improvement Partnership (HQIP), Royal College of Physicians
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 418 conditions for NIHR, Nuffield Foundation, Warwick CTU, and Versus Arthritis, and a paid expert panel
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 420 that might have an interest in the submitted work in the previous three years; no other relationships
 421 or activities that could appear to have influenced the submitted work.

422

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FIGURE CAPTIONS

Figure 1. Elective hip (left panel) and knee (right panel) replacement admissions at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 2. Average age on admission for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 3. Proportion of people having hip (left panel) and knee (right panel) replacements with 2+ Charlson comorbidities recorded
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 4. Ratio of public to private provision of elective hip (left panel) and knee (right panel) replacements for NHS patients in the Trust CCG
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 5. Bed occupancy for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

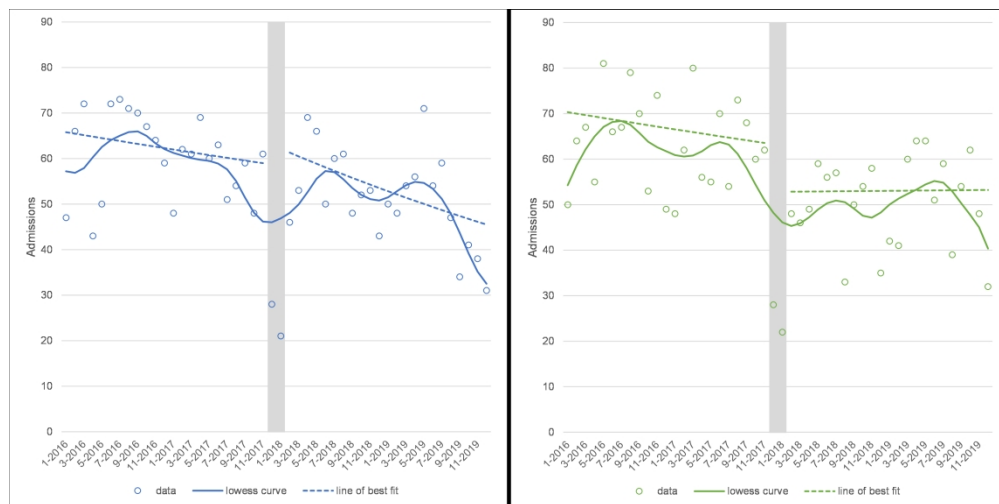


Figure 1. Elective hip (left panel) and knee (right panel) replacement admissions at the Trust
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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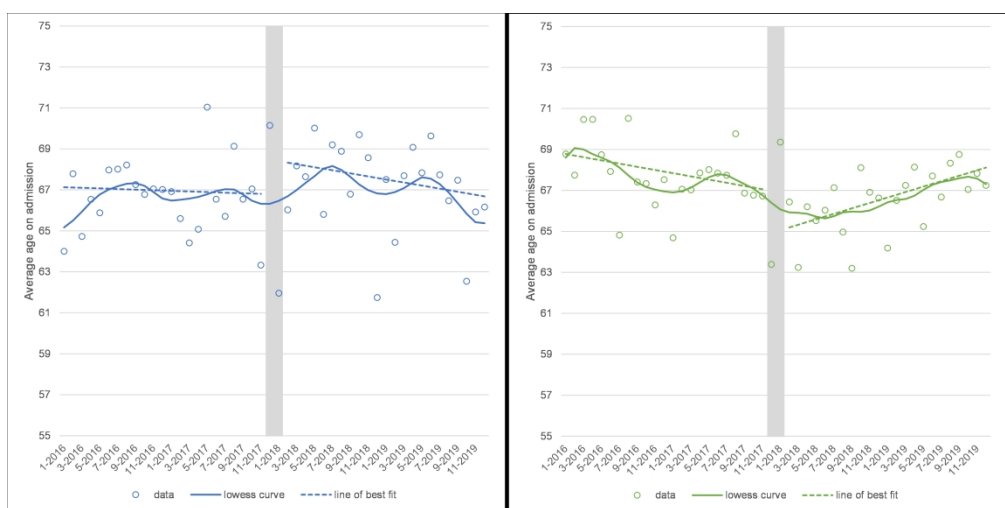


Figure 2. Average age on admission for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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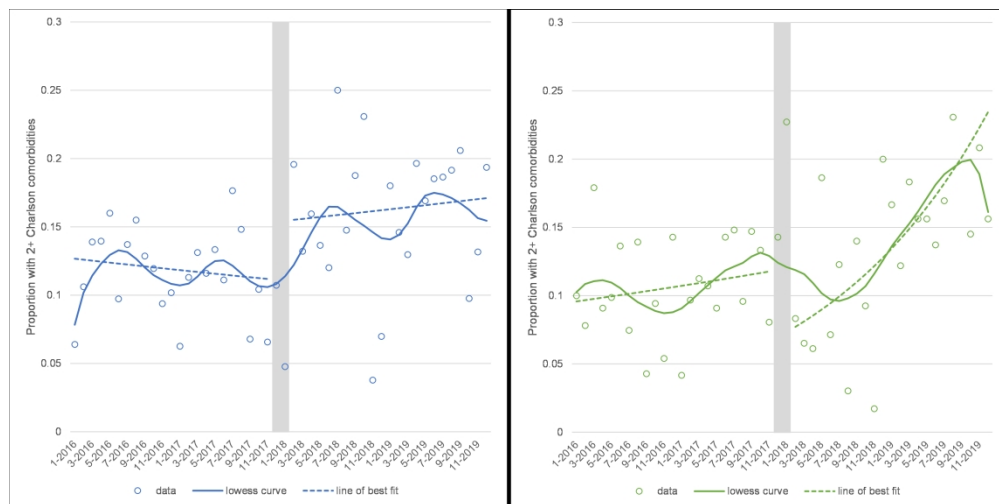


Figure 3. Proportion of people having hip (left panel) and knee (right panel) replacements with 2+ Charlson comorbidities recorded
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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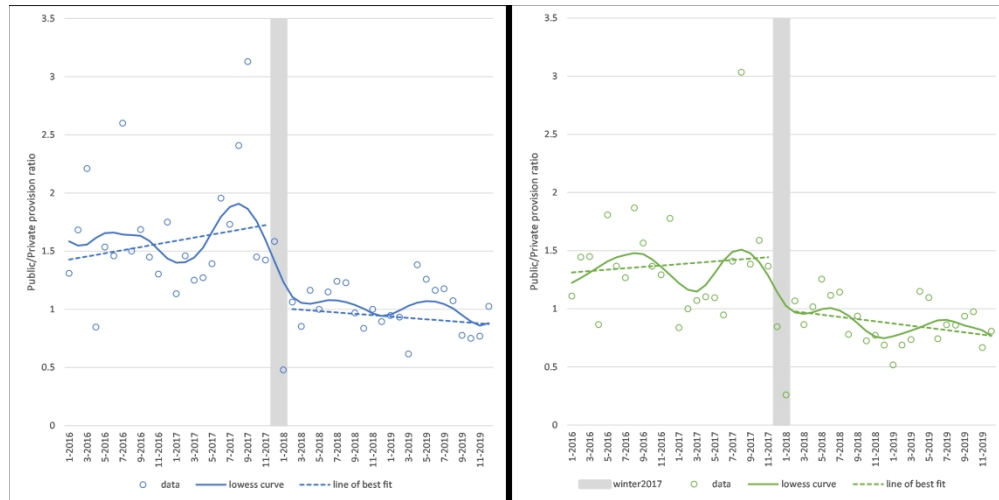


Figure 4. Ratio of public to private provision of elective hip (left panel) and knee (right panel) replacements for NHS patients in the Trust CCG
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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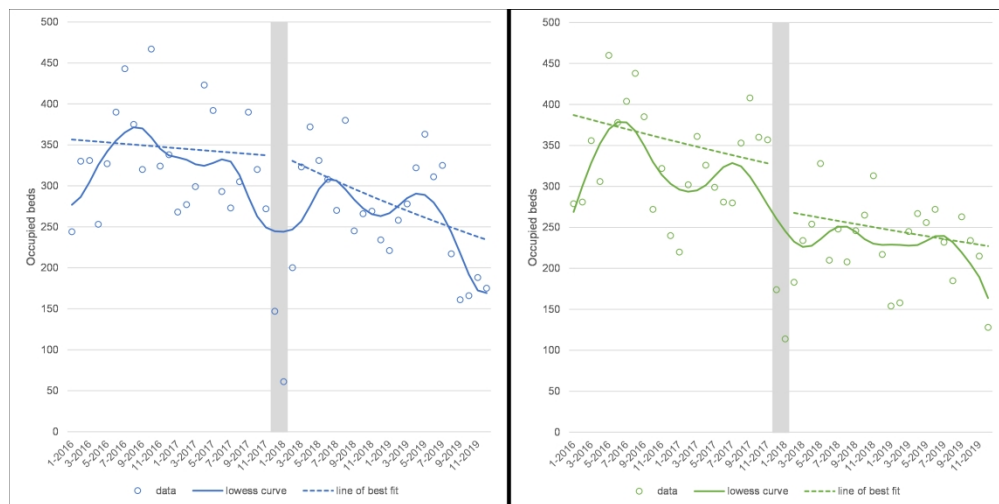
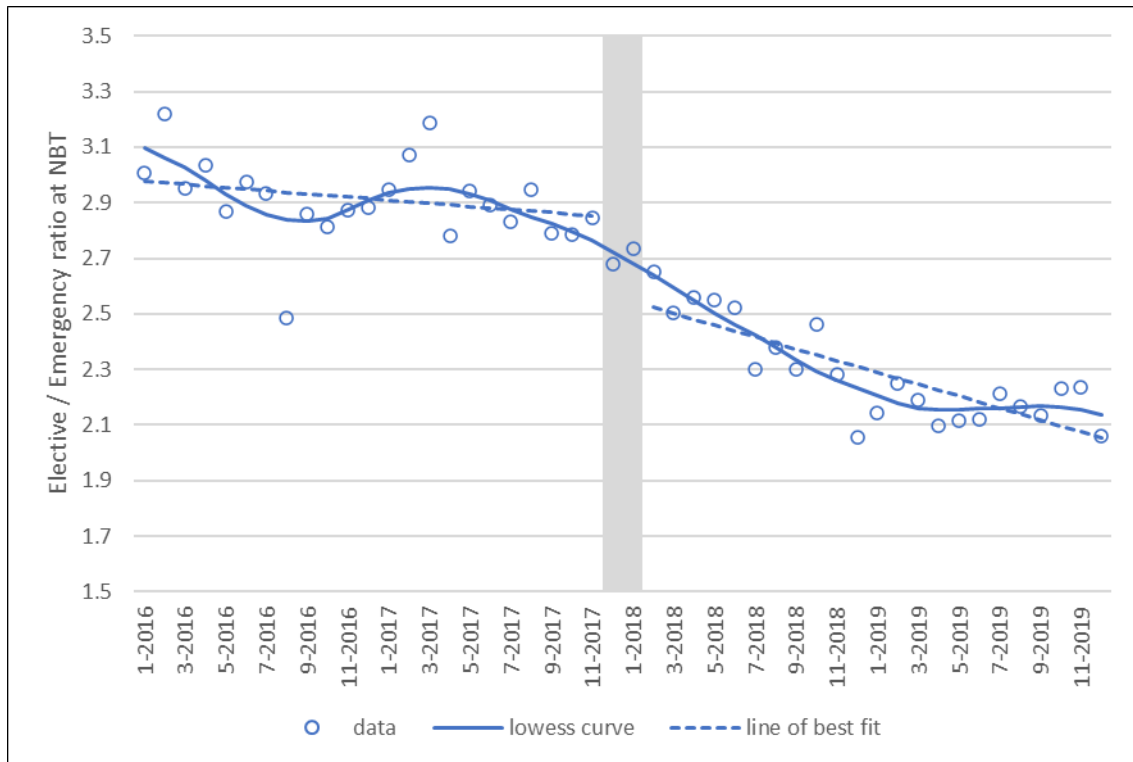


Figure 5. Bed occupancy for hip (left panel) and knee (right panel) replacements at the Trust
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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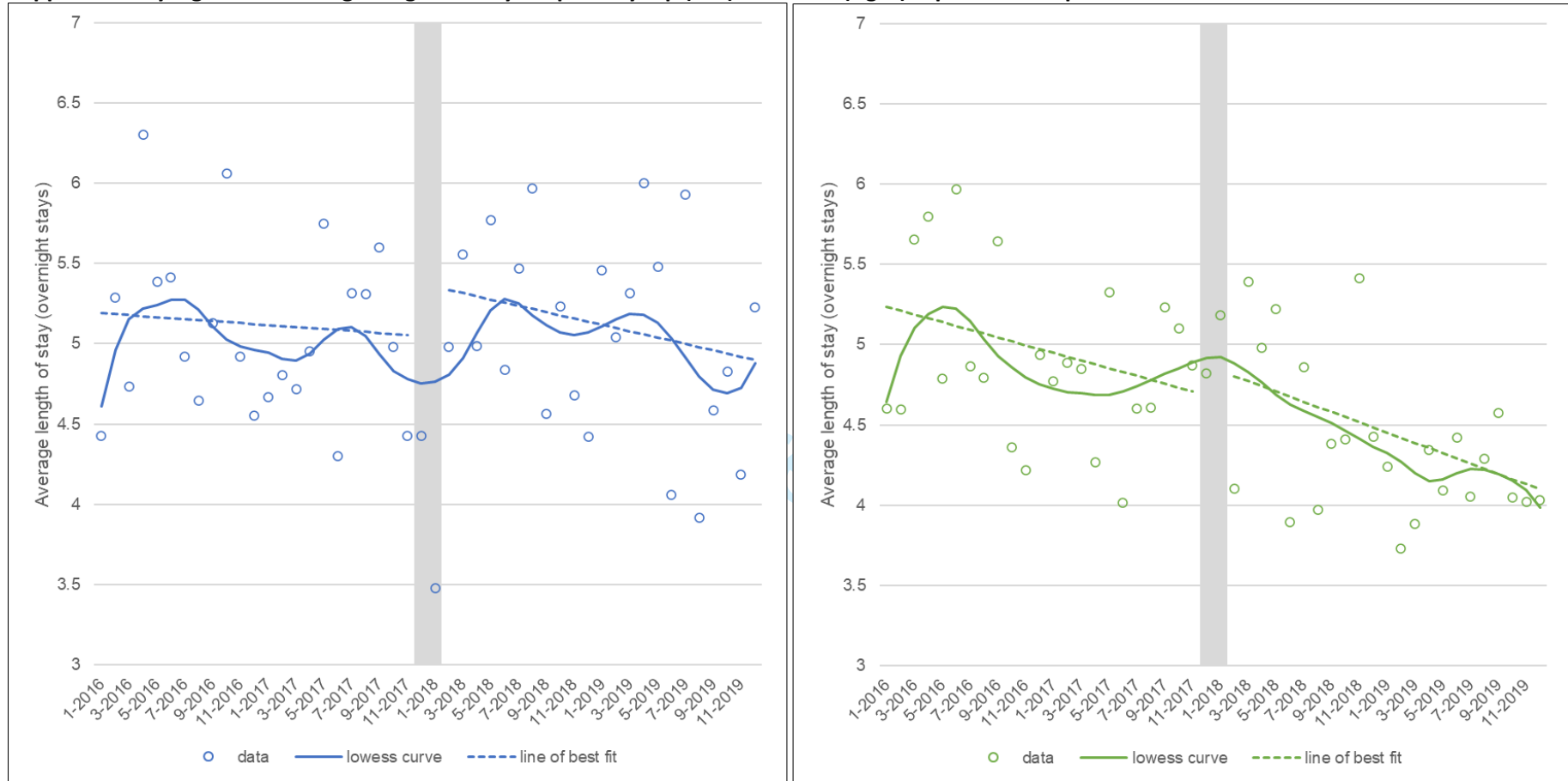
Supplementary Figure F1. Ratio of elective to emergency hospital admissions for any reason at the Trust



Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Review only

Supplementary Figure F2. Average length of stay for primary hip (left) and knee (right) replacement operations at NBT



Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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For peer review only

Supplementary Table T1. OPCS-4 codes used to identify primary hip and knee replacement operations

Category	Code	Description	Notes
<i>Primary Total Hip Replacement</i>	W37.1	Primary total prosthetic replacement of hip joint using cement	
	W37.8	Other specified total prosthetic replacement of hip joint using cement	
	W37.9	Unspecified total prosthetic replacement of hip joint using cement	
	W38.1	Primary total prosthetic replacement of hip joint not using cement	
	W38.8	Other specified total prosthetic replacement of hip joint not using cement	
	W38.9	Unspecified total prosthetic replacement of hip joint not using cement	
	W39.1	Primary total prosthetic replacement of hip joint NEC	
	W39.8	Other specified other total prosthetic replacement of hip joint	
	W39.9	Unspecified other total prosthetic replacement of hip joint	
	W43.1	Primary total prosthetic replacement of other joint using cement NEC	
	W43.8	Other specified total prosthetic replacement of other joint using cement NEC	
	W43.9	Unspecified total prosthetic replacement of other joint using cement NEC	
	W44.1	Primary total prosthetic replacement of other joint not using cement NEC	
	W44.8	Other specified total prosthetic replacement of other joint not using cement NEC	
	W44.9	Unspecified total prosthetic replacement of other joint not using cement NEC	
	W45.1	Other primary total prosthetic replacement of other joint NEC	
W45.8	Other specified total prosthetic replacement of other joint NEC		
W45.9	Unspecified total prosthetic replacement of other joint NEC		
W52.1	Primary prosthetic replacement of articulation of bone using cement NEC		

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3 W52.8 Other specified prosthetic replacement of articulation of bone using
4 cement NEC
5
6 W52.9 Unspecified prosthetic replacement of articulation of bone using
7 cement NEC
8
9 W53.1 Primary prosthetic replacement of articulation of bone not using
10 cement NEC
11
12 W53.8 Other specified prosthetic replacement of articulation of bone not
13 using cement NEC
14
15 W53.9 Unspecified prosthetic replacement of articulation of bone not using
16 cement NEC
17
18 W54.1 Primary prosthetic replacement of articulation of bone NEC
19
20 W54.8 Other specified prosthetic replacement of articulation of bone NEC
21
22 W54.9 Unspecified prosthetic replacement of articulation of bone NEC
23
24 W93.1 Primary hybrid prosthetic replacement of hip joint using cemented
25 acetabular component
26
27 W93.8 Other specified hybrid prosthetic replacement of hip joint using
28 cemented acetabular component
29
30 W93.9 Unspecified hybrid prosthetic replacement of hip joint using cemented
31 acetabular component
32
33 W94.1 Primary hybrid prosthetic replacement of hip joint using cemented
34 femoral component
35
36 W94.8 Other specified hybrid prosthetic replacement of hip joint using
37 cemented femoral component
38
39 W94.9 Unspecified hybrid prosthetic replacement of hip joint using cemented
40 femoral component
41
42 W95.1 Primary hybrid prosthetic replacement of hip joint using cement NEC
43
44 W95.8 Other specified hybrid prosthetic replacement of hip joint using
45 cement
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W95.9 Unspecified hybrid prosthetic replacement of hip joint using cement
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3	<i>Primary Total Knee</i>	W40.1	Primary total prosthetic replacement of knee joint using cement
4	<i>Replacement</i>		
5			
6		W40.8	Other specified total prosthetic replacement of knee joint using cement
7			
8		W40.9	Unspecified total prosthetic replacement of knee joint using cement
9		W41.1	Primary total prosthetic replacement of knee joint not using cement
10			
11		W41.8	Other specified total prosthetic replacement of knee joint not using cement
12			
13		W41.9	Unspecified total prosthetic replacement of knee joint not using cement
14			
15		W42.1	Primary total prosthetic replacement of knee joint NEC
16		W42.8	Other specified other total prosthetic replacement of knee joint
17		W42.9	Unspecified other total prosthetic replacement of knee joint
18		O18.1	Primary hybrid prosthetic replacement of knee joint using cement
19		O18.8	Other specified hybrid prosthetic replacement of knee joint using cement
20			
21		O18.9	Unspecified hybrid prosthetic replacement of knee joint using cement
22			
23	<i>Resurfacing / Reconstruction</i>	W58.1	Primary resurfacing arthroplasty of joint
24			Require combination with site + combination codes to ID
25		W58.8	Other specified reconstruction of joint
26			Require combination with site + combination codes to ID
27			
28		W58.9	Unspecified other reconstruction of joint
29			Require combination with site + combination codes to ID
30			
31	<i>Primary unicondylar /</i>	W52.1	Primary prosthetic replacement of articulation of bone using cement
32	<i>unicompartmental knee</i>		Require combination with site + combination codes to ID
33	<i>operations</i>	W52.8	Other specified prosthetic replacement of articulation of other bone using cement
34			Require combination with site + combination codes to ID
35			
36		W52.9	Unspecified prosthetic replacement of articulation of other bone using cement
37			Require combination with site + combination codes to ID
38			
39		W53.1	Primary prosthetic replacement of articulation of bone not using cement NEC
40			Require combination with site + combination codes to ID
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3	W53.9	Unspecified prosthetic replacement of articulation of other bone not	Require combination with site +
4		using cement	combination codes to ID
5			
6	W54.0	Conversion from previous prosthetic replacement of articulation of	Require combination with site +
7		bone NEC	combination codes to ID
8	W54.1	Primary prosthetic replacement of articulation of bone NEC	Require combination with site +
9			combination codes to ID
10			
11	W54.8	Other specified other prosthetic replacement of articulation of other	Require combination with site +
12		bone	combination codes to ID
13	W54.9	Unspecified other prosthetic replacement of articulation of other bone	Require combination with site +
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Supplementary Table T2. Interrupted time series model results with maximum auto-correlation lag 2

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.986,1.004)	0.300	1.055 (0.912,1.221)	0.469	0.991 (0.977,1.006)	0.239	1.19 (1.034,1.37)	0.015	1.207 (1.094,1.332)	0.000	1.101 (0.982,1.234)	0.099
Hip Average Age	-0.015 (-0.102,0.072)	0.737	1.571 (-0.1,3.242)	0.065	-0.06 (-0.175,0.055)	0.307	1.52 (-0.07,3.111)	0.061	2.09 (0.811,3.368)	0.001	1.031 (-0.598,2.66)	0.215
Hip Prop Women	0.999 (0.995,1.003)	0.582	0.966 (0.861,1.083)	0.549	1.007 (0.999,1.016)	0.089	1.023 (0.941,1.111)	0.596	1.088 (1.001,1.183)	0.048	0.981 (0.888,1.083)	0.700
Hip Prop 2+ Charlson	0.994 (0.982,1.007)	0.380	1.411 (1.064,1.873)	0.017	1.01 (0.994,1.027)	0.220	1.195 (0.982,1.455)	0.075	1.306 (1.096,1.557)	0.003	1.003 (0.788,1.276)	0.982
Hip Prop High Deprivation	1.003 (0.993,1.013)	0.587	1.027 (0.869,1.214)	0.754	1.004 (0.986,1.022)	0.660	0.937 (0.815,1.076)	0.358	0.877 (0.752,1.022)	0.093	0.996 (0.84,1.18)	0.963
Hip LoS	-0.006 (-0.034,0.021)	0.660	0.312 (-0.193,0.818)	0.225	-0.014 (-0.047,0.02)	0.425	0.502 (0.214,0.79)	0.001	0.135 (-0.194,0.463)	0.422	0.1 (-0.288,0.488)	0.613
Hip Bed Occ	0.997 (0.987,1.008)	0.643	1 (0.844,1.186)	0.997	0.987 (0.97,1.005)	0.149	1.291 (1.11,1.501)	0.001	1.283 (1.125,1.463)	0.000	1.146 (0.988,1.328)	0.071
Hip Public Private	1.013 (0.985,1.041)	0.377	0.477 (0.29,0.782)	0.003	0.981 (0.951,1.011)	0.218	0.992 (0.809,1.217)	0.939	1.361 (1.166,1.589)	0.000	1.038 (0.847,1.273)	0.718
Knee Admissions	0.995 (0.99,1.001)	0.106	0.843 (0.728,0.976)	0.022	1.005 (0.996,1.014)	0.256	1.308 (1.157,1.479)	0.000	1.26 (1.138,1.396)	0.000	1.286 (1.164,1.42)	0.000
Knee Average Age	-0.078 (-0.157,0.001)	0.054	-1.632 (-2.988,-0.276)	0.018	0.211 (0.117,0.305)	0.000	0.926 (-0.112,1.965)	0.080	0.953 (-0.021,1.927)	0.055	0.354 (-0.531,1.24)	0.433
Knee Prop Women	1.004 (0.998,1.01)	0.150	0.96 (0.85,1.084)	0.513	0.994 (0.986,1.003)	0.193	1.037 (0.963,1.117)	0.336	1.017 (0.924,1.118)	0.735	1.036 (0.958,1.12)	0.375
Knee Prop 2+ Charlson	1.009 (0.993,1.026)	0.249	0.638 (0.455,0.894)	0.009	1.042 (1.017,1.067)	0.001	1.156 (0.911,1.467)	0.234	1.074 (0.849,1.359)	0.551	0.909 (0.628,1.315)	0.612
Knee Prop High Deprivation	1.005 (0.997,1.013)	0.189	0.968 (0.786,1.191)	0.758	0.986 (0.974,0.998)	0.021	1.224 (1.077,1.39)	0.002	1.075 (0.942,1.227)	0.282	1.031 (0.902,1.178)	0.656
Knee LoS	-0.024 (-0.049,0.001)	0.058	0.176 (-0.279,0.63)	0.449	-0.008 (-0.036,0.02)	0.566	0.422 (0.073,0.771)	0.018	0.15 (-0.166,0.467)	0.352	0.396 (0.015,0.777)	0.042
Knee Bed Occ	0.993 (0.984,1.002)	0.103	0.834 (0.704,0.989)	0.037	1 (0.989,1.011)	0.993	1.42 (1.297,1.556)	0.000	1.373 (1.218,1.547)	0.000	1.465 (1.312,1.635)	0.000
Knee Public Private	1.006 (0.98,1.032)	0.667	0.621 (0.358,1.077)	0.090	0.985 (0.961,1.01)	0.225	1.119 (0.915,1.369)	0.274	1.318 (1.035,1.678)	0.025	1.139 (0.931,1.394)	0.205
Elec Emerg Ratio	0.995 (0.987,1.002)	0.171	0.725 (0.64,0.821)	0.000	0.984 (0.974,0.995)	0.003	0.992 (0.887,1.109)	0.886	0.948 (0.833,1.08)	0.424	0.973 (0.86,1.1)	0.661

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Supplementary Table T3. Interrupted time series model results with maximum auto-correlation lag 0

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.985,1.005)	0.323	1.055 (0.902,1.235)	0.503	0.991 (0.978,1.005)	0.220	1.19 (1.036,1.367)	0.014	1.207 (1.088,1.339)	0.000	1.101 (0.983,1.234)	0.098
Hip Average Age	-0.015 (-0.134,0.104)	0.806	1.571 (-0.863,4.004)	0.206	-0.06 (-0.208,0.088)	0.427	1.52 (-0.079,3.119)	0.062	2.09 (0.685,3.494)	0.004	1.031 (-0.505,2.567)	0.188
Hip Prop Women	0.999 (0.993,1.004)	0.674	0.966 (0.826,1.13)	0.662	1.007 (0.997,1.017)	0.158	1.023 (0.937,1.116)	0.617	1.088 (0.995,1.189)	0.064	0.981 (0.878,1.096)	0.730
Hip Prop 2+ Charlson	0.994 (0.98,1.009)	0.455	1.411 (0.969,2.055)	0.072	1.01 (0.989,1.031)	0.344	1.195 (0.971,1.471)	0.092	1.306 (1.043,1.637)	0.020	1.003 (0.734,1.37)	0.986
Hip Prop High Deprivation	1.003 (0.991,1.014)	0.631	1.027 (0.846,1.247)	0.787	1.004 (0.983,1.025)	0.704	0.937 (0.819,1.072)	0.342	0.877 (0.746,1.03)	0.110	0.996 (0.831,1.193)	0.965
Hip LoS	-0.006 (-0.038,0.026)	0.704	0.312 (-0.262,0.887)	0.287	-0.014 (-0.058,0.03)	0.542	0.502 (0.132,0.872)	0.008	0.135 (-0.292,0.562)	0.537	0.1 (-0.287,0.487)	0.612
Hip Bed Occ	0.997 (0.987,1.009)	0.653	1 (0.824,1.215)	0.997	0.987 (0.972,1.002)	0.097	1.291 (1.125,1.48)	0.000	1.283 (1.129,1.458)	0.000	1.146 (0.984,1.334)	0.080
Hip Public Private	1.013 (0.985,1.041)	0.377	0.477 (0.29,0.782)	0.003	0.981 (0.951,1.011)	0.218	0.992 (0.809,1.217)	0.939	1.361 (1.166,1.589)	0.000	1.038 (0.847,1.273)	0.718
Knee Admissions	0.995 (0.987,1.004)	0.274	0.843 (0.702,1.013)	0.068	1.005 (0.993,1.017)	0.422	1.308 (1.154,1.483)	0.000	1.26 (1.114,1.426)	0.000	1.286 (1.147,1.441)	0.000
Knee Average Age	-0.078 (-0.157,0.001)	0.053	-1.632 (-3.299,0.035)	0.055	0.211 (0.102,0.32)	0.000	0.926 (-0.129,1.981)	0.085	0.953 (-0.257,2.163)	0.123	0.354 (-0.777,1.485)	0.540
Knee Prop Women	1.004 (0.998,1.011)	0.182	0.96 (0.84,1.097)	0.551	0.994 (0.986,1.003)	0.184	1.037 (0.939,1.146)	0.474	1.017 (0.908,1.138)	0.776	1.036 (0.928,1.157)	0.529
Knee Prop 2+ Charlson	1.009 (0.988,1.031)	0.384	0.638 (0.392,1.037)	0.070	1.042 (1.008,1.077)	0.015	1.156 (0.891,1.501)	0.276	1.074 (0.829,1.393)	0.589	0.909 (0.636,1.299)	0.600
Knee Prop High Deprivation	1.005 (0.997,1.014)	0.237	0.968 (0.784,1.195)	0.761	0.986 (0.974,0.998)	0.023	1.224 (1.099,1.363)	0.000	1.075 (0.956,1.209)	0.225	1.031 (0.911,1.166)	0.631
Knee LoS	-0.024 (-0.052,0.004)	0.089	0.176 (-0.352,0.703)	0.515	-0.008 (-0.041,0.025)	0.625	0.422 (0.117,0.726)	0.007	0.15 (-0.174,0.475)	0.364	0.396 (0.027,0.765)	0.036
Knee Bed Occ	0.993 (0.984,1.001)	0.074	0.834 (0.711,0.979)	0.027	1 (0.989,1.011)	0.993	1.42 (1.269,1.59)	0.000	1.373 (1.217,1.548)	0.000	1.465 (1.287,1.667)	0.000
Knee Public Private	1.006 (0.98,1.032)	0.667	0.621 (0.358,1.077)	0.090	0.985 (0.961,1.01)	0.225	1.119 (0.915,1.369)	0.274	1.318 (1.035,1.678)	0.025	1.139 (0.931,1.394)	0.205
Elec Emerg Ratio	0.995 (0.987,1.002)	0.167	0.725 (0.637,0.825)	0.000	0.984 (0.975,0.994)	0.001	0.992 (0.889,1.106)	0.884	0.948 (0.84,1.07)	0.392	0.973 (0.879,1.076)	0.591

Supplementary Table T4. Interrupted time series model results with maximum auto-correlation lag 5

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.987,1.003)	0.249	1.055 (0.917,1.215)	0.454	0.991 (0.978,1.005)	0.217	1.19 (1.04,1.362)	0.012	1.207 (1.104,1.32)	0.000	1.101 (0.993,1.221)	0.069
Hip Average Age	-0.015 (-0.094,0.065)	0.714	1.571 (0.241,2.901)	0.021	-0.06 (-0.168,0.048)	0.277	1.52 (-0.178,3.218)	0.079	2.09 (0.818,3.361)	0.001	1.031 (-0.639,2.701)	0.226
Hip Prop Women	0.999 (0.995,1.002)	0.503	0.966 (0.895,1.042)	0.367	1.007 (1.001,1.014)	0.027	1.023 (0.932,1.122)	0.636	1.088 (1,1.184)	0.051	0.981 (0.879,1.094)	0.727
Hip Prop 2+ Charlson	0.994 (0.985,1.004)	0.261	1.411 (1.116,1.785)	0.004	1.01 (1,1.02)	0.042	1.195 (0.979,1.459)	0.079	1.306 (1.111,1.535)	0.001	1.003 (0.792,1.27)	0.981
Hip Prop High Deprivation	1.003 (0.994,1.012)	0.551	1.027 (0.883,1.195)	0.729	1.004 (0.99,1.018)	0.577	0.937 (0.805,1.091)	0.400	0.877 (0.752,1.022)	0.092	0.996 (0.847,1.171)	0.961
Hip LoS	-0.006 (-0.029,0.017)	0.605	0.312 (-0.12,0.745)	0.157	-0.014 (-0.042,0.015)	0.346	0.502 (0.286,0.718)	0.000	0.135 (-0.191,0.461)	0.418	0.1 (-0.332,0.532)	0.650
Hip Bed Occ	0.997 (0.987,1.008)	0.627	1 (0.862,1.161)	0.996	0.987 (0.97,1.004)	0.128	1.291 (1.116,1.492)	0.001	1.283 (1.14,1.444)	0.000	1.146 (0.99,1.326)	0.068
Hip Public Private	1.013 (0.985,1.041)	0.377	0.477 (0.29,0.782)	0.003	0.981 (0.951,1.011)	0.218	0.992 (0.809,1.217)	0.939	1.361 (1.166,1.589)	0.000	1.038 (0.847,1.273)	0.718
Knee Admissions	0.995 (0.992,0.999)	0.016	0.843 (0.761,0.934)	0.001	1.005 (0.998,1.012)	0.170	1.308 (1.154,1.482)	0.000	1.26 (1.16,1.369)	0.000	1.286 (1.178,1.403)	0.000
Knee Average Age	-0.078 (-0.152,-0.005)	0.037	-1.632 (-2.825,-0.439)	0.007	0.211 (0.128,0.293)	0.000	0.926 (-0.072,1.924)	0.069	0.953 (0.077,1.829)	0.033	0.354 (-0.422,1.13)	0.371
Knee Prop Women	1.004 (0.999,1.009)	0.086	0.96 (0.861,1.071)	0.465	0.994 (0.987,1.001)	0.097	1.037 (0.973,1.105)	0.260	1.017 (0.922,1.121)	0.743	1.036 (0.966,1.111)	0.319
Knee Prop 2+ Charlson	1.009 (0.993,1.026)	0.250	0.638 (0.468,0.869)	0.004	1.042 (1.021,1.064)	0.000	1.156 (0.931,1.436)	0.190	1.074 (0.841,1.372)	0.567	0.909 (0.626,1.321)	0.617
Knee Prop High Deprivation	1.005 (0.999,1.011)	0.107	0.968 (0.835,1.122)	0.664	0.986 (0.977,0.995)	0.003	1.224 (1.082,1.384)	0.001	1.075 (0.95,1.217)	0.251	1.031 (0.924,1.149)	0.586
Knee LoS	-0.024 (-0.047,-0.001)	0.042	0.176 (-0.2,0.551)	0.360	-0.008 (-0.031,0.015)	0.490	0.422 (0.033,0.81)	0.033	0.15 (-0.199,0.499)	0.398	0.396 (-0.011,0.803)	0.057
Knee Bed Occ	0.993 (0.986,0.999)	0.032	0.834 (0.728,0.956)	0.009	1 (0.991,1.009)	0.991	1.42 (1.308,1.542)	0.000	1.373 (1.213,1.553)	0.000	1.465 (1.318,1.627)	0.000
Knee Public Private	1.006 (0.98,1.032)	0.667	0.621 (0.358,1.077)	0.090	0.985 (0.961,1.01)	0.225	1.119 (0.915,1.369)	0.274	1.318 (1.035,1.678)	0.025	1.139 (0.931,1.394)	0.205
Elec Emerg Ratio	0.995 (0.987,1.003)	0.198	0.725 (0.635,0.828)	0.000	0.984 (0.974,0.995)	0.004	0.992 (0.898,1.095)	0.872	0.948 (0.835,1.077)	0.414	0.973 (0.849,1.114)	0.690

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract P2 L35-37 Abstract P2 L35-38
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Introduction P4-5 L76-113
Objectives	3	State specific objectives, including any prespecified hypotheses			Introduction P5 L107-113
Methods					
Study Design	4	Present key elements of study design early in the paper			Methods P5 L116-119
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Methods P5 L116-119 Methods P7-8 L70-176

Participants	6	<p>(a) <i>Cohort study</i> - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up</p> <p><i>Case-control study</i> - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls</p> <p><i>Cross-sectional study</i> - Give the eligibility criteria, and the sources and methods of selection of participants</p> <p>(b) <i>Cohort study</i> - For matched studies, give matching criteria and number of exposed and unexposed</p> <p><i>Case-control study</i> - For matched studies, give matching criteria and the number of controls per case</p>		<p>RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided.</p> <p>RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided.</p> <p>RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.</p>	Methods P6 L141-147 Supplementary Table T1
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Methods P6-7 L141-169
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group			Methods P5-6 L120-140

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34	Bias	9	Describe any efforts to address potential sources of bias			Methods P7-8 L170-185,
	Study size	10	Explain how the study size was arrived at			Methods P6 L141-147
	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods P6-7 L141-169
	Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) <i>Cohort study</i> - If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses			Methods P7-8 L170-185
35 36 37 38 39 40 41 42 43 44 45 46 47	Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	Data Sharing P17 L392-400

				RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	Methods P6-7 L141-169
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (<i>e.g.</i> , numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (<i>i.e.</i> , study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Methods P6 L141-147 Results P8 L191-194
Descriptive data	14	(a) Give characteristics of study participants (<i>e.g.</i> , demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) <i>Cohort study</i> - summarise follow-up time (<i>e.g.</i> , average and total amount)			Results P8 L191-194
Outcome data	15	<i>Cohort study</i> - Report numbers of outcome events or summary measures over time <i>Case-control study</i> - Report numbers in each exposure			Results P8-9 L195-206

		category, or summary measures of exposure <i>Cross-sectional study</i> - Report numbers of outcome events or summary measures			
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Results P9-11 L196-267
Other analyses	17	Report other analyses done— e.g., analyses of subgroups and interactions, and sensitivity analyses			Results P9-11 L196-267
Discussion					
Key results	18	Summarise key results with reference to study objectives			Discussion P11-12, L268-288
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	Discussion P12-13 L289-303
Interpretation	20	Give a cautious overall interpretation of results considering objectives,			Discussion P13-14 L317-340

		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			
Generalisability	21	Discuss the generalisability (external validity) of the study results			Discussion P13 L294-303
Other Information					
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*Reference: Benchimol EI, Smeeth L, Guttman A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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The impact of pausing elective hip and knee replacement surgery during winter 2017 on subsequent service provision at a major NHS Trust: a descriptive observational study using interrupted time series

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2
3 1 **Title:** The impact of pausing elective hip and knee replacement surgery during winter 2017 on
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5 2 subsequent service provision at a major NHS Trust: a descriptive observational study using
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7 3 interrupted time series
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12
13 5 **Authors:** Tim Jones^{1,2,3}, Christopher Penfold^{1,2,3}, Maria Theresa Redaniel^{1,2}, Emily Eyles^{1,2}, Tim Keen⁴,
14
15 6 Andrew Elliott⁴, Ashley Blom^{2,3}, Andrew Judge^{3,5}
16
17

18
19
20
21 8 ¹ NIHR ARC West, University Hospitals Bristol NHS Foundation Trust, Bristol, BS1 2NT, UK
22

23
24 9 ² Department of Population Health Sciences, Bristol Medical School, University of Bristol, BS8 2PS,
25
26 10 UK
27

28
29 11 ³ Musculoskeletal Research Unit, Translational Health Sciences, Bristol Medical School, University of
30
31 12 Bristol, Learning and Research Building, Level 1, Southmead Hospital, Bristol, BS10 5NB, UK
32

33
34 13 ⁴ North Bristol NHS Trust, Southmead Hospital, Westbury-on-Trym, Bristol, BS10 5NB, UK
35

36
37 14 ⁵ National Institute for Health Research Bristol Biomedical Research Centre, University Hospitals
38
39 15 Bristol and Weston NHS Foundation Trust and University of Bristol, Bristol, UK
40

41
42
43 16
44 17 **Corresponding author:**

45
46 18 Tim Jones
47 19 Research Fellow
48 20 NIHR ARC West,
49 21 9th Floor Whitefriars,
50 22 Lewin's Mead
51 23 Bristol, BS1 2NT
52 24 United Kingdom
53

54
55 25
56 26 Tel: ++44 (0)117 342 1265

57 27 Timothy.Jones@bristol.ac.uk
58

59 28
60 29 **Word count [3,826]**

1
2
3 30 **ABSTRACT**
4

5 31 **Objectives:** To explore the impact of a temporary cancellation of elective surgery in winter 2017 on
6
7 32 trends in primary hip and knee replacement at a major NHS Trust, and whether lessons can be learnt
8
9 33 about efficient surgery provision.
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11
12 34 **Design and Setting:** Observational descriptive study using interrupted time series analysis of hospital
13
14 35 records to explore trends in primary hip and knee replacement surgery at a major NHS Trust, as well
15
16 36 as patient characteristics, 2016-2019.
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19 37 **Intervention:** A temporary cancellation of elective services for two months in winter 2017
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22 38 **Outcomes:** NHS-funded hospital admissions for primary hip or knee replacement, length of stay and
23
24 39 bed occupancy. Additionally, we explored the ratio of elective to emergency admissions at the Trust
25
26 40 as a measure of elective capacity, and the ratio of public to private provision of NHS-funded hip and
27
28 41 knee surgery.
29

30
31 42 **Results:** After winter 2017 there was a sustained reduction in the number of knee replacements, a
32
33 43 decrease in the proportion of most deprived people having knee replacements, and an increase in
34
35 44 average age for knee replacement and comorbidity for both types of surgery. The ratio of public to
36
37 45 private provision dropped after winter 2017, and elective capacity generally has reduced over time.
38
39 46 There was clear seasonality in provision of elective surgery, with less-complex patients admitted
40
41 47 during winter.
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44
45 48 **Conclusions:** Declining elective capacity and seasonality has a marked effect on the provision of joint
46
47 49 replacement, despite efficiency improvements in hospital treatment. The Trust has outsourced less
48
49 50 complex patients to independent providers, and/or treated them during winter when capacity is
50
51 51 most limited. There is a need to explore whether these are strategies that could be used explicitly to
52
53 52 maximise the use of limited elective capacity, provide benefit to patients, and value for money for
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55 53 taxpayers.
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3 54 **STRENGTH AND LIMITATIONS OF THIS STUDY**
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- 6 55 • Trends analyses using data obtained from the electronic health records of a local hospital
7
8 56 NHS Trust are informative for clinicians and service managers in monitoring changes in
9
10 57 planning and delivery of elective surgery, and could be regularly updated in near real time
11
12 58 for monitoring.
13
14 59 • The inclusion of wider hospital admissions data beyond the NHS Trust allows us to estimate
15
16 60 the proportion of people within the Trust catchment area having NHS-funded treatment at
17
18 61 independent providers.
19
20 62 • We report the experience of one NHS Trust that is one of the larger elective orthopaedic
21
22 63 centres - the findings may not be generalisable to or reflect the experience of other trusts.
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24 64 • Our study does not include privately funded, privately provided hip and knee surgery which
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26 65 may also have been changing over time.
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75 INTRODUCTION

76 Primary hip and knee replacement operations are common planned elective surgical procedures.

77 They are highly clinically effective for improving symptoms of pain and functional limitations, and

78 have been shown to be safe and cost-effective.¹⁻⁴ Around 100,000 hip⁴ and over 100,000 knee

79 operations³ are carried out each year in the UK. Demand for these operations has been increasing

80 substantially in recent decades⁵ with an ageing population, rising levels of obesity, and widening

81 indications for surgery in younger patient groups.^{3 4}

82 Orthopaedic services have become more efficient over time, with length of hospital stay for primary

83 hip and knee replacements reducing from around 15 days in 1997 to roughly 5.5 days in 2014.⁶ This is

84 largely due to the introduction of 'fast track' surgery and enhanced recovery services,⁷ which reduce

85 length of stay whilst maintaining patient safety and outcomes of surgery.⁶ However, over the past

86 decade there has also been a reduction in the numbers of hospital beds and operating theatres

87 available for hip and knee replacement patients.⁸ Waiting lists for orthopaedic procedures have been

88 growing over time, and the average time people wait for treatment once on the waiting list has also

89 increased.⁹

90 Pressures on elective surgery are exacerbated during winter, when resources for planned surgery are

91 often displaced by more acute, unplanned hospital admissions.⁸ At the end of 2017, this led to all

92 planned elective hip and knee replacement operations in England being cancelled for the whole of

93 January.¹⁰ Even before the COVID-19 pandemic, over half a million people were already on the waiting

94 list.¹¹ Patients are having to wait longer with deteriorating severe pain and functional limitation,

95 affecting their health and quality of life. The COVID-19 pandemic has had an even greater impact on

96 cancelling planned elective surgery, with over 635,000 people waiting for hip and knee replacements

97 in April 2021, more than 10% of these waiting over a year, and over a third waiting longer than the 18

98 week target.¹¹

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3 99 The winter of 2017 provides a form of 'natural experiment', where elective capacity was intentionally
4
5 100 reduced close to zero. A natural experimental design is a valid methodological approach to evaluate
6
7 101 the impact of a range of events, policies and interventions which are not under the control of
8
9 102 researchers.¹² Researchers can use the variation in exposure that natural experiments generate to
10
11 103 analyse their impact on health outcomes. This provides a form of quasi-experimental study, where we
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13 104 can explore trends in provision of elective surgery before and after Winter 2017, which is a robust
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15 105 approach to explore real-world impact when randomisation is not possible.^{13 14}

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19 106 Our aim was to understand what happens after common, planned elective surgery is temporarily
20
21 107 cancelled, and how this might inform optimum planning of elective surgery when capacity is limited,
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23 108 such as following the COVID-19 pandemic. We used interrupted time series analysis to model trends
24
25 109 in elective hip and knee replacement surgery for a major NHS Trust from 2016 to 2019 and see how
26
27 110 these were impacted by the withdrawal of elective surgery in winter 2017. We explored these trends
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29 111 by patient factors (age, sex, deprivation, number of comorbidities) and seasonality to see when
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31 112 demand was highest for different patient groups.

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37 114 **METHODS**

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41 115 This study is a longitudinal observational descriptive study using routinely collected administrative
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43 116 information about patients admitted to a major NHS Trust for elective hip and knee replacements,
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45 117 2016 to 2019. It was developed and reported according to the RECORD extension¹⁵ to STROBE
46
47 118 guidelines for observational studies using routinely collected data.

48 49 50 119 **Data Sources**

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52
53 120 We used two data sources for our analyses. The first was an extract of elective primary hip and knee
54
55 121 replacement inpatient admissions identified from the Trust's electronic medical records (EMR)
56
57 122 between 1st January 2016 and 31st December 2019. Up to 29 diagnoses were provided per entry using
58
59 123 the International Classification of Diseases version 10 (ICD-10), and up to 11 procedures were provided

1
2
3 124 per entry using the Office of Population Censuses and Surveys Classification of Interventions and
4
5 125 Procedures version 4 (OPCS-4). The extract included patient demographics such as age, sex,
6
7 126 deprivation quintile, and comorbidities; and other characteristics of the hospital admissions such as
8
9
10 127 length of stay. This data source was used for all analyses of hip and knee replacements at the Trust,
11
12 128 including those relating to patient demographics, length of stay, and bed occupancy.
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15 129 The second data source was pseudonymised national admitted patient care Hospital Episode
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17 130 Statistics (HES-APC) between 1st January 2016 and 31st December 2019. HES-APC is a routinely
18
19 131 collected dataset that records all episodes of admitted (day case or inpatient) care provided to
20
21 132 patients at NHS hospitals in England and to NHS-funded patients treated in independent hospitals.¹⁶
22
23 133 Each episode represents a period of care under one consultant team. Up to 20 diagnoses and 24
24
25 134 clinical procedures are recorded per episode using ICD-10 codes and OPCS-4 codes, respectively. HES
26
27 135 also includes the Lower Super Output Area (LSOA; an area of around 1,500 people) of residence for
28
29 136 each patient, which can be linked to CCG of residence. This data source was used to estimate
30
31 137 elective capacity overall at the Trust, and the ratio of public/private provision of hip and knee
32
33 138 replacements in the catchment area for the Trust (see details below), which could not be gathered
34
35 139 from the extract provided from the Trust EMR.
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40 140 **Hospital admissions for hip and knee replacements**

41
42 141 Hospital admissions for elective hip and knee replacements were identified by entries with a primary
43
44 142 procedure code representing primary hip or knee replacement (Supplementary Table T1) using the
45
46 143 Trust EMR. We used this information to explore summary characteristics of the hospital admissions
47
48 144 over time (overall counts of admissions, average age, proportion of women, proportion with 2+
49
50 145 comorbidities, proportion in the two most deprived quintiles) stratified by primary hip or knee
51
52 146 replacements.
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56 57 147 **Length of stay and bed occupancy**

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3 148 We used the average number of overnight stays in hospital (days) for length of stay, trimmed at 30
4
5 149 days to exclude a small number of outliers (n=32, 0.6%). Trimming allowed us to model averages
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7 150 assuming a roughly normal distribution which we felt was more easily interpretable. Bed occupancy
8
9 151 was the total number of beds used overnight for hip and knee replacement patients.
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13 152 **Comorbidity of Admissions**

14
15 153 For each admission, we counted the number of conditions from the Charlson comorbidity index¹⁷
16
17 154 recorded in the diagnosis fields. The Charlson index provides a summary of weighted scores relating
18
19 155 to different comorbidities and has been shown to be associated with mortality. Admissions were
20
21 156 categorised into those with zero, one, and two or more Charlson comorbidities.
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25 157 **Ratio of Elective to Emergency Admissions**

26
27 158 To estimate the ratio of elective to emergency admissions for all purposes at the Trust (as a proxy for
28
29 159 elective capacity), we extracted all hospital admissions from HES-APC with the Trust as a provider
30
31 160 and categorised them into elective and emergency (admission method beginning with '1' or '2',
32
33 161 respectively).
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37 162 **Ratio of Public to Private Provision of Hip and Knee Replacements**

38
39 163 To estimate the ratio of public to private provision of NHS-funded elective hip and knee surgery for
40
41 164 the Trust catchment area, we extracted all hospital admissions for primary hip and knee
42
43 165 replacements (codes in Supplementary Table T1) for residents of the major local clinical
44
45 166 commissioning groups (CCGs) from HES-APC (using 2021 CCG boundaries after local CCGs had
46
47 167 merged into one CCG¹⁸), and categorised providers into public and private (provider code beginning
48
49 168 with 'R' or 'N', respectively).
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53 169 **Statistical Analysis**

54
55 170 We explored the change in trend for the following outcomes before/after the winter 2017 cancellation
56
57 171 of elective surgery, stratified by primary hip and knee replacements: number of hospital admissions;
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3 172 average age of patients; proportion of women; proportion with 2+ comorbidities; proportion in more
4
5 173 deprived deprivation quintiles (4 and 5); average length of stay; bed occupancy; and ratio of public to
6
7 174 private provision of surgery. Additionally, we explored the overall ratio of elective to emergency
8
9 175 admissions at the hospital for any purpose without stratification. For each of the outcomes, we
10
11 176 conducted interrupted time series (ITS) analyses using segmented regression models comparing
12
13 177 hospital admissions in the 'before' period (January 2016 to November 2017) to the 'after' period
14
15 178 (February 2018 to December 2019). We excluded the winter 2017 period when admissions were very
16
17 179 low (December 2017 and January 2018). The ITS analyses explored the 'pre-trend' before winter 2017,
18
19 180 and how this trend changed after winter 2017^{12 19}, allowing for an immediate 'level change' up or
20
21 181 down in February 2018, and a longer-term 'trend change' in the slope afterwards. We explored
22
23 182 seasonality in the data by including indicator variables for spring, summer, and autumn¹⁹ compared
24
25 183 to winter as a baseline, and adjusted for serial autocorrelation using Newey-West standard errors with
26
27 184 a maximum lag of two²⁰⁻²². For count or proportion outcomes (number of admissions, proportion
28
29 185 women, proportion with 2+ comorbidities, proportion in top two deprivation quintiles, bed
30
31 186 occupancy) segmented Poisson regression models were fit to the data, whilst for averages/ratios
32
33 187 (average age, average length of stay, ratio of elective to emergency admissions, ratio of public to
34
35 188 private provision) segmented linear regression models were fit, using the 'glm' command in Stata.
36
37 189 Sensitivity analyses were conducted adjusting the maximum lag for serial autocorrelation to zero and
38
39 190 five; this would not affect point estimates but could alter standard errors, confidence intervals, and p-
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41 191 values.

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43 192 All statistical analyses were conducted using Stata/MP version 16.1. Smoothed trends were fit to the
44
45 193 data on all plots using the 'lowess' command with bandwidth 0.3. Stata code is available at:
46
47 194 https://github.com/jonestim2002/hdr_uk_hospital_efficiency

195 **Patient and public involvement**

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3 196 Initial research ideas for the grant application of which this work is part were presented to the public
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5 197 in a workshop and suggestions and comments were incorporated in the protocol. Feedback during
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7 198 the workshop was positive, with participants agreeing with the research objectives and the
8
9 199 identified need.
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201 RESULTS

202 *Descriptive information and demographics*

203 A total of 2,623 patients had a hip replacement and 2,674 had a knee replacement at the Trust in the
24 204 4 years between 2016 and 2019. The mean age of patients was 67 years and 60% were women for
25
26 205 both types of operations.
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302 *Trend changes after winter 2017*

303 Table 1 shows the results of our interrupted time series analyses for all outcomes, including the
304 trend before winter 2017 (pre-trend), any immediate change after winter 2017 (level change) and
305 any change in the slope after winter 2017 (trend change). These are described in more detail below.
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312 **Table 1. Interrupted time series model results**

	pre-trend		level change		trend change	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	1 (0.99,1)	0.300	1.06 (0.91,1.22)	0.469	0.99 (0.98,1.01)	0.239
Hip Age*	-0.01 (-0.1,0.07)	0.737	1.57 (-0.1,3.24)	0.065	-0.06 (-0.17,0.05)	0.307
Hip Prop Women	1 (0.99,1)	0.582	0.97 (0.86,1.08)	0.549	1.01 (1,1.02)	0.089
Hip Charlson	0.99 (0.98,1.01)	0.380	1.41 (1.06,1.87)	0.017	1.01 (0.99,1.03)	0.220
Hip Deprivation	1 (0.99,1.01)	0.587	1.03 (0.87,1.21)	0.754	1 (0.99,1.02)	0.660
Hip LoS*	-0.01 (-0.03,0.02)	0.660	0.31 (-0.19,0.82)	0.225	-0.01 (-0.05,0.02)	0.425
Hip Bed Occ	1 (0.99,1.01)	0.643	1 (0.84,1.19)	0.997	0.99 (0.97,1)	0.149
Hip Public Private*	0.01 (-0.02,0.04)	0.377	-0.74 (-1.24,-0.25)	0.003	-0.02 (-0.05,0.01)	0.218
Knee Admissions	1 (0.99,1)	0.106	0.84 (0.73,0.98)	0.022	1 (1,1.01)	0.256
Knee Age*	-0.08 (-0.16,0)	0.054	-1.63 (-2.99,-0.28)	0.018	0.21 (0.12,0.31)	0.000

Knee Prop Women	1 (1,1.01)	0.150	0.96 (0.85,1.08)	0.513	0.99 (0.99,1)	0.193
Knee Charlson	1.01 (0.99,1.03)	0.249	0.64 (0.46,0.89)	0.009	1.04 (1.02,1.07)	0.001
Knee Deprivation	1.01 (1,1.01)	0.189	0.97 (0.79,1.19)	0.758	0.99 (0.97,1)	0.021
Knee LoS*	-0.02 (-0.05,0)	0.058	0.18 (-0.28,0.63)	0.449	-0.01 (-0.04,0.02)	0.566
Knee Bed Occ	0.99 (0.98,1)	0.103	0.83 (0.7,0.99)	0.037	1 (0.99,1.01)	0.993
Knee Public Private*	0.01 (-0.02,0.03)	0.667	-0.48 (-1.03,0.07)	0.090	-0.02 (-0.04,0.01)	0.225
Elec Emerg Ratio*	-0.01 (-0.01,0)	0.171	-0.32 (-0.45,-0.2)	0.000	-0.02 (-0.03,-0.01)	0.003

Notes: *Linear regression model (additive) rather than Poisson regression model (multiplicative). Shaded cells indicate $p < 0.05$.

Trends in hip and knee elective hospital admissions over time

The overall numbers of elective primary hip and knee replacement operations gradually declined over the study period from 63 hip and 65 knee replacements per month in 2016 to 49 hip and 51 knee replacements per month in 2019. Whilst there was a drop off in winter 2017, after elective surgery was re-started hip replacements resumed at similar numbers and continued to decline along a similar trajectory. Numbers of knee replacements dropped by 16% after winter 2017 (level change=0.843, 95% CI: 0.728 to 0.976, $p=0.022$), and the slope appeared to level off, although there was little evidence for this in the regression model (trend change=1.005, 95% CI: 0.996 to 1.014, $p=0.256$); see Figure 1 and Supplementary Table T2.

Age on Admission

There was a change in the trend in average age for knee replacements after winter 2017 (trend change=+0.21, 95% CI: 0.12 to 0.31, $p < 0.001$) towards treating older patients over time (+1.59 years of age per year); see Figure 2.

Comorbidity of Admissions

There was a level change upwards in the proportion having hip replacements with 2+ comorbidities after winter 2017 (level change=1.411, 95% CI: 1.064 to 1.873, $p=0.017$), and an upward slope change for knee replacements (trend change=1.042, 95% CI: 1.017 to 1.067, $p=0.001$); see Figure 3.

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3 235
45 236 *Deprivation*

7 237 There was evidence of a reducing proportion of the most deprived people having knee replacements
8
9 238 after winter 2017 (trend change=0.986, 95% CI: 0.974 to 0.998, p=0.021).

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12 239
1314 240 *Ratio of elective admissions to emergency admissions at the Trust*

17 241 There was an overall downward trend in the ratio of elective to emergency admissions at the Trust,
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19 242 from an average of 2.91 (SD: 0.17) electives for every emergency in 2016 to 2.16 (SD: 0.06) in 2019;
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21 243 see Supplementary Figure F1. The ratio reduced after winter 2017 (level change=-0.322, 95% CI: -
22
23 244 0.446 to -0.198, p<0.001), and started to decrease more rapidly afterwards (trend change=-0.016,
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25 245 95% CI: -0.026 to -0.005, p=0.003).

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3132 247 *Ratio of public to private provision of hip/knee elective surgery at the Trust*

35 248 There was evidence of a level change downwards in public provision compared to private provision
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37 249 after winter 2017 for both types of surgery, but particularly for hip replacements (hips level
38
39 250 change=-0.741, 95% CI: -1.237 to -0.245, p=0.003; knees level change=-0.476, 95% CI: -1.026 to
40
41 251 +0.074, p=0.09); see Figure 4.

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4647 253 *Bed Occupancy*

50 254 For hip and knee replacements, bed occupancy has reduced over time, although there wasn't
51
52 255 evidence of this in the regression model for hip replacements, and there was a level change
53
54 256 downwards (level change=0.834, 95% CI: 0.704 to 0.989, p=0.037) for knee surgery after winter
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56 257 2017; see Figure 5.

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259 *Length of Stay*

260 The average length of hospital stay was 5.5 days (SD: 5.9 days) for hip replacements and 5.2 days
261 (SD: 5.0 days) for knee replacements in 2016, compared to 5.1 days (SD: 4.1 days) and 4.3 days (SD:
262 3.4 days) respectively in 2019 (see Supplementary Figure F2). However, there was no evidence in the
263 regression models for a change after winter 2017.

265 *Seasonality*

266 Supplementary Table T2 shows seasonality results for each of our interrupted time series analyses.
267 Hip and knee operations were clearly seasonal, with higher admissions in non-winter months
268 compared to winter; 21% higher in the highest season (summer) for hips (summer=1.207, 95% CI:
269 1.094 to 1.332, $p<0.001$), and 31% higher in the highest season (spring) for knee replacements
270 (spring=1.308, 95% CI: 1.157 to 1.479, $p<0.001$), excluding winter 2017. Bed occupancy for both
271 types of operation was also seasonal, with lower occupancy in the winter months compared to all
272 other seasons (see Supplementary Table T2); e.g. summer bed occupancy was 324 beds for hips and
273 291 beds for knees on average compared to winter bed occupancy of 225 beds for hips and 199 beds
274 for knees on average. Length of stay was longer in spring than winter for hip replacements
275 (spring=+0.502 days, 95% CI: 0.214 to 0.79, $p=0.001$), and longer in spring (+0.422 days, 95% CI:
276 0.073 to 0.771, $p=0.018$) and autumn (+0.396 days, 95% CI: 0.015 to 0.777, $p=0.042$) compared to
277 winter for knee replacements.

278 The ratio of public to private provision was higher in the summer (1.56 for hips and 1.28 for knees)
279 compared to winter (1.22 and 0.99, respectively) months (hips summer=+0.308, 95% CI 0.154 to
280 0.463, $p<0.001$; knees summer=+0.276, 95% CI: 0.035 to 0.517, $p=0.025$).

281 There was also some evidence of seasonality in the types of patients being admitted for hip and
282 knee replacements. For hip replacements, the mean age of patients was 66 in winter compared to

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3 283 68 in summer (summer=+2.09; 95% CI: 0.81 to 3.37, p = 0.001); a higher proportion were performed
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5 284 on women in the summer (64%) compared to winter (58%) months (summer=1.088, 95% CI: 1.001 to
6
7 285 1.183, p=0.048); and a higher proportion of people had 2+ comorbidities in the summer (15.9%)
8
9 286 compared to winter (12.3%) months (summer=1.306, 95% CI: 1.096 to 1.557, p=0.003). For knee
10
11 287 replacements, there was a higher proportion of more deprived people (quintiles 4 and 5) in the
12
13 288 spring (37.6%) compared to the winter (30.2%) months (spring=1.224, 95% CI: 1.077 to 1.49,
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15 289 p=0.002).

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22 291 **DISCUSSION**

25 292 *Principal findings*

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29 293 The temporary cancellation of elective services during winter 2017 does appear to have had some
30
31 294 impact on service provision at the Trust after that time. There was an immediate and sustained
32
33 295 reduction in the number of knee replacements being done at the Trust and this was also reflected in
34
35 296 the drop in bed occupancy for knee surgery. The average age for knee replacement and comorbidity
36
37 297 of hip and knee surgery patients increased after winter 2017, whilst the proportion of more deprived
38
39 298 people having knee replacements decreased, and the ratio of public to private provision of hip and
40
41 299 knee replacements in the local area dropped after winter 2017. This suggests an NHS-funded
42
43 300 outsourcing of less comorbid hip and knee replacement surgery to independent providers, and
44
45 301 therefore on average the patients being treated at the Trust became older and more comorbid.
46
47 302 There was a general decrease in capacity for elective surgery at the Trust (ratio of elective to
48
49 303 emergency admissions), mostly driven by increasing non-elective admissions even before the COVID-
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51 304 19 pandemic. The winter 2017 cancellation may have been just one symptom of this overall pressure
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53 305 on elective surgery that underlies some of the longer-term changes in provision.
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3 306 There was also some seasonality in service provision. It is no surprise that elective admissions and
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5 307 bed occupancy are lower in winter when the hospital requires capacity for an increase in unplanned
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7 308 admissions. There were also indications that people being admitted in winter were younger, less
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9
10 309 comorbid, and less deprived (particularly for knee surgery). Length of stay for hip and knee
11
12 310 replacements was lower in winter compared to spring. This suggests the admission of younger, less
13
14 311 comorbid patients during the winter months given the reduced elective capacity and delaying
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16 312 surgery for more comorbid patients to when capacity is higher in the following months.

20 313 *Strengths and limitations*

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23 314 Trends analyses such as these, using data obtained from the EHR of a local hospital NHS Trust, are
24
25 315 informative for clinicians and service managers in monitoring changes in planning and delivery of
26
27 316 elective surgery, and could be regularly updated in near real time for monitoring. This concept might
28
29 317 be informative for other commissioning groups / Trusts to adopt for monitoring of their own elective
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31 318 surgery and capacity. We report the experience of just one trust that is one of the larger elective
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33 319 orthopaedic centres, and hence the findings may not be generalisable to or reflect the experience of
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35 320 other trusts. Our findings are observational and report changes observed at the Trust following
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37 321 cancellation of elective services in winter 2017; further work would be needed to understand the
38
39 322 impact of any changes on outcomes such as throughput of patients, waiting times, waiting lists,
40
41 323 outcomes of surgery, costs, and equity of access to surgery. We should be aware that some results
42
43 324 may reflect chance findings due to multiple testing and type 1 error. The trends in the data as
44
45 325 plotted do not change substantially in sensitivity analyses accounting for different autocorrelation
46
47 326 lags (Supplementary Tables T3-T4). The catchment area of the Trust is not exactly the same as the
48
49 327 major local CCG and is difficult to define exactly. However, 89.4% of admissions at the Trust were for
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51 328 residents of the local CCG and we felt this was a reasonable approximation to estimate the ratio of
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53 329 public to private provision in the Trust catchment area. Our analyses only include NHS-funded
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55 330 surgery and not privately-funded, privately-provided surgery.

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3 331 *Comparison to other studies*
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6 332 A previous study²³ using data for England from Hospital Episode Statistics found increasing private
7
8 333 provision of elective hip arthroplasties nationally from 2007/8 to 2012/13, particularly for less
9
10 334 deprived people, which echoes our findings. More recent news stories have suggested that 20% of
11
12 335 NHS-funded hip replacements and 29% of NHS-funded knee replacements were carried out by
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14 336 independent providers in 2016/17²⁴, and that independently-provided hip and knee replacement
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16 337 surgery (privately or NHS-funded) has now overtaken NHS provision.²⁵ A UK-wide study⁶ using
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18 338 primary care data (CPRD) linked to hospital admissions found similar effects of patient
19
20 339 characteristics (age, sex, comorbidity, and deprivation) on length of stay for primary hip and knee
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22 340 replacements, although they did not explore seasonality. A recent qualitative study²⁶ highlighted the
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24 341 negative financial and emotional impact of winter elective cancellations on patients and their
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26 342 families and recommended better advanced planning of elective operations to reduce these
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28 343 impacts.
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34 344 *Implications for clinicians and policy makers*
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36 345 Outsourcing of less complex hip and knee replacements to take advantage of spare capacity in non-
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38 346 NHS hospitals may be a good strategy to reduce waiting times and waiting lists for surgery and get
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40 347 the best results for patients given the evident capacity limitations. However, this would leave the
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42 348 NHS Trust to cope with more complex cases and has training implications because trainee surgeons
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44 349 are usually trained by first undertaking less-complex cases on healthier patients. There are also
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46 350 potential equity implications, if less complex cases have the option of surgery with shorter waiting
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48 351 times at independent providers, whilst more complex (and potentially more deprived) cases do not.
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50 352 We would need to consider the acceptability of this outsourcing to patients and practitioners, and
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52 353 the quality of patient outcomes.
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3 354 There is an indication that some selection of patients for elective surgery depending on available
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5 355 capacity already takes place at the Trust. It is possible that this could become a more explicit
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7 356 strategy, based on evidence, to optimise the use of limited capacity in hospitals at different times of
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9
10 357 the year. However, this could mean that people placed earlier on the waiting list for surgery might
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12 358 get their surgery later due to such scheduling strategies, so acceptability to patients would need to
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14 359 be explored. We need to understand how the scheduling and possible outsourcing of elective
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16 360 surgery for different types of patients, depending on capacity, may impact on throughput of
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18 361 patients, waiting times, waiting lists, outcomes of surgery, costs, and equity of access to surgery.
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21 362 Inevitably outsourcing simpler patients to the independent sector will leave more complex patients
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23 363 being treated by NHS Trusts, which could have a detrimental impact on their service. An appropriate
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25 364 balance would need to be achieved to maximise the benefits for patients, and research is needed to
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27 365 understand what that balance is. Additionally, we need to understand whether this type of
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29 366 scheduling and outsourcing is acceptable to people waiting for hip and knee surgery as well as
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31 367 clinicians. These issues of optimising limited elective resources are in even sharper focus due to the
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33 368 backlog in waiting lists caused by the COVID-19 pandemic.
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369 *Unanswered questions and future research*

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40 370 We need to understand how the scheduling and possible outsourcing of elective surgery for
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42 371 different types of patients, depending on capacity, may impact on throughput of patients, waiting
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44 372 times, waiting lists, outcomes of surgery, costs, and equity of access to surgery. Inevitably
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46 373 outsourcing simpler patients to the independent sector will leave more complex patients being
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48 374 treated by NHS Trusts, which could have a detrimental impact on their service. An appropriate
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50 375 balance would need to be achieved to maximise the benefits for patients, and research is needed to
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52 376 understand what that balance is. Additionally, we need to understand whether this type of
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54 377 scheduling and outsourcing is acceptable to people waiting for hip and knee surgery as well as
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56 378 clinicians.
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3 379 *Conclusions*
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6 380 Declining elective capacity and seasonality has a marked effect on the provision of joint
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8 381 replacement, despite efficiency improvements in hospital treatment. The Trust has outsourced less
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10 382 complex patients to independent providers, and/or treated them during winter when capacity is
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12 383 most limited. There is a need to explore whether these are strategies that could be used explicitly to
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14 384 maximise the use of limited elective capacity, provide benefit to patients, and value for money for
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16 385 taxpayers.
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23 387 **Author Contributions**
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25

26 388 This publication is the work of the authors, who serve as guarantors for the contents of this paper. TJ
27
28 389 contributed to study design, data cleaning, data analysis, interpretation of results and writing the
29
30 390 manuscript. MTR contributed to study conceptualisation, supervision, interpretation of results and
31
32 391 reviewing the manuscript. TK contributed to data curation, supervision, interpretation of results and
33
34 392 reviewing the manuscript. AE contributed to data curation, interpretation of results and reviewing
35
36 393 the manuscript. CP and EE contributed to interpretation of results and reviewing the manuscript. AB
37
38 394 contributed to study conceptualisation, supervision, interpretation of results and reviewing the
39
40 395 manuscript. AJ contributed to study conceptualisation and design, supervision, and writing the
41
42 396 manuscript. TJ had full access to the data in the study and takes responsibility for the integrity of the
43
44 397 data and the accuracy of the data analysis.
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55 400 The study reported here would not have been possible without information provided by the NHS
56
57 401 Trust, and the use of their hospital admissions data via the NIHR ARC West Partnership Agreement.
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7
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1415 407 Centre at University Hospitals Bristol and Weston NHS Foundation Trust and the University of Bristol.
1617 408 The views expressed in this article are those of the author(s) and not necessarily those of the NHS,
1819 409 the NIHR, the Department of Health and Social Care or HDR UK.
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2223 410
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2526 411 **Ethical Approval**
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2829 412 We were provided with pseudonymised hospital admissions data from the NHS Trust under the NIHR
3031 413 ARC West Partnership Agreement. The project received ethical approval from the University of
3233 414 Bristol Faculty of Health Sciences ethical review board on 3rd November 2020 (ref# 109024).
34
3536 415 We were provided with routinely-collected Hospital Episode Statistics data under licence from NHS
3738 416 Digital (DARS-NIC-17875-X7K1V). The licence allows us to use the information under Section 261 of
3940 417 the Health and Social Care Act 2012, 2(b)(ii): "after taking into account the public interest as well as
4142 418 the interests of the relevant person, considers that it is appropriate for the information to be
4344 419 disseminated".
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4748 420
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5051 421 **Data Sharing**
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5354 422 The data from the NHS Trust was obtained under the NIHR ARC West Partnership Agreement. The
5556 423 agreement precludes us from sharing the raw data but it can be published and shared once
5758 424 aggregated to a non-identifiable level.
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3 425 The data from Hospital Episode Statistics (HES) was obtained under licence (DARS-NIC-17875-X7K1V)
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5 426 from NHS Digital (previously the Health and Social Care Information Centre); *Copyright © 2022, re-*
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7 427 *used with the permission of The Health & Social Care Information Centre. All rights reserved.* The
8
9 428 data are provided by patients and collected by the NHS as part of their care and support. HES data
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12 429 can be accessed via NHS Digital: <https://digital.nhs.uk/services/data-access-request-service-dars>
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18 431 **Transparency**

21 432 The manuscript's guarantor (TJ) affirms that the manuscript is an honest, accurate, and transparent
22
23 433 account of the study being reported; that no important aspects of the study have been omitted; and
24
25 434 that any discrepancies from the study as originally planned have been explained.
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28 435

31 436 **Competing Interests**

34 437 All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf
35
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37
38 439 had financial support in the previous three years through institutional grants from NIHR, HDR UK,
40
41 440 Versus Arthritis, Healthcare Quality Improvement Partnership (HQIP), Royal College of Physicians
42
43 441 (RCP), and Health Foundation, had unpaid committee or leadership roles relating to musculoskeletal
44
45 442 conditions for NIHR, Nuffield Foundation, Warwick CTU, and Versus Arthritis, and a paid expert panel
46
47 443 role for Nuffield Foundation Oliver Bird Fund; no other financial relationships with any organisations
48
49 444 that might have an interest in the submitted work in the previous three years; no other relationships
50
51 445 or activities that could appear to have influenced the submitted work.
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FIGURE CAPTIONS

Figure 1. Elective hip (left panel) and knee (right panel) replacement admissions at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 2. Average age on admission for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 3. Proportion of people having hip (left panel) and knee (right panel) replacements with 2+ Charlson comorbidities recorded
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 4. Ratio of public to private provision of elective hip (left panel) and knee (right panel) replacements for NHS patients in the Trust CCG
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 5. Bed occupancy for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis



Figure 1. Elective hip (left panel) and knee (right panel) replacement admissions at the Trust
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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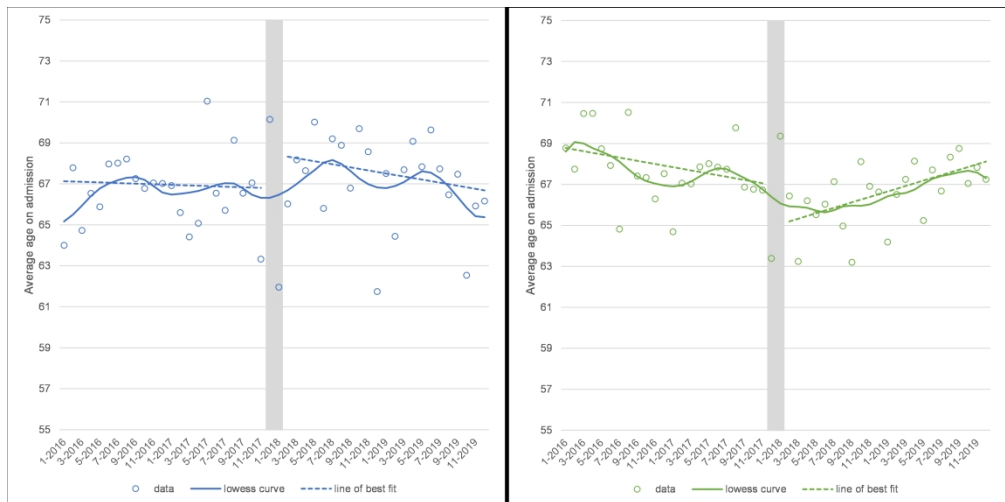


Figure 2. Average age on admission for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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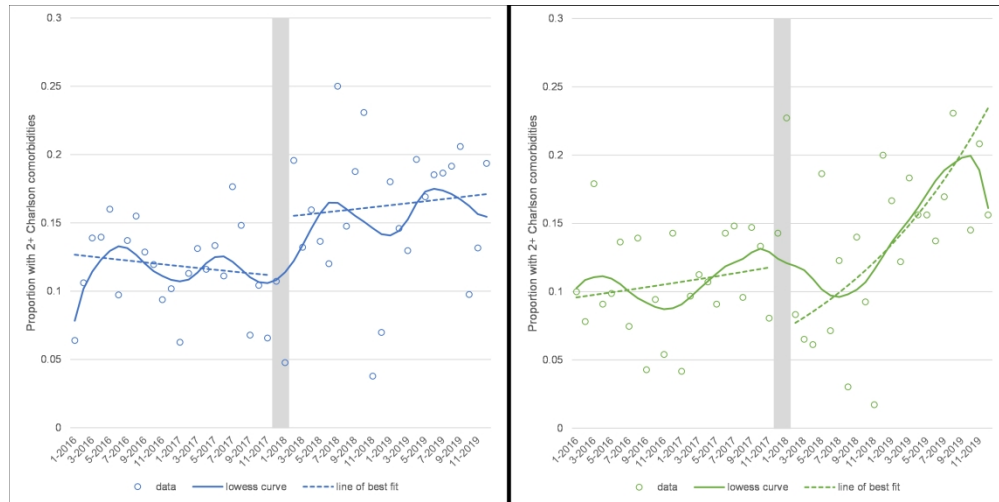


Figure 3. Proportion of people having hip (left panel) and knee (right panel) replacements with 2+ Charlson comorbidities recorded
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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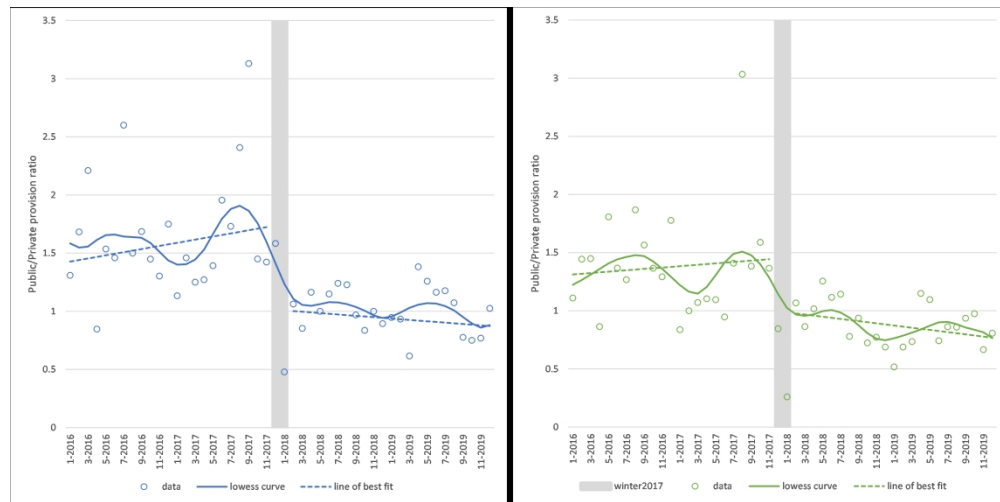


Figure 4. Ratio of public to private provision of elective hip (left panel) and knee (right panel) replacements for NHS patients in the Trust CCG
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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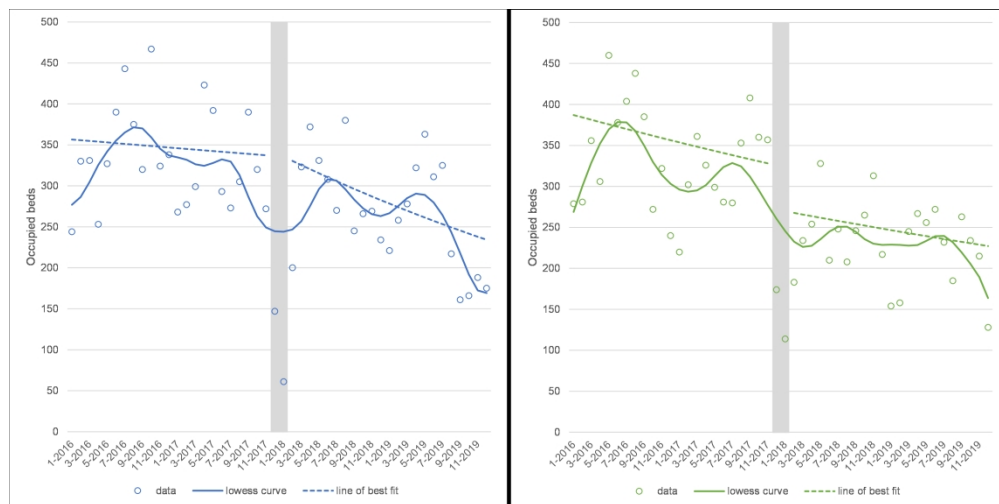
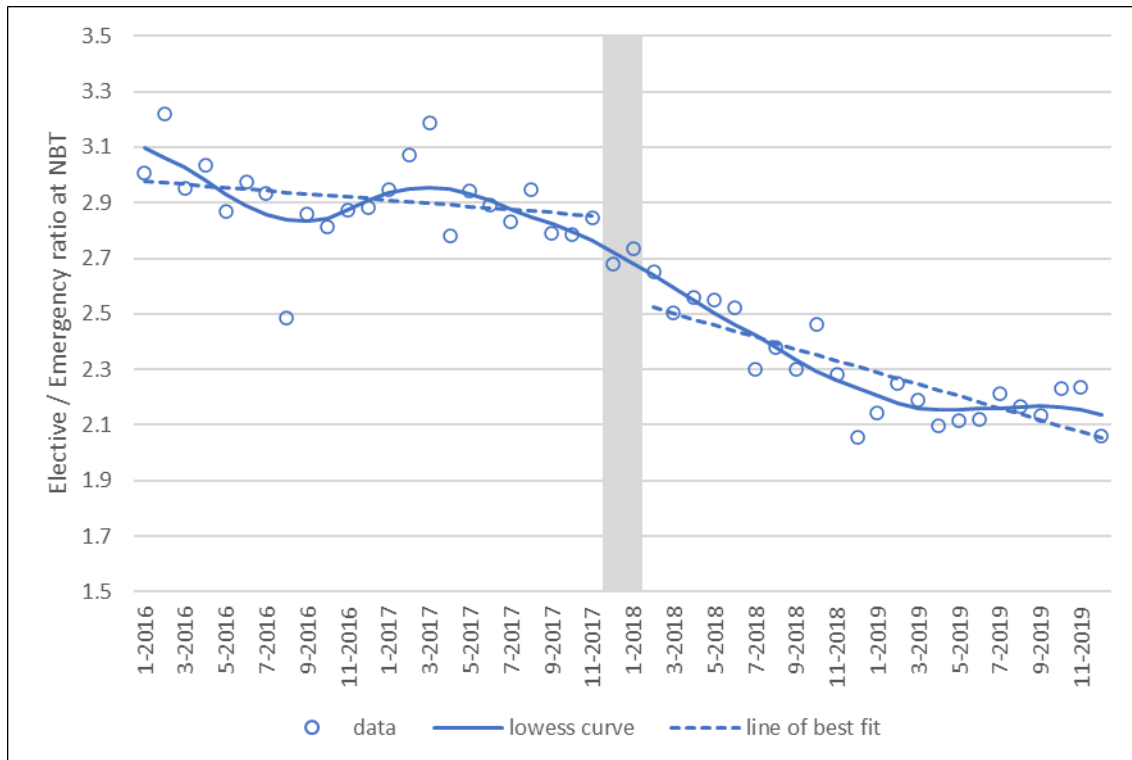


Figure 5. Bed occupancy for hip (left panel) and knee (right panel) replacements at the Trust
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

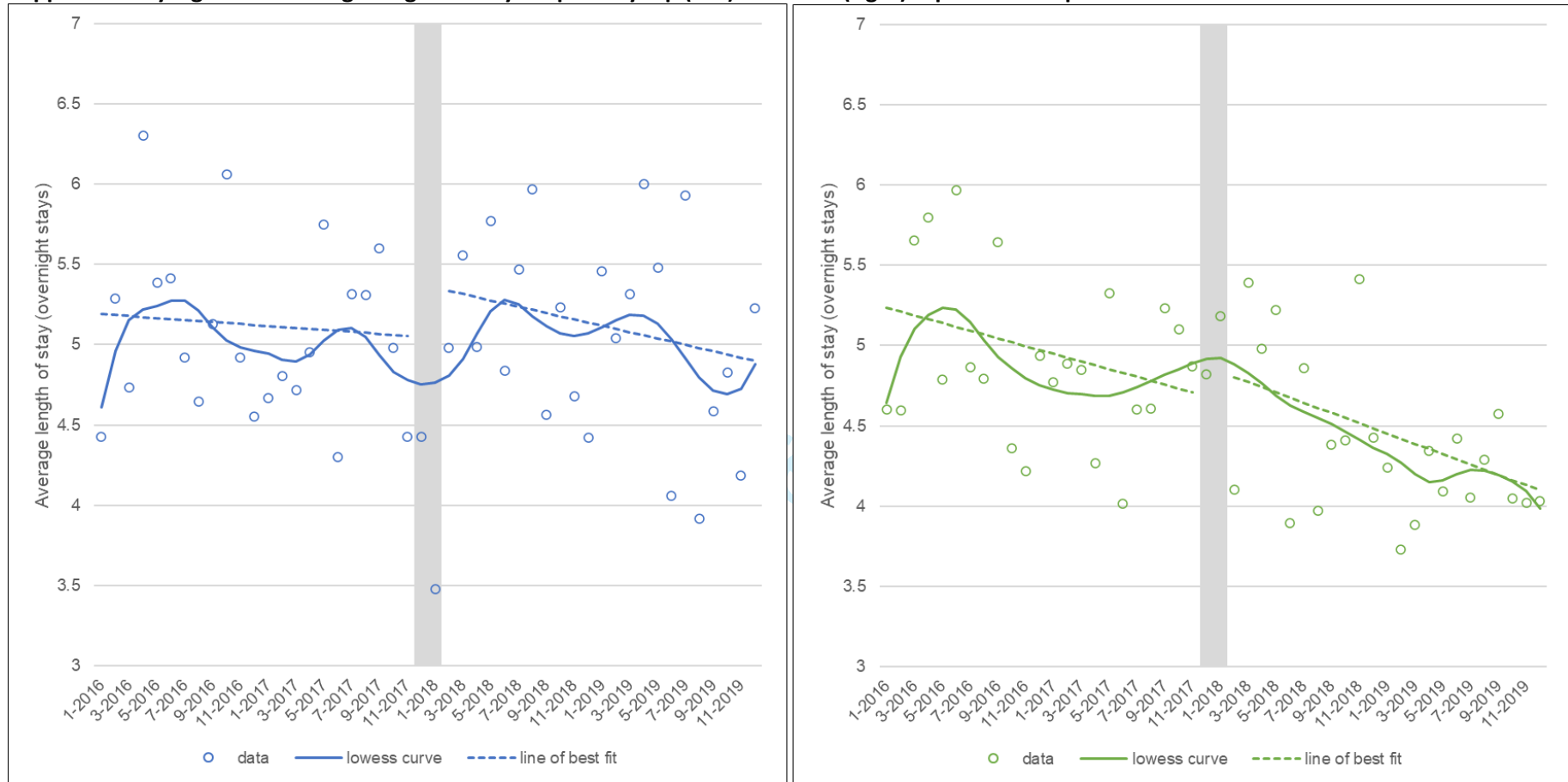
301x150mm (300 x 300 DPI)

Supplementary Figure F1. Ratio of elective to emergency hospital admissions for any reason at the Trust



Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Supplementary Figure F2. Average length of stay for primary hip (left) and knee (right) replacement operations at NBT



Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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For peer review only

Supplementary Table T1. OPCS-4 codes used to identify primary hip and knee replacement operations

Category	Code	Description	Notes
<i>Primary Total Hip Replacement</i>	W37.1	Primary total prosthetic replacement of hip joint using cement	
	W37.8	Other specified total prosthetic replacement of hip joint using cement	
	W37.9	Unspecified total prosthetic replacement of hip joint using cement	
	W38.1	Primary total prosthetic replacement of hip joint not using cement	
	W38.8	Other specified total prosthetic replacement of hip joint not using cement	
	W38.9	Unspecified total prosthetic replacement of hip joint not using cement	
	W39.1	Primary total prosthetic replacement of hip joint NEC	
	W39.8	Other specified other total prosthetic replacement of hip joint	
	W39.9	Unspecified other total prosthetic replacement of hip joint	
	W43.1	Primary total prosthetic replacement of other joint using cement NEC	
	W43.8	Other specified total prosthetic replacement of other joint using cement NEC	
	W43.9	Unspecified total prosthetic replacement of other joint using cement NEC	
	W44.1	Primary total prosthetic replacement of other joint not using cement NEC	
	W44.8	Other specified total prosthetic replacement of other joint not using cement NEC	
	W44.9	Unspecified total prosthetic replacement of other joint not using cement NEC	
W45.1	Other primary total prosthetic replacement of other joint NEC		
W45.8	Other specified total prosthetic replacement of other joint NEC		
W45.9	Unspecified total prosthetic replacement of other joint NEC		
W52.1	Primary prosthetic replacement of articulation of bone using cement NEC		

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3 W52.8 Other specified prosthetic replacement of articulation of bone using
4 cement NEC
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6 W52.9 Unspecified prosthetic replacement of articulation of bone using
7 cement NEC
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9 W53.1 Primary prosthetic replacement of articulation of bone not using
10 cement NEC
11
12 W53.8 Other specified prosthetic replacement of articulation of bone not
13 using cement NEC
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15 W53.9 Unspecified prosthetic replacement of articulation of bone not using
16 cement NEC
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18 W54.1 Primary prosthetic replacement of articulation of bone NEC
19
20 W54.8 Other specified prosthetic replacement of articulation of bone NEC
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22 W54.9 Unspecified prosthetic replacement of articulation of bone NEC
23
24 W93.1 Primary hybrid prosthetic replacement of hip joint using cemented
25 acetabular component
26
27 W93.8 Other specified hybrid prosthetic replacement of hip joint using
28 cemented acetabular component
29
30 W93.9 Unspecified hybrid prosthetic replacement of hip joint using cemented
31 acetabular component
32
33 W94.1 Primary hybrid prosthetic replacement of hip joint using cemented
34 femoral component
35
36 W94.8 Other specified hybrid prosthetic replacement of hip joint using
37 cemented femoral component
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39 W94.9 Unspecified hybrid prosthetic replacement of hip joint using cemented
40 femoral component
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42 W95.1 Primary hybrid prosthetic replacement of hip joint using cement NEC
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44 W95.8 Other specified hybrid prosthetic replacement of hip joint using
45 cement
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47 W95.9 Unspecified hybrid prosthetic replacement of hip joint using cement
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3	<i>Primary Total Knee</i>	W40.1	Primary total prosthetic replacement of knee joint using cement
4	<i>Replacement</i>		
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6		W40.8	Other specified total prosthetic replacement of knee joint using cement
7			
8		W40.9	Unspecified total prosthetic replacement of knee joint using cement
9		W41.1	Primary total prosthetic replacement of knee joint not using cement
10			
11		W41.8	Other specified total prosthetic replacement of knee joint not using cement
12			
13		W41.9	Unspecified total prosthetic replacement of knee joint not using cement
14			
15		W42.1	Primary total prosthetic replacement of knee joint NEC
16		W42.8	Other specified other total prosthetic replacement of knee joint
17		W42.9	Unspecified other total prosthetic replacement of knee joint
18		O18.1	Primary hybrid prosthetic replacement of knee joint using cement
19		O18.8	Other specified hybrid prosthetic replacement of knee joint using cement
20			
21		O18.9	Unspecified hybrid prosthetic replacement of knee joint using cement
22			
23	<i>Resurfacing / Reconstruction</i>	W58.1	Primary resurfacing arthroplasty of joint
24			Require combination with site + combination codes to ID
25		W58.8	Other specified reconstruction of joint
26			Require combination with site + combination codes to ID
27			
28		W58.9	Unspecified other reconstruction of joint
29			Require combination with site + combination codes to ID
30			
31	<i>Primary unicondylar /</i>	W52.1	Primary prosthetic replacement of articulation of bone using cement
32	<i>unicompartmental knee</i>		Require combination with site + combination codes to ID
33	<i>operations</i>	W52.8	Other specified prosthetic replacement of articulation of other bone using cement
34			Require combination with site + combination codes to ID
35			
36		W52.9	Unspecified prosthetic replacement of articulation of other bone using cement
37			Require combination with site + combination codes to ID
38			
39		W53.1	Primary prosthetic replacement of articulation of bone not using cement NEC
40			Require combination with site + combination codes to ID
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W53.9	Unspecified prosthetic replacement of articulation of other bone not using cement	Require combination with site + combination codes to ID
W54.0	Conversion from previous prosthetic replacement of articulation of bone NEC	Require combination with site + combination codes to ID
W54.1	Primary prosthetic replacement of articulation of bone NEC	Require combination with site + combination codes to ID
W54.8	Other specified other prosthetic replacement of articulation of other bone	Require combination with site + combination codes to ID
W54.9	Unspecified other prosthetic replacement of articulation of other bone	Require combination with site + combination codes to ID

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Supplementary Table T2. Interrupted time series model results with maximum auto-correlation lag 2

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.986,1.004)	0.300	1.055 (0.912,1.221)	0.469	0.991 (0.977,1.006)	0.239	1.19 (1.034,1.37)	0.015	1.207 (1.094,1.332)	0.000	1.101 (0.982,1.234)	0.099
Hip Average Age	-0.015 (-0.102,0.072)	0.737	1.571 (-0.1,3.242)	0.065	-0.06 (-0.175,0.055)	0.307	1.52 (-0.07,3.111)	0.061	2.09 (0.811,3.368)	0.001	1.031 (-0.598,2.66)	0.215
Hip Prop Women	0.999 (0.995,1.003)	0.582	0.966 (0.861,1.083)	0.549	1.007 (0.999,1.016)	0.089	1.023 (0.941,1.111)	0.596	1.088 (1.001,1.183)	0.048	0.981 (0.888,1.083)	0.700
Hip Prop 2+ Charlson	0.994 (0.982,1.007)	0.380	1.411 (1.064,1.873)	0.017	1.01 (0.994,1.027)	0.220	1.195 (0.982,1.455)	0.075	1.306 (1.096,1.557)	0.003	1.003 (0.788,1.276)	0.982
Hip Prop High Deprivation	1.003 (0.993,1.013)	0.587	1.027 (0.869,1.214)	0.754	1.004 (0.986,1.022)	0.660	0.937 (0.815,1.076)	0.358	0.877 (0.752,1.022)	0.093	0.996 (0.84,1.18)	0.963
Hip LoS	-0.006 (-0.034,0.021)	0.660	0.312 (-0.193,0.818)	0.225	-0.014 (-0.047,0.02)	0.425	0.502 (0.214,0.79)	0.001	0.135 (-0.194,0.463)	0.422	0.1 (-0.288,0.488)	0.613
Hip LoS Age 16-59	-0.003 (-0.028,0.021)	0.788	0.379 (-0.094,0.851)	0.116	-0.026 (-0.065,0.013)	0.190	0.223 (-0.156,0.602)	0.249	0.384 (0.065,0.703)	0.018	0.219 (-0.183,0.622)	0.285
Hip LoS Age 60-69	-0.004 (-0.034,0.026)	0.818	0.013 (-0.807,0.832)	0.976	0 (-0.053,0.052)	0.988	0.107 (-0.44,0.654)	0.702	0.158 (-0.468,0.783)	0.621	0.162 (-0.487,0.811)	0.625
Hip LoS Age 70-79	0.006 (-0.058,0.069)	0.862	-0.753 (-2.003,0.497)	0.238	0.007 (-0.06,0.073)	0.847	-0.433 (-1.416,0.549)	0.387	-0.842 (-1.93,0.246)	0.129	-0.865 (-1.991,0.262)	0.132
Hip LoS Age 80+	-0.068 (-0.171,0.036)	0.199	2.109 (0.683,3.535)	0.004	-0.002 (-0.128,0.123)	0.971	1.506 (0.515,2.497)	0.003	0.222 (-0.773,1.217)	0.662	1.003 (-0.229,2.235)	0.111
Hip LoS Men	-0.007 (-0.055,0.041)	0.776	0.347 (-0.583,1.278)	0.464	-0.02 (-0.083,0.043)	0.536	0.293 (-0.126,0.712)	0.170	0.289 (-0.196,0.774)	0.243	0.458 (-0.111,1.026)	0.114
Hip LoS Women	-0.004 (-0.041,0.033)	0.842	0.235 (-0.308,0.778)	0.396	-0.014 (-0.055,0.027)	0.505	0.693 (0.309,1.077)	0.000	0.009 (-0.428,0.446)	0.966	-0.203 (-0.728,0.323)	0.449
Hip LoS Charlson 0	-0.011 (-0.042,0.019)	0.469	0.297 (-0.288,0.882)	0.319	-0.005 (-0.042,0.031)	0.782	0.912 (0.549,1.276)	0.000	0.178 (-0.148,0.503)	0.285	0.222 (-0.065,0.509)	0.129
Hip LoS Charlson 1	0.034 (-0.012,0.08)	0.146	0.238 (-0.709,1.184)	0.623	-0.077 (-0.145,-0.01)	0.024	0.191 (-0.418,0.801)	0.538	0.312 (-0.405,1.029)	0.393	0.014 (-0.578,0.606)	0.963
Hip LoS Charlson 2+	-0.123 (-0.259,0.013)	0.077	0.172 (-2.224,2.569)	0.888	0.116 (-0.016,0.249)	0.085	-0.789 (-2.141,0.563)	0.253	-0.783 (-2.087,0.521)	0.239	0.188 (-2.051,2.427)	0.869
Hip LoS Dep 1	0.004 (-0.032,0.04)	0.829	0.553 (-0.391,1.496)	0.251	-0.017 (-0.068,0.035)	0.529	0.784 (0.107,1.462)	0.023	0.42 (-0.024,0.863)	0.064	0.299 (-0.358,0.956)	0.373
Hip LoS Dep 2	-0.038 (-0.083,0.006)	0.092	0.822 (-0.392,2.035)	0.184	-0.015 (-0.086,0.055)	0.670	1.509 (0.759,2.258)	0.000	0.66 (-0.246,1.567)	0.154	0.589 (-0.417,1.594)	0.251
Hip LoS Dep 3	-0.034 (-0.107,0.038)	0.353	0.617 (-0.897,2.131)	0.424	0.01 (-0.076,0.095)	0.827	-0.216 (-1.224,0.792)	0.675	-0.424 (-1.378,0.53)	0.384	-0.701 (-1.536,0.135)	0.100
Hip LoS Dep 4	0.081 (-0.005,0.166)	0.064	-0.473 (-2.181,1.236)	0.588	-0.112 (-0.215,-0.009)	0.034	-0.374 (-1.65,0.903)	0.566	-1.204 (-2.351,-0.057)	0.040	-0.491 (-1.918,0.935)	0.500
Hip LoS Dep 5	0.015 (-0.086,0.116)	0.773	-0.72 (-2.059,0.62)	0.292	0 (-0.098,0.099)	0.999	0.621 (-0.084,1.327)	0.084	0.689 (-0.31,1.689)	0.176	0.816 (-0.784,2.416)	0.317
Hip Bed Occ	0.997 (0.987,1.008)	0.643	1 (0.844,1.186)	0.997	0.987 (0.97,1.005)	0.149	1.291 (1.11,1.501)	0.001	1.283 (1.125,1.463)	0.000	1.146 (0.988,1.328)	0.071
Hip Public Private	0.013 (-0.015,0.041)	0.377	-0.741 (-1.237,-0.245)	0.003	-0.019 (-0.05,0.011)	0.218	-0.008 (-0.212,0.196)	0.939	0.308 (0.154,0.463)	0.000	0.038 (-0.166,0.241)	0.718
Knee Admissions	0.995 (0.99,1.001)	0.106	0.843 (0.728,0.976)	0.022	1.005 (0.996,1.014)	0.256	1.308 (1.157,1.479)	0.000	1.26 (1.138,1.396)	0.000	1.286 (1.164,1.42)	0.000
Knee Average Age	-0.078 (-0.157,0.001)	0.054	-1.632 (-2.988,-0.276)	0.018	0.211 (0.117,0.305)	0.000	0.926 (-0.112,1.965)	0.080	0.953 (-0.021,1.927)	0.055	0.354 (-0.531,1.24)	0.433
Knee Prop Women	1.004 (0.998,1.01)	0.150	0.96 (0.85,1.084)	0.513	0.994 (0.986,1.003)	0.193	1.037 (0.963,1.117)	0.336	1.017 (0.924,1.118)	0.735	1.036 (0.958,1.12)	0.375
Knee Prop 2+ Charlson	1.009 (0.993,1.026)	0.249	0.638 (0.455,0.894)	0.009	1.042 (1.017,1.067)	0.001	1.156 (0.911,1.467)	0.234	1.074 (0.849,1.359)	0.551	0.909 (0.628,1.315)	0.612
Knee Prop High Deprivation	1.005 (0.997,1.013)	0.189	0.968 (0.786,1.191)	0.758	0.986 (0.974,0.998)	0.021	1.224 (1.077,1.39)	0.002	1.075 (0.942,1.227)	0.282	1.031 (0.902,1.178)	0.656
Knee LoS	-0.024 (-0.049,0.001)	0.058	0.176 (-0.279,0.63)	0.449	-0.008 (-0.036,0.02)	0.566	0.422 (0.073,0.771)	0.018	0.15 (-0.166,0.467)	0.352	0.396 (0.015,0.777)	0.042

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Knee LoS Age 16-59	-0.016 (-0.037,0.006)	0.151	0.403 (-0.045,0.852)	0.078	-0.028 (-0.06,0.005)	0.096	0.484 (0.13,0.839)	0.007	0.422 (-0.021,0.866)	0.062	0.475 (0.19,0.76)	0.001
Knee LoS Age 16-59	0.007 (-0.028,0.043)	0.684	-0.295 (-1.015,0.426)	0.423	-0.026 (-0.072,0.02)	0.262	0.069 (-0.46,0.599)	0.797	-0.194 (-0.687,0.3)	0.441	-0.096 (-0.725,0.532)	0.764
Knee LoS Age 70-79	-0.009 (-0.057,0.038)	0.705	0.77 (0.002,1.538)	0.049	-0.054 (-0.11,0.003)	0.061	-0.086 (-0.715,0.542)	0.787	-0.552 (-1.163,0.059)	0.077	0.367 (-0.352,1.085)	0.317
Knee LoS Age 80+	-0.051 (-0.118,0.015)	0.131	-0.562 (-2.298,1.173)	0.525	0.028 (-0.081,0.137)	0.612	1.521 (0.03,3.011)	0.046	1.37 (0.169,2.57)	0.025	1.361 (0.496,2.227)	0.002
Knee LoS Men	-0.007 (-0.031,0.018)	0.581	0.096 (-0.405,0.597)	0.708	-0.033 (-0.068,0.002)	0.064	0.082 (-0.367,0.531)	0.720	0.157 (-0.262,0.575)	0.464	0.205 (-0.221,0.631)	0.346
Knee LoS Women	-0.042 (-0.084,0)	0.052	0.252 (-0.461,0.966)	0.488	0.017 (-0.029,0.063)	0.478	0.635 (0.048,1.223)	0.034	0.15 (-0.397,0.698)	0.590	0.49 (-0.17,1.151)	0.146
Knee LoS Charlson 0	-0.021 (-0.046,0.004)	0.095	0.067 (-0.362,0.495)	0.760	-0.011 (-0.045,0.024)	0.545	0.645 (0.334,0.956)	0.000	0.193 (-0.111,0.497)	0.213	0.415 (0.069,0.76)	0.019
Knee LoS Charlson 1	-0.03 (-0.074,0.015)	0.191	0.47 (-0.391,1.331)	0.284	-0.029 (-0.083,0.025)	0.298	0.455 (-0.043,0.953)	0.073	0.324 (-0.297,0.945)	0.307	1.058 (0.367,1.748)	0.003
Knee LoS Charlson 2+	-0.04 (-0.107,0.028)	0.247	0.407 (-2.28,3.095)	0.766	-0.022 (-0.196,0.151)	0.802	-0.627 (-1.698,0.443)	0.251	-0.949 (-2.342,0.444)	0.182	-1.433 (-2.229,-0.637)	0.000
Knee LoS Dep 1	-0.009 (-0.06,0.041)	0.712	-0.035 (-0.726,0.656)	0.920	-0.008 (-0.073,0.056)	0.800	0.257 (-0.47,0.985)	0.488	0.096 (-0.619,0.811)	0.793	-0.127 (-0.725,0.472)	0.678
Knee LoS Dep 2	-0.019 (-0.06,0.022)	0.358	0.199 (-0.699,1.097)	0.664	-0.043 (-0.098,0.012)	0.124	0.018 (-0.776,0.812)	0.965	-0.731 (-1.49,0.029)	0.059	0.05 (-0.822,0.922)	0.911
Knee LoS Dep 3	0.014 (-0.036,0.064)	0.586	-0.426 (-1.355,0.503)	0.369	-0.036 (-0.106,0.033)	0.302	0.976 (0.061,1.892)	0.036	0.909 (-0.034,1.852)	0.059	0.547 (-0.217,1.312)	0.160
Knee LoS Dep 4	-0.064 (-0.123,-0.004)	0.035	0.634 (-0.293,1.56)	0.180	0.033 (-0.039,0.105)	0.373	0.669 (-0.187,1.525)	0.126	0.617 (0.02,1.214)	0.043	0.852 (-0.208,1.912)	0.115
Knee LoS Dep 5	-0.035 (-0.09,0.021)	0.224	0.709 (-0.303,1.721)	0.170	0.015 (-0.046,0.076)	0.628	0.123 (-0.73,0.976)	0.778	-0.387 (-1.281,0.507)	0.397	1.104 (0.077,2.131)	0.035
Knee Bed Occ	0.993 (0.984,1.002)	0.103	0.834 (0.704,0.989)	0.037	1 (0.989,1.011)	0.993	1.42 (1.297,1.556)	0.000	1.373 (1.218,1.547)	0.000	1.465 (1.312,1.635)	0.000
Knee Public Private	0.006 (-0.02,0.031)	0.667	-0.476 (-1.026,0.074)	0.090	-0.015 (-0.04,0.009)	0.225	0.113 (-0.089,0.314)	0.274	0.276 (0.035,0.517)	0.025	0.131 (-0.071,0.332)	0.205
Elec Emerg Ratio	-0.005 (-0.013,0.002)	0.171	-0.322 (-0.446,-0.198)	0.000	-0.016 (-0.026,-0.005)	0.003	-0.008 (-0.12,0.103)	0.886	-0.053 (-0.182,0.077)	0.424	-0.028 (-0.151,0.096)	0.661

Supplementary Table T3. Interrupted time series model results with maximum auto-correlation lag 0

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.985,1.005)	0.323	1.055 (0.902,1.235)	0.503	0.991 (0.978,1.005)	0.220	1.19 (1.036,1.367)	0.014	1.207 (1.088,1.339)	0.000	1.101 (0.983,1.234)	0.098
Hip Average Age	-0.015 (-0.134,0.104)	0.806	1.571 (-0.863,4.004)	0.206	-0.06 (-0.208,0.088)	0.427	1.52 (-0.079,3.119)	0.062	2.09 (0.685,3.494)	0.004	1.031 (-0.505,2.567)	0.188
Hip Prop Women	0.999 (0.993,1.004)	0.674	0.966 (0.826,1.13)	0.662	1.007 (0.997,1.017)	0.158	1.023 (0.937,1.116)	0.617	1.088 (0.995,1.189)	0.064	0.981 (0.878,1.096)	0.730
Hip Prop 2+ Charlson	0.994 (0.98,1.009)	0.455	1.411 (0.969,2.055)	0.072	1.01 (0.989,1.031)	0.344	1.195 (0.971,1.471)	0.092	1.306 (1.043,1.637)	0.020	1.003 (0.734,1.37)	0.986
Hip Prop High Deprivation	1.003 (0.991,1.014)	0.631	1.027 (0.846,1.247)	0.787	1.004 (0.983,1.025)	0.704	0.937 (0.819,1.072)	0.342	0.877 (0.746,1.03)	0.110	0.996 (0.831,1.193)	0.965
Hip LoS	-0.006 (-0.038,0.026)	0.704	0.312 (-0.262,0.887)	0.287	-0.014 (-0.058,0.03)	0.542	0.502 (0.132,0.872)	0.008	0.135 (-0.292,0.562)	0.537	0.1 (-0.287,0.487)	0.612
Hip LoS Age 16-59	-0.003 (-0.033,0.026)	0.821	0.379 (-0.165,0.922)	0.172	-0.026 (-0.067,0.015)	0.210	0.223 (-0.17,0.617)	0.266	0.384 (0.053,0.715)	0.023	0.219 (-0.168,0.607)	0.267
Hip LoS Age 60-69	-0.004 (-0.046,0.039)	0.871	0.013 (-1.026,1.052)	0.981	0 (-0.069,0.068)	0.990	0.107 (-0.592,0.805)	0.765	0.158 (-0.514,0.829)	0.645	0.162 (-0.588,0.912)	0.672
Hip LoS Age 70-79	0.006 (-0.067,0.078)	0.879	-0.753 (-2.031,0.525)	0.248	0.007 (-0.069,0.082)	0.865	-0.433 (-1.583,0.716)	0.460	-0.842 (-2.028,0.344)	0.164	-0.865 (-2.164,0.435)	0.192
Hip LoS Age 80+	-0.068 (-0.193,0.058)	0.291	2.109 (0.536,3.682)	0.009	-0.002 (-0.16,0.155)	0.977	1.506 (-0.007,3.018)	0.051	0.222 (-1.036,1.48)	0.729	1.003 (-0.375,2.38)	0.154
Hip LoS Men	-0.007 (-0.056,0.042)	0.783	0.347 (-0.58,1.275)	0.463	-0.02 (-0.084,0.044)	0.543	0.293 (-0.283,0.87)	0.319	0.289 (-0.314,0.892)	0.347	0.458 (-0.15,1.066)	0.140
Hip LoS Women	-0.004 (-0.048,0.041)	0.868	0.235 (-0.563,1.033)	0.564	-0.014 (-0.071,0.043)	0.634	0.693 (0.164,1.222)	0.010	0.009 (-0.543,0.562)	0.973	-0.203 (-0.727,0.322)	0.448
Hip LoS Charlson 0	-0.011 (-0.047,0.024)	0.532	0.297 (-0.428,1.023)	0.422	-0.005 (-0.049,0.039)	0.817	0.912 (0.522,1.302)	0.000	0.178 (-0.232,0.587)	0.396	0.222 (-0.135,0.579)	0.223
Hip LoS Charlson 1	0.034 (-0.023,0.091)	0.240	0.238 (-0.704,1.179)	0.621	-0.077 (-0.157,0.002)	0.056	0.191 (-0.562,0.945)	0.619	0.312 (-0.397,1.022)	0.388	0.014 (-0.544,0.572)	0.960
Hip LoS Charlson 2+	-0.123 (-0.266,0.02)	0.092	0.172 (-2.155,2.5)	0.885	0.116 (-0.04,0.273)	0.144	-0.789 (-2.218,0.64)	0.279	-0.783 (-2.108,0.541)	0.246	0.188 (-1.779,2.156)	0.851
Hip LoS Dep 1	0.004 (-0.039,0.047)	0.857	0.553 (-0.509,1.614)	0.307	-0.017 (-0.078,0.045)	0.599	0.784 (0.118,1.451)	0.021	0.42 (-0.084,0.923)	0.102	0.299 (-0.356,0.954)	0.371
Hip LoS Dep 2	-0.038 (-0.087,0.01)	0.124	0.822 (-0.528,2.172)	0.233	-0.015 (-0.103,0.072)	0.730	1.509 (0.797,2.22)	0.000	0.66 (-0.225,1.546)	0.144	0.589 (-0.26,1.437)	0.174
Hip LoS Dep 3	-0.034 (-0.096,0.027)	0.275	0.617 (-1.066,2.3)	0.472	0.01 (-0.09,0.109)	0.851	-0.216 (-1.343,0.912)	0.708	-0.424 (-1.475,0.627)	0.429	-0.701 (-1.667,0.266)	0.155
Hip LoS Dep 4	0.081 (-0.023,0.185)	0.129	-0.473 (-2.643,1.698)	0.670	-0.112 (-0.258,0.034)	0.134	-0.374 (-1.695,0.947)	0.579	-1.204 (-2.409,0.001)	0.050	-0.491 (-1.978,0.995)	0.517
Hip LoS Dep 5	0.015 (-0.112,0.142)	0.819	-0.72 (-2.66,1.221)	0.467	0 (-0.135,0.135)	0.999	0.621 (-0.412,1.655)	0.239	0.689 (-0.485,1.864)	0.250	0.816 (-0.891,2.524)	0.349
Hip Bed Occ	0.997 (0.987,1.009)	0.653	1 (0.824,1.215)	0.997	0.987 (0.972,1.002)	0.097	1.291 (1.125,1.48)	0.000	1.283 (1.129,1.458)	0.000	1.146 (0.984,1.334)	0.080
Hip Public Private	0.013 (-0.015,0.041)	0.377	-0.741 (-1.237,-0.245)	0.003	-0.019 (-0.05,0.011)	0.218	-0.008 (-0.212,0.196)	0.939	0.308 (0.154,0.463)	0.000	0.038 (-0.166,0.241)	0.718
Knee Admissions	0.995 (0.987,1.004)	0.274	0.843 (0.702,1.013)	0.068	1.005 (0.993,1.017)	0.422	1.308 (1.154,1.483)	0.000	1.26 (1.114,1.426)	0.000	1.286 (1.147,1.441)	0.000
Knee Average Age	-0.078 (-0.157,0.001)	0.053	-1.632 (-3.299,0.035)	0.055	0.211 (0.102,0.32)	0.000	0.926 (-0.129,1.981)	0.085	0.953 (-0.257,2.163)	0.123	0.354 (-0.777,1.485)	0.540
Knee Prop Women	1.004 (0.998,1.011)	0.182	0.96 (0.84,1.097)	0.551	0.994 (0.986,1.003)	0.184	1.037 (0.939,1.146)	0.474	1.017 (0.908,1.138)	0.776	1.036 (0.928,1.157)	0.529
Knee Prop 2+ Charlson	1.009 (0.988,1.031)	0.384	0.638 (0.392,1.037)	0.070	1.042 (1.008,1.077)	0.015	1.156 (0.891,1.501)	0.276	1.074 (0.829,1.393)	0.589	0.909 (0.636,1.299)	0.600
Knee Prop High Deprivation	1.005 (0.997,1.014)	0.237	0.968 (0.784,1.195)	0.761	0.986 (0.974,0.998)	0.023	1.224 (1.099,1.363)	0.000	1.075 (0.956,1.209)	0.225	1.031 (0.911,1.166)	0.631
Knee LoS	-0.024 (-0.052,0.004)	0.089	0.176 (-0.352,0.703)	0.515	-0.008 (-0.041,0.025)	0.625	0.422 (0.117,0.726)	0.007	0.15 (-0.174,0.475)	0.364	0.396 (0.027,0.765)	0.036

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Knee LoS Age 16-59	-0.016 (-0.048,0.017)	0.352	0.403 (-0.286,1.093)	0.252	-0.028 (-0.074,0.019)	0.246	0.484 (0.111,0.857)	0.011	0.422 (-0.111,0.956)	0.121	0.475 (0.056,0.893)	0.026
Knee LoS Age 16-59	0.007 (-0.026,0.041)	0.664	-0.295 (-1.22,0.63)	0.532	-0.026 (-0.085,0.033)	0.384	0.069 (-0.465,0.604)	0.799	-0.194 (-0.754,0.366)	0.497	-0.096 (-0.673,0.48)	0.743
Knee LoS Age 70-79	-0.009 (-0.072,0.054)	0.775	0.77 (-0.267,1.807)	0.145	-0.054 (-0.128,0.02)	0.154	-0.086 (-0.782,0.609)	0.808	-0.552 (-1.267,0.163)	0.130	0.367 (-0.528,1.261)	0.421
Knee LoS Age 80+	-0.051 (-0.154,0.051)	0.327	-0.562 (-2.568,1.443)	0.583	0.028 (-0.105,0.161)	0.678	1.521 (-0.076,3.118)	0.062	1.37 (-0.178,2.918)	0.083	1.361 (-0.071,2.794)	0.063
Knee LoS Men	-0.007 (-0.037,0.023)	0.656	0.096 (-0.512,0.704)	0.758	-0.033 (-0.075,0.009)	0.121	0.082 (-0.382,0.547)	0.729	0.157 (-0.272,0.585)	0.474	0.205 (-0.265,0.675)	0.392
Knee LoS Women	-0.042 (-0.088,0.004)	0.071	0.252 (-0.495,1)	0.508	0.017 (-0.036,0.07)	0.536	0.635 (0.107,1.164)	0.019	0.15 (-0.365,0.666)	0.567	0.49 (-0.022,1.003)	0.061
Knee LoS Charlson 0	-0.021 (-0.054,0.012)	0.214	0.067 (-0.49,0.624)	0.814	-0.011 (-0.056,0.034)	0.643	0.645 (0.278,1.013)	0.001	0.193 (-0.146,0.533)	0.265	0.415 (-0.078,0.907)	0.099
Knee LoS Charlson 1	-0.03 (-0.081,0.022)	0.260	0.47 (-0.741,1.681)	0.447	-0.029 (-0.093,0.036)	0.384	0.455 (-0.111,1.021)	0.115	0.324 (-0.426,1.074)	0.398	1.058 (0.262,1.854)	0.009
Knee LoS Charlson 2+	-0.04 (-0.111,0.032)	0.276	0.407 (-2.137,2.951)	0.754	-0.022 (-0.184,0.14)	0.788	-0.627 (-1.883,0.628)	0.327	-0.949 (-2.145,0.247)	0.120	-1.433 (-2.278,-0.589)	0.001
Knee LoS Dep 1	-0.009 (-0.064,0.045)	0.733	-0.035 (-0.918,0.847)	0.937	-0.008 (-0.082,0.066)	0.826	0.257 (-0.443,0.958)	0.471	0.096 (-0.699,0.89)	0.813	-0.127 (-0.786,0.532)	0.706
Knee LoS Dep 2	-0.019 (-0.065,0.026)	0.413	0.199 (-1.031,1.429)	0.751	-0.043 (-0.116,0.031)	0.253	0.018 (-0.822,0.858)	0.967	-0.731 (-1.538,0.077)	0.076	0.05 (-0.819,0.919)	0.910
Knee LoS Dep 3	0.014 (-0.05,0.078)	0.670	-0.426 (-1.892,1.04)	0.569	-0.036 (-0.116,0.043)	0.369	0.976 (-0.09,2.043)	0.073	0.909 (-0.134,1.952)	0.088	0.547 (-0.408,1.503)	0.261
Knee LoS Dep 4	-0.064 (-0.143,0.015)	0.113	0.634 (-0.591,1.858)	0.310	0.033 (-0.057,0.123)	0.474	0.669 (-0.193,1.531)	0.128	0.617 (-0.032,1.266)	0.063	0.852 (-0.138,1.842)	0.092
Knee LoS Dep 5	-0.035 (-0.116,0.047)	0.405	0.709 (-0.701,2.119)	0.324	0.015 (-0.076,0.106)	0.745	0.123 (-0.882,1.128)	0.810	-0.387 (-1.379,0.606)	0.445	1.104 (-0.268,2.476)	0.115
Knee Bed Occ	0.993 (0.984,1.001)	0.074	0.834 (0.711,0.979)	0.027	1 (0.989,1.011)	0.993	1.42 (1.269,1.59)	0.000	1.373 (1.217,1.548)	0.000	1.465 (1.287,1.667)	0.000
Knee Public Private	0.006 (-0.02,0.031)	0.667	-0.476 (-1.026,0.074)	0.090	-0.015 (-0.04,0.009)	0.225	0.113 (-0.089,0.314)	0.274	0.276 (0.035,0.517)	0.025	0.131 (-0.071,0.332)	0.205
Elec Emerg Ratio	-0.005 (-0.013,0.002)	0.167	-0.322 (-0.451,-0.192)	0.000	-0.016 (-0.025,-0.006)	0.001	-0.008 (-0.117,0.101)	0.884	-0.053 (-0.174,0.068)	0.392	-0.028 (-0.128,0.073)	0.591

Supplementary Table T4. Interrupted time series model results with maximum auto-correlation lag 5

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.987,1.003)	0.249	1.055 (0.917,1.215)	0.454	0.991 (0.978,1.005)	0.217	1.19 (1.04,1.362)	0.012	1.207 (1.104,1.32)	0.000	1.101 (0.993,1.221)	0.069
Hip Average Age	-0.015 (-0.094,0.065)	0.714	1.571 (0.241,2.901)	0.021	-0.06 (-0.168,0.048)	0.277	1.52 (-0.178,3.218)	0.079	2.09 (0.818,3.361)	0.001	1.031 (-0.639,2.701)	0.226
Hip Prop Women	0.999 (0.995,1.002)	0.503	0.966 (0.895,1.042)	0.367	1.007 (1.001,1.014)	0.027	1.023 (0.932,1.122)	0.636	1.088 (1,1.184)	0.051	0.981 (0.879,1.094)	0.727
Hip Prop 2+ Charlson	0.994 (0.985,1.004)	0.261	1.411 (1.116,1.785)	0.004	1.01 (1,1.02)	0.042	1.195 (0.979,1.459)	0.079	1.306 (1.111,1.535)	0.001	1.003 (0.792,1.27)	0.981
Hip Prop High Deprivation	1.003 (0.994,1.012)	0.551	1.027 (0.883,1.195)	0.729	1.004 (0.99,1.018)	0.577	0.937 (0.805,1.091)	0.400	0.877 (0.752,1.022)	0.092	0.996 (0.847,1.171)	0.961
Hip LoS	-0.006 (-0.029,0.017)	0.605	0.312 (-0.12,0.745)	0.157	-0.014 (-0.042,0.015)	0.346	0.502 (0.286,0.718)	0.000	0.135 (-0.191,0.461)	0.418	0.1 (-0.332,0.532)	0.650
Hip LoS Age 16-59	-0.003 (-0.026,0.02)	0.773	0.379 (-0.046,0.803)	0.080	-0.026 (-0.062,0.01)	0.152	0.223 (-0.113,0.559)	0.193	0.384 (0.09,0.679)	0.011	0.219 (-0.191,0.63)	0.295
Hip LoS Age 60-69	-0.004 (-0.031,0.024)	0.799	0.013 (-0.766,0.791)	0.975	0 (-0.051,0.05)	0.987	0.107 (-0.33,0.543)	0.632	0.158 (-0.451,0.766)	0.611	0.162 (-0.352,0.676)	0.537
Hip LoS Age 70-79	0.006 (-0.054,0.065)	0.853	-0.753 (-1.944,0.438)	0.215	0.007 (-0.056,0.069)	0.836	-0.433 (-1.343,0.476)	0.350	-0.842 (-1.91,0.226)	0.122	-0.865 (-2.063,0.334)	0.157
Hip LoS Age 80+	-0.068 (-0.147,0.012)	0.097	2.109 (0.803,3.414)	0.002	-0.002 (-0.111,0.107)	0.967	1.506 (0.499,2.513)	0.003	0.222 (-0.799,1.243)	0.670	1.003 (-0.111,2.116)	0.078
Hip LoS Men	-0.007 (-0.047,0.033)	0.732	0.347 (-0.44,1.135)	0.387	-0.02 (-0.073,0.033)	0.458	0.293 (-0.117,0.704)	0.161	0.289 (-0.193,0.771)	0.239	0.458 (-0.163,1.079)	0.149
Hip LoS Women	-0.004 (-0.035,0.028)	0.816	0.235 (-0.271,0.741)	0.362	-0.014 (-0.046,0.018)	0.391	0.693 (0.395,0.991)	0.000	0.009 (-0.421,0.439)	0.966	-0.203 (-0.762,0.357)	0.477
Hip LoS Charlson 0	-0.011 (-0.039,0.016)	0.418	0.297 (-0.242,0.837)	0.280	-0.005 (-0.035,0.025)	0.738	0.912 (0.617,1.208)	0.000	0.178 (-0.123,0.478)	0.247	0.222 (-0.066,0.51)	0.131
Hip LoS Charlson 1	0.034 (0.003,0.065)	0.030	0.238 (-0.604,1.08)	0.580	-0.077 (-0.137,-0.018)	0.011	0.191 (-0.385,0.767)	0.515	0.312 (-0.431,1.056)	0.410	0.014 (-0.563,0.591)	0.962
Hip LoS Charlson 2+	-0.123 (-0.239,-0.007)	0.038	0.172 (-1.97,2.314)	0.875	0.116 (0.005,0.228)	0.040	-0.789 (-2.189,0.611)	0.269	-0.783 (-2.119,0.553)	0.250	0.188 (-2.176,2.552)	0.876
Hip LoS Dep 1	0.004 (-0.029,0.037)	0.814	0.553 (-0.303,1.408)	0.206	-0.017 (-0.065,0.032)	0.501	0.784 (0.131,1.437)	0.019	0.42 (-0.034,0.874)	0.070	0.299 (-0.401,0.999)	0.402
Hip LoS Dep 2	-0.038 (-0.083,0.006)	0.092	0.822 (-0.167,1.81)	0.103	-0.015 (-0.078,0.047)	0.630	1.509 (0.737,2.28)	0.000	0.66 (-0.202,1.522)	0.133	0.589 (-0.461,1.638)	0.272
Hip LoS Dep 3	-0.034 (-0.102,0.033)	0.319	0.617 (-0.789,2.023)	0.390	0.01 (-0.072,0.091)	0.819	-0.216 (-1.011,0.579)	0.595	-0.424 (-1.293,0.445)	0.339	-0.701 (-1.351,-0.05)	0.035
Hip LoS Dep 4	0.081 (0.017,0.144)	0.013	-0.473 (-1.858,0.913)	0.504	-0.112 (-0.189,-0.035)	0.004	-0.374 (-1.59,0.842)	0.547	-1.204 (-2.355,-0.053)	0.040	-0.491 (-1.989,1.007)	0.520
Hip LoS Dep 5	0.015 (-0.056,0.085)	0.682	-0.72 (-1.647,0.208)	0.128	0 (-0.07,0.07)	0.998	0.621 (-0.104,1.347)	0.093	0.689 (-0.25,1.629)	0.150	0.816 (-0.696,2.329)	0.290
Hip Bed Occ	0.997 (0.987,1.008)	0.627	1 (0.862,1.161)	0.996	0.987 (0.97,1.004)	0.128	1.291 (1.116,1.492)	0.001	1.283 (1.14,1.444)	0.000	1.146 (0.99,1.326)	0.068
Hip Public Private	0.013 (-0.015,0.041)	0.377	-0.741 (-1.237,-0.245)	0.003	-0.019 (-0.05,0.011)	0.218	-0.008 (-0.212,0.196)	0.939	0.308 (0.154,0.463)	0.000	0.038 (-0.166,0.241)	0.718
Knee Admissions	0.995 (0.992,0.999)	0.016	0.843 (0.761,0.934)	0.001	1.005 (0.998,1.012)	0.170	1.308 (1.154,1.482)	0.000	1.26 (1.16,1.369)	0.000	1.286 (1.178,1.403)	0.000
Knee Average Age	-0.078 (-0.152,-0.005)	0.037	-1.632 (-2.825,-0.439)	0.007	0.211 (0.128,0.293)	0.000	0.926 (-0.072,1.924)	0.069	0.953 (0.077,1.829)	0.033	0.354 (-0.422,1.13)	0.371
Knee Prop Women	1.004 (0.999,1.009)	0.086	0.96 (0.861,1.071)	0.465	0.994 (0.987,1.001)	0.097	1.037 (0.973,1.105)	0.260	1.017 (0.922,1.121)	0.743	1.036 (0.966,1.111)	0.319
Knee Prop 2+ Charlson	1.009 (0.993,1.026)	0.250	0.638 (0.468,0.869)	0.004	1.042 (1.021,1.064)	0.000	1.156 (0.931,1.436)	0.190	1.074 (0.841,1.372)	0.567	0.909 (0.626,1.321)	0.617
Knee Prop High Deprivation	1.005 (0.999,1.011)	0.107	0.968 (0.835,1.122)	0.664	0.986 (0.977,0.995)	0.003	1.224 (1.082,1.384)	0.001	1.075 (0.95,1.217)	0.251	1.031 (0.924,1.149)	0.586
Knee LoS	-0.024 (-0.047,-0.001)	0.042	0.176 (-0.2,0.551)	0.360	-0.008 (-0.031,0.015)	0.490	0.422 (0.033,0.81)	0.033	0.15 (-0.199,0.499)	0.398	0.396 (-0.011,0.803)	0.057

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Knee LoS Age 16-59	-0.016 (-0.032,0.001)	0.068	0.403 (0.008,0.799)	0.046	-0.028 (-0.059,0.003)	0.081	0.484 (0.198,0.77)	0.001	0.422 (-0.01,0.855)	0.056	0.475 (0.216,0.734)	0.000
Knee LoS Age 16-59	0.007 (-0.018,0.033)	0.571	-0.295 (-0.854,0.265)	0.302	-0.026 (-0.062,0.009)	0.147	0.069 (-0.455,0.593)	0.795	-0.194 (-0.652,0.265)	0.407	-0.096 (-0.713,0.52)	0.759
Knee LoS Age 70-79	-0.009 (-0.045,0.027)	0.616	0.77 (0.101,1.439)	0.024	-0.054 (-0.096,-0.012)	0.012	-0.086 (-0.736,0.563)	0.794	-0.552 (-1.116,0.012)	0.055	0.367 (-0.3,1.034)	0.281
Knee LoS Age 80+	-0.051 (-0.097,-0.006)	0.026	-0.562 (-1.849,0.724)	0.391	0.028 (-0.062,0.119)	0.541	1.521 (0.119,2.923)	0.034	1.37 (0.391,2.349)	0.006	1.361 (0.617,2.106)	0.000
Knee LoS Men	-0.007 (-0.028,0.014)	0.514	0.096 (-0.297,0.488)	0.633	-0.033 (-0.062,-0.004)	0.024	0.082 (-0.416,0.58)	0.746	0.157 (-0.244,0.558)	0.444	0.205 (-0.149,0.559)	0.256
Knee LoS Women	-0.042 (-0.079,-0.005)	0.027	0.252 (-0.356,0.861)	0.416	0.017 (-0.018,0.052)	0.350	0.635 (-0.036,1.307)	0.064	0.15 (-0.454,0.754)	0.625	0.49 (-0.258,1.239)	0.199
Knee LoS Charlson 0	-0.021 (-0.044,0.002)	0.077	0.067 (-0.312,0.446)	0.730	-0.011 (-0.036,0.015)	0.419	0.645 (0.331,0.959)	0.000	0.193 (-0.129,0.516)	0.240	0.415 (0.075,0.754)	0.017
Knee LoS Charlson 1	-0.03 (-0.064,0.005)	0.092	0.47 (-0.199,1.139)	0.169	-0.029 (-0.067,0.01)	0.145	0.455 (-0.097,1.007)	0.106	0.324 (-0.341,0.988)	0.340	1.058 (0.384,1.731)	0.002
Knee LoS Charlson 2+	-0.04 (-0.092,0.012)	0.134	0.407 (-1.956,2.771)	0.736	-0.022 (-0.184,0.14)	0.789	-0.627 (-1.625,0.37)	0.218	-0.949 (-2.374,0.476)	0.192	-1.433 (-2.175,-0.691)	0.000
Knee LoS Dep 1	-0.009 (-0.05,0.031)	0.644	-0.035 (-0.656,0.586)	0.911	-0.008 (-0.059,0.043)	0.750	0.257 (-0.541,1.056)	0.527	0.096 (-0.581,0.772)	0.782	-0.127 (-0.724,0.47)	0.677
Knee LoS Dep 2	-0.019 (-0.055,0.017)	0.300	0.199 (-0.57,0.968)	0.612	-0.043 (-0.086,0)	0.049	0.018 (-0.731,0.767)	0.962	-0.731 (-1.507,0.046)	0.065	0.05 (-0.887,0.987)	0.917
Knee LoS Dep 3	0.014 (-0.031,0.059)	0.544	-0.426 (-1.102,0.25)	0.217	-0.036 (-0.095,0.022)	0.220	0.976 (0.281,1.672)	0.006	0.909 (-0.067,1.886)	0.068	0.547 (-0.12,1.215)	0.108
Knee LoS Dep 4	-0.064 (-0.127,-0.001)	0.047	0.634 (-0.165,1.432)	0.120	0.033 (-0.04,0.106)	0.380	0.669 (-0.076,1.414)	0.079	0.617 (0.007,1.227)	0.047	0.852 (-0.274,1.978)	0.138
Knee LoS Dep 5	-0.035 (-0.087,0.018)	0.194	0.709 (-0.225,1.643)	0.137	0.015 (-0.042,0.072)	0.606	0.123 (-0.701,0.947)	0.770	-0.387 (-1.304,0.531)	0.409	1.104 (0.188,2.02)	0.018
Knee Bed Occ	0.993 (0.986,0.999)	0.032	0.834 (0.728,0.956)	0.009	1 (0.991,1.009)	0.991	1.42 (1.308,1.542)	0.000	1.373 (1.213,1.553)	0.000	1.465 (1.318,1.627)	0.000
Knee Public Private	0.006 (-0.02,0.031)	0.667	-0.476 (-1.026,0.074)	0.090	-0.015 (-0.04,0.009)	0.225	0.113 (-0.089,0.314)	0.274	0.276 (0.035,0.517)	0.025	0.131 (-0.071,0.332)	0.205
Elec Emerg Ratio	-0.005 (-0.013,0.003)	0.198	-0.322 (-0.455,-0.189)	0.000	-0.016 (-0.026,-0.005)	0.004	-0.008 (-0.107,0.091)	0.872	-0.053 (-0.18,0.074)	0.414	-0.028 (-0.163,0.108)	0.690

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract P2 L35-37 Abstract P2 L35-38
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Introduction P4-5 L76-113
Objectives	3	State specific objectives, including any prespecified hypotheses			Introduction P5 L107-113
Methods					
Study Design	4	Present key elements of study design early in the paper			Methods P5 L116-119
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Methods P5 L116-119 Methods P7-8 L70-176

<p>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27</p> <p>Participants</p>	<p>6</p>	<p>(a) <i>Cohort study</i> - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> - Give the eligibility criteria, and the sources and methods of selection of participants</p> <p>(b) <i>Cohort study</i> - For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> - For matched studies, give matching criteria and the number of controls per case</p>		<p>RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided.</p> <p>RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided.</p> <p>RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.</p>	<p>Methods P6 L141-147 Supplementary Table T1</p>
<p>28 29 30 31 32 33 34</p> <p>Variables</p>	<p>7</p>	<p>Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.</p>		<p>RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.</p>	<p>Methods P6-7 L141-169</p>
<p>35 36 37 38 39 40 41 42</p> <p>Data sources/ measurement</p>	<p>8</p>	<p>For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group</p>			<p>Methods P5-6 L120-140</p>

1 2 3 4 5 6 7 8 9 10	Bias	9	Describe any efforts to address potential sources of bias			Methods P7-8 L170-185,
11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34	Study size	10	Explain how the study size was arrived at			Methods P6 L141-147
35 36 37 38 39 40 41 42 43 44 45 46 47	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods P6-7 L141-169
	Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) <i>Cohort study</i> - If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses			Methods P7-8 L170-185
	Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	Data Sharing P17 L392-400

				RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	Methods P6-7 L141-169
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (<i>e.g.</i> , numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (<i>i.e.</i> , study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Methods P6 L141-147 Results P8 L191-194
Descriptive data	14	(a) Give characteristics of study participants (<i>e.g.</i> , demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) <i>Cohort study</i> - summarise follow-up time (<i>e.g.</i> , average and total amount)			Results P8 L191-194
Outcome data	15	<i>Cohort study</i> - Report numbers of outcome events or summary measures over time <i>Case-control study</i> - Report numbers in each exposure			Results P8-9 L195-206

		category, or summary measures of exposure <i>Cross-sectional study</i> - Report numbers of outcome events or summary measures			
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Results P9-11 L196-267
Other analyses	17	Report other analyses done— e.g., analyses of subgroups and interactions, and sensitivity analyses			Results P9-11 L196-267
Discussion					
Key results	18	Summarise key results with reference to study objectives			Discussion P11-12, L268-288
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	Discussion P12-13 L289-303
Interpretation	20	Give a cautious overall interpretation of results considering objectives,			Discussion P13-14 L317-340

		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			
Generalisability	21	Discuss the generalisability (external validity) of the study results			Discussion P13 L294-303
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based			Funding Statement P16 L375-380
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Methods P8 L186-188 Data Sharing P17 L392-400

*Reference: Benchimol EI, Smeeth L, Guttman A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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BMJ Open

The impact of pausing elective hip and knee replacement surgery during winter 2017 on subsequent service provision at a major NHS Trust: a descriptive observational study using interrupted time series

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2
3 1 **Title:** The impact of pausing elective hip and knee replacement surgery during winter 2017 on
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5 2 subsequent service provision at a major NHS Trust: a descriptive observational study using
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7 3 interrupted time series
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12
13 5 **Authors:** Tim Jones^{1,2,3}, Christopher Penfold^{1,2,3}, Maria Theresa Redaniel^{1,2}, Emily Eyles^{1,2}, Tim Keen⁴,
14
15 6 Andrew Elliott⁴, Ashley Blom^{2,3}, Andrew Judge^{3,5}
16
17

18
19
20
21 8 ¹ NIHR ARC West, University Hospitals Bristol NHS Foundation Trust, Bristol, BS1 2NT, UK
22

23
24 9 ² Department of Population Health Sciences, Bristol Medical School, University of Bristol, BS8 2PS,
25
26 10 UK
27

28
29 11 ³ Musculoskeletal Research Unit, Translational Health Sciences, Bristol Medical School, University of
30
31 12 Bristol, Learning and Research Building, Level 1, Southmead Hospital, Bristol, BS10 5NB, UK
32

33
34 13 ⁴ North Bristol NHS Trust, Southmead Hospital, Westbury-on-Trym, Bristol, BS10 5NB, UK
35

36
37 14 ⁵ National Institute for Health Research Bristol Biomedical Research Centre, University Hospitals
38
39 15 Bristol and Weston NHS Foundation Trust and University of Bristol, Bristol, UK
40

41
42
43 16
44 17 **Corresponding author:**

45
46 18 Tim Jones
47
48 19 Research Fellow
49
50 20 NIHR ARC West,
51
52 21 9th Floor Whitefriars,
53
54 22 Lewin's Mead
55
56 23 Bristol, BS1 2NT
57
58 24 United Kingdom

59
60 25
26 26 Tel: ++44 (0)117 342 1265

27 27 Timothy.Jones@bristol.ac.uk

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29 28
29 29 **Word count [3,957]**

1
2
3 30 **ABSTRACT**

4
5 31 **Objectives:** To explore the impact of a temporary cancellation of elective surgery in winter 2017 on
6
7 32 trends in primary hip and knee replacement at a major NHS Trust, and whether lessons can be learnt
8
9 33 about efficient surgery provision.

10
11
12 34 **Design and Setting:** Observational descriptive study using interrupted time series analysis of hospital
13
14 35 records to explore trends in primary hip and knee replacement surgery at a major NHS Trust, as well
15
16 36 as patient characteristics, 2016-2019.

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18
19 37 **Intervention:** A temporary cancellation of elective services for two months in winter 2017

20
21
22 38 **Outcomes:** NHS-funded hospital admissions for primary hip or knee replacement, length of stay and
23
24 39 bed occupancy. Additionally, we explored the ratio of elective to emergency admissions at the Trust
25
26 40 as a measure of elective capacity, and the ratio of public to private provision of NHS-funded hip and
27
28 41 knee surgery.

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30
31 42 **Results:** After winter 2017 there was a sustained reduction in the number of knee replacements, a
32
33 43 decrease in the proportion of most deprived people having knee replacements, and an increase in
34
35 44 average age for knee replacement and comorbidity for both types of surgery. The ratio of public to
36
37 45 private provision dropped after winter 2017, and elective capacity generally has reduced over time.
38
39 46 There was clear seasonality in provision of elective surgery, with less-complex patients admitted
40
41 47 during winter.

42
43
44 48 **Conclusions:** Declining elective capacity and seasonality has a marked effect on the provision of joint
45
46 49 replacement, despite efficiency improvements in hospital treatment. The Trust has outsourced less
47
48 50 complex patients to independent providers, and/or treated them during winter when capacity is
49
50 51 most limited. There is a need to explore whether these are strategies that could be used explicitly to
51
52 52 maximise the use of limited elective capacity, provide benefit to patients, and value for money for
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54 53 taxpayers.
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3 54 **STRENGTH AND LIMITATIONS OF THIS STUDY**
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- 6 55 • Trends analyses using data obtained from the electronic health records of a local hospital
7
8 NHS Trust are informative for clinicians and service managers in monitoring changes in
9 56
10 planning and delivery of elective surgery, and could be regularly updated in near real time
11 57
12 for monitoring.
13 58
14 • The inclusion of wider hospital admissions data beyond the NHS Trust allows us to estimate
15 59
16 the proportion of people within the Trust catchment area having NHS-funded treatment at
17 60
18 independent providers.
19 61
20 • We report the experience of one NHS Trust that is one of the larger elective orthopaedic
21 62
22 centres - the findings may not be generalisable to or reflect the experience of other trusts.
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24 • Our study does not include privately funded, privately provided hip and knee surgery which
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26 may also have been changing over time.
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75 INTRODUCTION

76 Primary hip and knee replacement operations are common planned elective surgical procedures.

77 They are highly clinically effective for improving symptoms of pain and functional limitations, and

78 have been shown to be safe and cost-effective.¹⁻⁴ Around 100,000 hip⁴ and over 100,000 knee

79 operations³ are carried out each year in the UK. Demand for these operations has been increasing

80 substantially in recent decades⁵ with an ageing population, rising levels of obesity, and widening

81 indications for surgery in younger patient groups.^{3 4}

82 Orthopaedic services have become more efficient over time, with length of hospital stay for primary

83 hip and knee replacements reducing from around 15 days in 1997 to roughly 5.5 days in 2014.⁶ This is

84 largely due to the introduction of 'fast track' surgery and enhanced recovery services,⁷ which reduce

85 length of stay whilst maintaining patient safety and outcomes of surgery.⁶ However, over the past

86 decade there has also been a reduction in the numbers of hospital beds and operating theatres

87 available for hip and knee replacement patients.⁸ Waiting lists for orthopaedic procedures have been

88 growing over time, and the average time people wait for treatment once on the waiting list has also

89 increased.⁹

90 Pressures on elective surgery are exacerbated during winter, when resources for planned surgery are

91 often displaced by more acute, unplanned hospital admissions.⁸ At the end of 2017, this led to all

92 planned elective hip and knee replacement operations in England being cancelled for the whole of

93 January.¹⁰ Even before the COVID-19 pandemic, over half a million people were already on the waiting

94 list.¹¹ Patients are having to wait longer with deteriorating severe pain and functional limitation,

95 affecting their health and quality of life. The COVID-19 pandemic has had an even greater impact on

96 cancelling planned elective surgery, with over 635,000 people waiting for hip and knee replacements

97 in April 2021, more than 10% of these waiting over a year, and over a third waiting longer than the 18

98 week target.¹¹

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3 99 The winter of 2017 provides a form of 'natural experiment', where elective capacity was intentionally
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5 100 reduced close to zero. A natural experimental design is a valid methodological approach to evaluate
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7 101 the impact of a range of events, policies and interventions which are not under the control of
8
9 102 researchers.¹² Researchers can use the variation in exposure that natural experiments generate to
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11 103 analyse their impact on health outcomes. This provides a form of quasi-experimental study, where we
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13 104 can explore trends in provision of elective surgery before and after Winter 2017, which is a robust
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15 105 approach to explore real-world impact when randomisation is not possible.^{13 14}

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19 106 Our aim was to understand what happens after common, planned elective surgery is temporarily
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21 107 cancelled, and how this might inform optimum planning of elective surgery when capacity is limited,
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23 108 such as following the COVID-19 pandemic. We used interrupted time series analysis to model trends
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25 109 in elective hip and knee replacement surgery for a major NHS Trust from 2016 to 2019 and see how
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27 110 these were impacted by the withdrawal of elective surgery in winter 2017. We explored these trends
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29 111 by patient factors (age, sex, deprivation, number of comorbidities) and seasonality to see when
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31 112 demand was highest for different patient groups.

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37 114 **METHODS**

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41 115 This study is a longitudinal observational descriptive study using routinely collected administrative
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43 116 information about patients admitted to a major NHS Trust for elective hip and knee replacements,
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45 117 2016 to 2019. It was developed and reported according to the RECORD extension¹⁵ to STROBE
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47 118 guidelines for observational studies using routinely collected data.

48 49 50 119 **Data Sources**

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53 120 We used two data sources for our analyses. The first was an extract of elective primary hip and knee
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55 121 replacement inpatient admissions identified from the Trust's electronic medical records (EMR)
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57 122 between 1st January 2016 and 31st December 2019. Up to 29 diagnoses were provided per entry using
58
59 123 the International Classification of Diseases version 10 (ICD-10), and up to 11 procedures were provided

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3 124 per entry using the Office of Population Censuses and Surveys Classification of Interventions and
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5 125 Procedures version 4 (OPCS-4). The extract included patient demographics such as age, sex,
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7 126 deprivation quintile, and comorbidities; and other characteristics of the hospital admissions such as
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9
10 127 length of stay. This data source was used for all analyses of hip and knee replacements at the Trust,
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12 128 including those relating to patient demographics, length of stay, and bed occupancy.
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15 129 The second data source was pseudonymised national admitted patient care Hospital Episode
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17 130 Statistics (HES-APC) between 1st January 2016 and 31st December 2019. HES-APC is a routinely
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19 131 collected dataset that records all episodes of admitted (day case or inpatient) care provided to
20
21 132 patients at NHS hospitals in England and to NHS-funded patients treated in independent hospitals.¹⁶
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23 133 Each episode represents a period of care under one consultant team. Up to 20 diagnoses and 24
24
25 134 clinical procedures are recorded per episode using ICD-10 codes and OPCS-4 codes, respectively. HES
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27 135 also includes the Lower Super Output Area (LSOA; an area of around 1,500 people) of residence for
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29 136 each patient, which can be linked to CCG of residence. This data source was used to estimate
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31 137 elective capacity overall at the Trust, and the ratio of public/private provision of hip and knee
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33 138 replacements in the catchment area for the Trust (see details below), which could not be gathered
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35 139 from the extract provided from the Trust EMR.
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40 140 **Hospital admissions for hip and knee replacements**

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42 141 Hospital admissions for elective hip and knee replacements were identified by entries with a primary
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44 142 procedure code representing primary hip or knee replacement (Supplementary Table T1) using the
45
46 143 Trust EMR. We used this information to explore summary characteristics of the hospital admissions
47
48 144 over time (overall counts of admissions, average age, proportion of women, proportion with 2+
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50 145 comorbidities, proportion in the two most deprived quintiles) stratified by primary hip or knee
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52 146 replacements.
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56 147 **Length of stay and bed occupancy**

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3 148 We used the average number of overnight stays in hospital (days) for length of stay, trimmed at 30
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5 149 days to exclude a small number of outliers (n=32, 0.6%). Trimming allowed us to model averages
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7 150 assuming a roughly normal distribution which we felt was more easily interpretable. Bed occupancy
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9 151 was the total number of beds used overnight for hip and knee replacement patients.
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13 152 **Comorbidity of Admissions**

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15 153 For each admission, we counted the number of conditions from the Charlson comorbidity index¹⁷
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17 154 recorded in the diagnosis fields. The Charlson index provides a summary of weighted scores relating
18
19 155 to different comorbidities and has been shown to be associated with mortality. Admissions were
20
21 156 categorised into those with zero, one, and two or more Charlson comorbidities.
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24

25 157 **Ratio of Elective to Emergency Admissions**

26
27 158 To estimate the ratio of elective to emergency admissions for all purposes at the Trust (as a proxy for
28
29 159 elective capacity), we extracted all hospital admissions from HES-APC with the Trust as a provider
30
31 160 and categorised them into elective and emergency (admission method beginning with '1' or '2',
32
33 161 respectively).
34
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37 162 **Ratio of Public to Private Provision of Hip and Knee Replacements**

38
39 163 To estimate the ratio of public to private provision of NHS-funded elective hip and knee surgery for
40
41 164 the Trust catchment area, we extracted all hospital admissions for primary hip and knee
42
43 165 replacements (codes in Supplementary Table T1) for residents of the major local clinical
44
45 166 commissioning groups (CCGs) from HES-APC (using 2021 CCG boundaries after local CCGs had
46
47 167 merged into one CCG¹⁸), and categorised providers into public and private (provider code beginning
48
49 168 with 'R' or 'N', respectively).
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51
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53 169 **Statistical Analysis**

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56 170 We explored the change in trend for the following outcomes before/after the winter 2017 cancellation
57
58 171 of elective surgery, stratified by primary hip and knee replacements: number of hospital admissions;
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3 172 average age of patients; proportion of women; proportion with 2+ comorbidities; proportion in more
4
5 173 deprived deprivation quintiles (4 and 5); average length of stay; bed occupancy; and ratio of public to
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7 174 private provision of surgery. Additionally, we explored the overall ratio of elective to emergency
8
9 175 admissions at the hospital for any purpose without stratification. For each of the outcomes, we
10
11 176 conducted interrupted time series (ITS) analyses using segmented regression models comparing
12
13 177 hospital admissions in the 'before' period (January 2016 to November 2017) to the 'after' period
14
15 178 (February 2018 to December 2019). We excluded the winter 2017 period when admissions were very
16
17 179 low (December 2017 and January 2018). The ITS analyses explored the 'pre-trend' before winter 2017,
18
19 180 and how this trend changed after winter 2017^{12 19}, allowing for an immediate 'level change' up or
20
21 181 down in February 2018, and a longer-term 'trend change' in the slope afterwards. We explored
22
23 182 seasonality in the data by including indicator variables for spring, summer, and autumn¹⁹ compared
24
25 183 to winter as a baseline, and adjusted for serial autocorrelation using Newey-West standard errors with
26
27 184 a maximum lag of two²⁰⁻²². For count or proportion outcomes (number of admissions, proportion
28
29 185 women, proportion with 2+ comorbidities, proportion in top two deprivation quintiles, bed
30
31 186 occupancy) segmented Poisson regression models were fit to the data, whilst for averages/ratios
32
33 187 (average age, average length of stay, ratio of elective to emergency admissions, ratio of public to
34
35 188 private provision) segmented linear regression models were fit, using the 'glm' command in Stata.
36
37 189 Sensitivity analyses were conducted adjusting the maximum lag for serial autocorrelation to zero and
38
39 190 five; this would not affect point estimates but could alter standard errors, confidence intervals, and p-
40
41 191 values.

42
43 192 All statistical analyses were conducted using Stata/MP version 16.1. Smoothed trends were fit to the
44
45 193 data on all plots using the 'lowess' command with bandwidth 0.3. Stata code is available at:
46
47 194 https://github.com/jonestim2002/hdr_uk_hospital_efficiency

195 **Patient and public involvement**

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3 196 Initial research ideas for the grant application of which this work is part were presented to the public
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5 197 in a workshop and suggestions and comments were incorporated in the protocol. Feedback during
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7 198 the workshop was positive, with participants agreeing with the research objectives and the
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9 199 identified need.
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16 201 RESULTS

17 202 *Descriptive information and demographics*

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21
22 203 A total of 2,623 patients had a hip replacement and 2,674 had a knee replacement at the Trust in the
23
24 204 4 years between 2016 and 2019. The mean age of patients was 67 years and 60% were women for
25
26 205 both types of operations.
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32 207 *Trend changes after winter 2017*

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34
35 208 Table 1 shows the results of our interrupted time series analyses for all outcomes, including the
36
37 209 trend before winter 2017 (pre-trend), any immediate change after winter 2017 (level change) and
38
39 210 any change in the slope after winter 2017 (trend change). These are described in more detail below.
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45 212 **Table 1. Interrupted time series model results**

	pre-trend		level change		trend change	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	1 (0.99,1)	0.300	1.06 (0.91,1.22)	0.469	0.99 (0.98,1.01)	0.239
Hip Age*	-0.01 (-0.1,0.07)	0.737	1.57 (-0.1,3.24)	0.065	-0.06 (-0.17,0.05)	0.307
Hip Prop Women	1 (0.99,1)	0.582	0.97 (0.86,1.08)	0.549	1.01 (1,1.02)	0.089
Hip Charlson	0.99 (0.98,1.01)	0.380	1.41 (1.06,1.87)	0.017	1.01 (0.99,1.03)	0.220
Hip Deprivation	1 (0.99,1.01)	0.587	1.03 (0.87,1.21)	0.754	1 (0.99,1.02)	0.660
Hip LoS*	-0.01 (-0.03,0.02)	0.660	0.31 (-0.19,0.82)	0.225	-0.01 (-0.05,0.02)	0.425
Hip Bed Occ	1 (0.99,1.01)	0.643	1 (0.84,1.19)	0.997	0.99 (0.97,1)	0.149
Hip Public Private*	0.01 (-0.02,0.04)	0.377	-0.74 (-1.24,-0.25)	0.003	-0.02 (-0.05,0.01)	0.218
Knee Admissions	1 (0.99,1)	0.106	0.84 (0.73,0.98)	0.022	1 (1,1.01)	0.256
Knee Age*	-0.08 (-0.16,0)	0.054	-1.63 (-2.99,-0.28)	0.018	0.21 (0.12,0.31)	0.000

Knee Prop Women	1 (1,1.01)	0.150	0.96 (0.85,1.08)	0.513	0.99 (0.99,1)	0.193
Knee Charlson	1.01 (0.99,1.03)	0.249	0.64 (0.46,0.89)	0.009	1.04 (1.02,1.07)	0.001
Knee Deprivation	1.01 (1,1.01)	0.189	0.97 (0.79,1.19)	0.758	0.99 (0.97,1)	0.021
Knee LoS*	-0.02 (-0.05,0)	0.058	0.18 (-0.28,0.63)	0.449	-0.01 (-0.04,0.02)	0.566
Knee Bed Occ	0.99 (0.98,1)	0.103	0.83 (0.7,0.99)	0.037	1 (0.99,1.01)	0.993
Knee Public Private*	0.01 (-0.02,0.03)	0.667	-0.48 (-1.03,0.07)	0.090	-0.02 (-0.04,0.01)	0.225
Elec Emerg Ratio*	-0.01 (-0.01,0)	0.171	-0.32 (-0.45,-0.2)	0.000	-0.02 (-0.03,-0.01)	0.003

Notes: *Linear regression model (additive) rather than Poisson regression model (multiplicative). Shaded cells indicate $p < 0.05$.

Trends in hip and knee elective hospital admissions over time

The overall numbers of elective primary hip and knee replacement operations gradually declined over the study period from 63 hip and 65 knee replacements per month in 2016 to 49 hip and 51 knee replacements per month in 2019. Whilst there was a drop off in winter 2017, after elective surgery was re-started hip replacements resumed at similar numbers and continued to decline along a similar trajectory. Numbers of knee replacements dropped by 16% after winter 2017 (level change=0.843, 95% CI: 0.728 to 0.976, $p=0.022$), and the slope appeared to level off, although there was little evidence for this in the regression model (trend change=1.005, 95% CI: 0.996 to 1.014, $p=0.256$); see Figure 1 and Supplementary Table T2.

Age on Admission

There was a change in the trend in average age for knee replacements after winter 2017 (trend change=+0.21, 95% CI: 0.12 to 0.31, $p < 0.001$) towards treating older patients over time (+1.59 years of age per year); see Figure 2.

Comorbidity of Admissions

There was a level change upwards in the proportion having hip replacements with 2+ comorbidities after winter 2017 (level change=1.411, 95% CI: 1.064 to 1.873, $p=0.017$), and an upward slope change for knee replacements (trend change=1.042, 95% CI: 1.017 to 1.067, $p=0.001$); see Figure 3.

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5 236*Deprivation*

7 237 There was evidence of a reducing proportion of the most deprived people having knee replacements
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10 238 after winter 2017 (trend change=0.986, 95% CI: 0.974 to 0.998, p=0.021).

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12 239
1314 240 *Ratio of elective admissions to emergency admissions at the Trust*

17 241 There was an overall downward trend in the ratio of elective to emergency admissions at the Trust,
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19 242 from an average of 2.91 (SD: 0.17) electives for every emergency in 2016 to 2.16 (SD: 0.06) in 2019;
20
21 243 see Supplementary Figure F1. The ratio reduced after winter 2017 (level change=-0.322, 95% CI: -
22
23 244 0.446 to -0.198, p<0.001), and started to decrease more rapidly afterwards (trend change=-0.016,
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25 245 95% CI: -0.026 to -0.005, p=0.003).

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3132 247 *Ratio of public to private provision of hip/knee elective surgery at the Trust*

35 248 There was evidence of a level change downwards in public provision compared to private provision
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37 249 after winter 2017 for both types of surgery, but particularly for hip replacements (hips level
38
39 250 change=-0.741, 95% CI: -1.237 to -0.245, p=0.003; knees level change=-0.476, 95% CI: -1.026 to
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41 251 +0.074, p=0.09); see Figure 4.

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44 252
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4647 253 *Bed Occupancy*

50 254 For hip and knee replacements, bed occupancy has reduced over time, although there wasn't
51
52 255 evidence of this in the regression model for hip replacements, and there was a level change
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54 256 downwards (level change=0.834, 95% CI: 0.704 to 0.989, p=0.037) for knee surgery after winter
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56 257 2017; see Figure 5.

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3 259 *Length of Stay*
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6 260 The average length of hospital stay was 5.5 days (SD: 5.9 days) for hip replacements and 5.2 days
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8 261 (SD: 5.0 days) for knee replacements in 2016, compared to 5.1 days (SD: 4.1 days) and 4.3 days (SD:
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10 262 3.4 days) respectively in 2019 (see Supplementary Figure F2). However, there was no evidence in the
11
12 263 regression models for a change after winter 2017.
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17
18 265 *Seasonality*
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21 266 Supplementary Table T2 shows seasonality results for each of our interrupted time series analyses.
22
23 267 Hip and knee operations were clearly seasonal, with higher admissions in non-winter months
24
25 268 compared to winter; 21% higher in the highest season (summer) for hips (summer=1.207, 95% CI:
26
27 269 1.094 to 1.332, $p<0.001$), and 31% higher in the highest season (spring) for knee replacements
28
29 270 (spring=1.308, 95% CI: 1.157 to 1.479, $p<0.001$), excluding winter 2017. Bed occupancy for both
30
31 271 types of operation was also seasonal, with lower occupancy in the winter months compared to all
32
33 272 other seasons (see Supplementary Table T2); e.g. summer bed occupancy was 324 beds for hips and
34
35 273 291 beds for knees on average compared to winter bed occupancy of 225 beds for hips and 199 beds
36
37 274 for knees on average. Length of stay was longer in spring than winter for hip replacements
38
39 275 (spring=+0.502 days, 95% CI: 0.214 to 0.79, $p=0.001$), and longer in spring (+0.422 days, 95% CI:
40
41 276 0.073 to 0.771, $p=0.018$) and autumn (+0.396 days, 95% CI: 0.015 to 0.777, $p=0.042$) compared to
42
43 277 winter for knee replacements.
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49 278 The ratio of public to private provision was higher in the summer (1.56 for hips and 1.28 for knees)
50
51 279 compared to winter (1.22 and 0.99, respectively) months (hips summer=+0.308, 95% CI 0.154 to
52
53 280 0.463, $p<0.001$; knees summer=+0.276, 95% CI: 0.035 to 0.517, $p=0.025$).
54
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56 281 There was also some evidence of seasonality in the types of patients being admitted for hip and
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58 282 knee replacements. For hip replacements, the mean age of patients was 66 in winter compared to
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3 283 68 in summer (summer=+2.09; 95% CI: 0.81 to 3.37, p = 0.001); a higher proportion were performed
4
5 284 on women in the summer (64%) compared to winter (58%) months (summer=1.088, 95% CI: 1.001 to
6
7 285 1.183, p=0.048); and a higher proportion of people had 2+ comorbidities in the summer (15.9%)
8
9 286 compared to winter (12.3%) months (summer=1.306, 95% CI: 1.096 to 1.557, p=0.003). For knee
10
11 287 replacements, there was a higher proportion of more deprived people (quintiles 4 and 5) in the
12
13 288 spring (37.6%) compared to the winter (30.2%) months (spring=1.224, 95% CI: 1.077 to 1.49,
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15 289 p=0.002).

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22 291 **DISCUSSION**

25 292 *Principal findings*

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29 293 The temporary cancellation of elective services during winter 2017 does appear to have had some
30
31 294 impact on service provision at the Trust after that time. There was an immediate and sustained
32
33 295 reduction in the number of knee replacements being done at the Trust and this was also reflected in
34
35 296 the drop in bed occupancy for knee surgery. The average age for knee replacement and comorbidity
36
37 297 of hip and knee surgery patients increased after winter 2017, whilst the proportion of more deprived
38
39 298 people having knee replacements decreased, and the ratio of public to private provision of hip and
40
41 299 knee replacements in the local area dropped after winter 2017. This suggests an NHS-funded
42
43 300 outsourcing of less comorbid hip and knee replacement surgery to independent providers, and
44
45 301 therefore on average the patients being treated at the Trust became older and more comorbid.
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47 302 There was a general decrease in capacity for elective surgery at the Trust (ratio of elective to
48
49 303 emergency admissions), mostly driven by increasing non-elective admissions even before the COVID-
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51 304 19 pandemic. The winter 2017 cancellation may have been just one symptom of this overall pressure
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53 305 on elective surgery that underlies some of the longer-term changes in provision.
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3 306 There was also some seasonality in service provision. It is no surprise that elective admissions and
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5 307 bed occupancy are lower in winter when the hospital requires capacity for an increase in unplanned
6
7 308 admissions. There were also indications that people being admitted in winter were younger, less
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9
10 309 comorbid, and less deprived (particularly for knee surgery). Length of stay for hip and knee
11
12 310 replacements was lower in winter compared to spring. This suggests the admission of younger, less
13
14 311 comorbid patients during the winter months given the reduced elective capacity and delaying
15
16 312 surgery for more comorbid patients to when capacity is higher in the following months.

20 313 *Strengths and limitations*

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23 314 Trends analyses such as these, using data obtained from the EHR of a local hospital NHS Trust, are
24
25 315 informative for clinicians and service managers in monitoring changes in planning and delivery of
26
27 316 elective surgery, and could be regularly updated in near real time for monitoring. This concept might
28
29 317 be informative for other commissioning groups / Trusts to adopt for monitoring of their own elective
30
31 318 surgery and capacity. We report the experience of just one trust that is one of the larger elective
32
33 319 orthopaedic centres, and hence the findings may not be generalisable to or reflect the experience of
34
35 320 other trusts. Our findings are observational and report changes observed at the Trust following
36
37 321 cancellation of elective services in winter 2017; further work would be needed to understand the
38
39 322 impact of any changes on outcomes such as throughput of patients, waiting times, waiting lists,
40
41 323 outcomes of surgery, costs, and equity of access to surgery. There is likely to be some correlation
42
43 324 between the covariables explored; for example, older people tend to be less deprived and have
44
45 325 more comorbidities, which may account for some of our results. Some of the increase in age at
46
47 326 operation after winter 2017 may be due to increased waiting times for surgery. We should be aware
48
49 327 that some results may reflect chance findings due to multiple testing and type 1 error. The trends in
50
51 328 the data as plotted do not change substantially in sensitivity analyses accounting for different
52
53 329 autocorrelation lags (Supplementary Tables T3-T4). The catchment area of the Trust is not exactly
54
55 330 the same as the major local CCG and is difficult to define exactly. However, 89.4% of admissions at
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3 331 the Trust were for residents of the local CCG and we felt this was a reasonable approximation to
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5 332 estimate the ratio of public to private provision in the Trust catchment area. Our analyses only
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7 333 include NHS-funded surgery and not privately-funded, privately-provided surgery.
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9

10 334 *Comparison to other studies*

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14 335 A previous study²³ using data for England from Hospital Episode Statistics found increasing private
15
16 336 provision of elective hip arthroplasties nationally from 2007/8 to 2012/13, particularly for less
17
18 337 deprived people, which echoes our findings. More recent news stories have suggested that 20% of
19
20 338 NHS-funded hip replacements and 29% of NHS-funded knee replacements were carried out by
21
22 339 independent providers in 2016/17²⁴, and that independently-provided hip and knee replacement
23
24 340 surgery (privately or NHS-funded) has now overtaken NHS provision.²⁵ A UK-wide study⁶ using
25
26 341 primary care data (CPRD) linked to hospital admissions found similar effects of patient
27
28 342 characteristics (age, sex, comorbidity, and deprivation) on length of stay for primary hip and knee
29
30 343 replacements, although they did not explore seasonality. A recent qualitative study²⁶ highlighted the
31
32 344 negative financial and emotional impact of winter elective cancellations on patients and their
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34 345 families and recommended better advanced planning of elective operations to reduce these
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36 346 impacts.
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41 347 *Implications for clinicians and policy makers*

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44 348 Outsourcing of less complex hip and knee replacements to take advantage of spare capacity in non-
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46 349 NHS hospitals may be a good strategy to reduce waiting times and waiting lists for surgery and get
47
48 350 the best results for patients given the evident capacity limitations. It is a strategy that has already
49
50 351 been used in other NHS Trusts,²⁷ and outsourcing more generally is recognised by the British Medical
51
52 352 Association as a short-term solution to reducing waiting lists, although they recommend this goes
53
54 353 alongside a longer-term commitment to increased NHS capacity.²⁸ The evidence is unclear regarding
55
56 354 the impact of private provision on quality of care for patients and value for money for the public
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58 355 sector,^{29 30} with some studies indicating potentially lower quality of healthcare.³¹ There are questions
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3 356 about how much it increases staff capacity because some staff transfer from public to private
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5 357 practice.^{28 29} It would also leave the NHS Trust to cope with more complex cases,³⁰ which could have
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8 358 a detrimental impact on their service.
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10
11 359 There are training implications of outsourcing because trainee surgeons are usually trained in NHS
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13 360 hospitals by first undertaking less-complex cases on healthier patients. Trainees can find they are
14
15 361 redeployed away from training to cover for a lack of trained staff in the public sector, which may be
16
17 362 detrimental to their training and potentially harmful for patients.^{32 33} The Royal College of Surgeons
18
19 363 offers guidance around appropriate redeployment of trainees.³⁴
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23 364 There are also potential equity implications of outsourcing, if less complex cases have the option of
24
25 365 surgery with shorter waiting times at independent providers, whilst more complex (and potentially
26
27 366 more deprived) cases do not. We would need to consider the acceptability of this outsourcing to
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29 367 patients and practitioners, and the quality of patient outcomes.
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33 368 There is an indication that some selection of patients for elective surgery depending on available
34
35 369 capacity already takes place at the Trust. It is possible that this could become a more explicit
36
37 370 strategy, based on evidence, to optimise the use of limited capacity in hospitals at different times of
38
39 371 the year. However, this could mean that people placed earlier on the waiting list for surgery might
40
41 372 get their surgery later due to such scheduling strategies, so acceptability to patients would need to
42
43 373 be explored. We need to understand how the scheduling and possible outsourcing of elective
44
45 374 surgery for different types of patients, depending on capacity, may impact on throughput of
46
47 375 patients, waiting times, waiting lists, outcomes of surgery, costs, and equity of access to surgery. An
48
49 376 appropriate balance would need to be achieved to maximise the benefits for patients, and research
50
51 377 is needed to understand what that balance is. Additionally, we need to understand whether this
52
53 378 type of scheduling and outsourcing is acceptable to people waiting for hip and knee surgery as well
54
55 379 as clinicians. These issues of optimising limited elective resources are in even sharper focus due to
56
57 380 the backlog in waiting lists caused by the COVID-19 pandemic.
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3 381 *Unanswered questions and future research*
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6 382 We need to understand how the scheduling and possible outsourcing of elective surgery for
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8 383 different types of patients, depending on capacity, may impact on throughput of patients, waiting
9
10 384 times, waiting lists, outcomes of surgery, costs, and equity of access to surgery. Inevitably
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12 385 outsourcing simpler patients to the independent sector will leave more complex patients being
13
14 386 treated by NHS Trusts, which could have a detrimental impact on their service. An appropriate
15
16 387 balance would need to be achieved to maximise the benefits for patients, and research is needed to
17
18 388 understand what that balance is. Additionally, we need to understand whether this type of
19
20 389 scheduling and outsourcing is acceptable to people waiting for hip and knee surgery as well as
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22 390 clinicians.
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27 391 *Conclusions*
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30 392 Declining elective capacity and seasonality has a marked effect on the provision of joint
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32 393 replacement, despite efficiency improvements in hospital treatment. The Trust has outsourced less
33
34 394 complex patients to independent providers, and/or treated them during winter when capacity is
35
36 395 most limited. There is a need to explore whether these are strategies that could be used explicitly to
37
38 396 maximise the use of limited elective capacity, provide benefit to patients, and value for money for
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40 397 taxpayers.
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47 398

47 399 **Author Contributions**
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49

50 400 This publication is the work of the authors, who serve as guarantors for the contents of this paper. TJ
51
52 401 contributed to study design, data cleaning, data analysis, interpretation of results and writing the
53
54 402 manuscript. MTR contributed to study conceptualisation, supervision, interpretation of results and
55
56 403 reviewing the manuscript. TK contributed to data curation, supervision, interpretation of results and
57
58 404 reviewing the manuscript. AE contributed to data curation, interpretation of results and reviewing
59
60

1
2
3 405 the manuscript. CP and EE contributed to interpretation of results and reviewing the manuscript. AB
4
5 406 contributed to study conceptualisation, supervision, interpretation of results and reviewing the
6
7 407 manuscript. AJ contributed to study conceptualisation and design, supervision, and writing the
8
9 408 manuscript. TJ had full access to the data in the study and takes responsibility for the integrity of the
10
11 409 data and the accuracy of the data analysis.
12
13
14
15 410

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18
19
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21
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23
24
25
26 414

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32
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34
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36
37 419 Centre at University Hospitals Bristol and Weston NHS Foundation Trust and the University of Bristol.
38
39 420 The views expressed in this article are those of the author(s) and not necessarily those of the NHS,
40
41 421 the NIHR, the Department of Health and Social Care or HDR UK.
42
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46 422

47 48 423 **Ethical Approval**

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50
51 424 Not applicable / No human participants included.
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53
54 425

55 56 426 **Data Sharing**

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2
3 427 The data from the NHS Trust was obtained under the NIHR ARC West Partnership Agreement. The
4
5 428 agreement precludes us from sharing the raw data but it can be published and shared once
6
7 429 aggregated to a non-identifiable level.
8
9

10 430 The data from Hospital Episode Statistics (HES) was obtained under licence (DARS-NIC-17875-X7K1V)
11
12 431 from NHS Digital (previously the Health and Social Care Information Centre); *Copyright © 2022, re-*
13
14 432 *used with the permission of The Health & Social Care Information Centre. All rights reserved.* The
15
16 433 data are provided by patients and collected by the NHS as part of their care and support. HES data
17
18 434 can be accessed via NHS Digital: <https://digital.nhs.uk/services/data-access-request-service-dars>
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436 **Transparency**

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26
27
28 437 The manuscript's guarantor (TJ) affirms that the manuscript is an honest, accurate, and transparent
29
30 438 account of the study being reported; that no important aspects of the study have been omitted; and
31
32 439 that any discrepancies from the study as originally planned have been explained.
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440

441 **Competing Interests**

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40
41 442 All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf
42
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44
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46
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48
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50
51 447 conditions for NIHR, Nuffield Foundation, Warwick CTU, and Versus Arthritis, and a paid expert panel
52
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54
55 449 that might have an interest in the submitted work in the previous three years; no other relationships
56
57 450 or activities that could appear to have influenced the submitted work.
58
59
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FIGURE CAPTIONS

Figure 1. Elective hip (left panel) and knee (right panel) replacement admissions at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 2. Average age on admission for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 3. Proportion of people having hip (left panel) and knee (right panel) replacements with 2+ Charlson comorbidities recorded
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 4. Ratio of public to private provision of elective hip (left panel) and knee (right panel) replacements for NHS patients in the Trust CCG
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Figure 5. Bed occupancy for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis



Figure 1. Elective hip (left panel) and knee (right panel) replacement admissions at the Trust
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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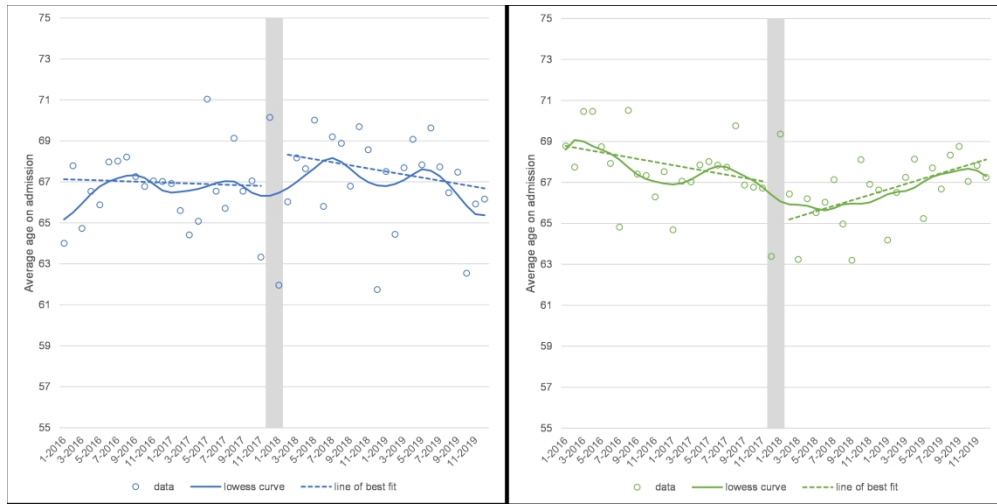


Figure 2. Average age on admission for hip (left panel) and knee (right panel) replacements at the Trust
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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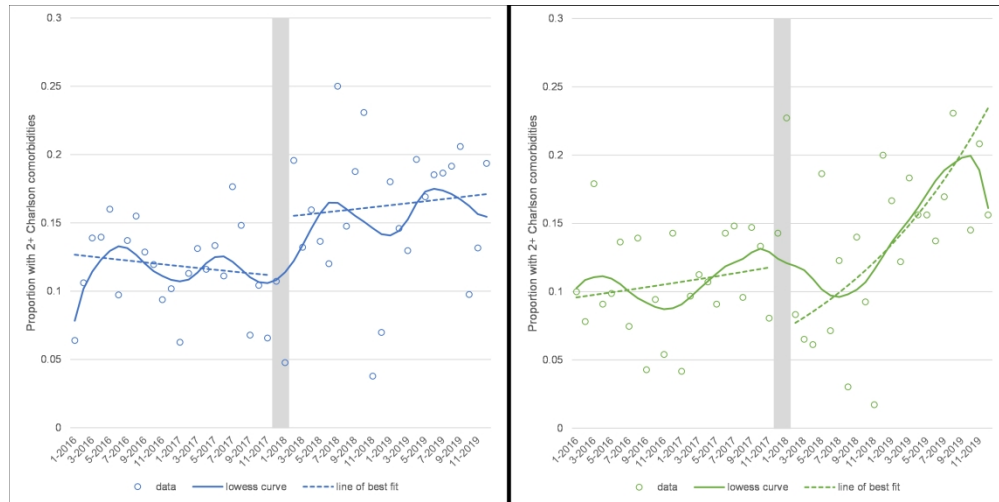


Figure 3. Proportion of people having hip (left panel) and knee (right panel) replacements with 2+ Charlson comorbidities recorded
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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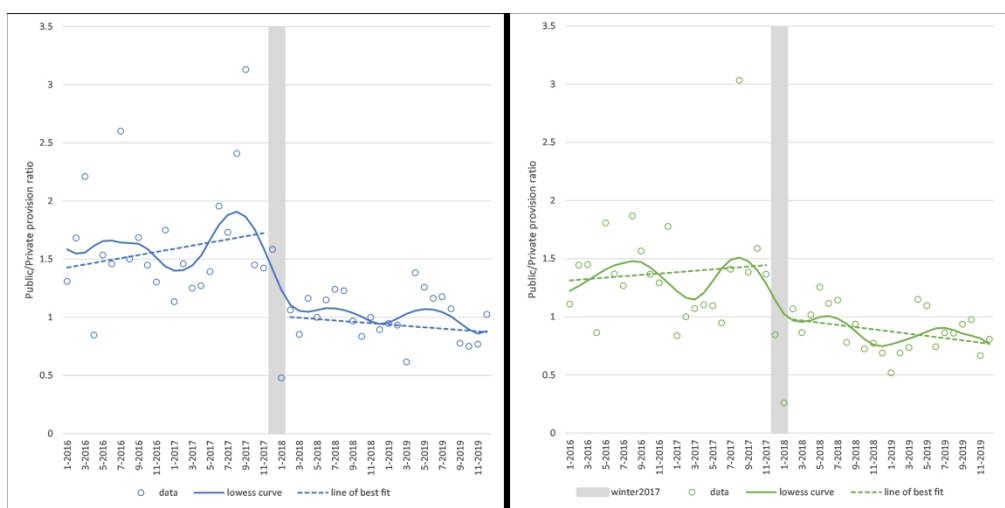


Figure 4. Ratio of public to private provision of elective hip (left panel) and knee (right panel) replacements for NHS patients in the Trust CCG
Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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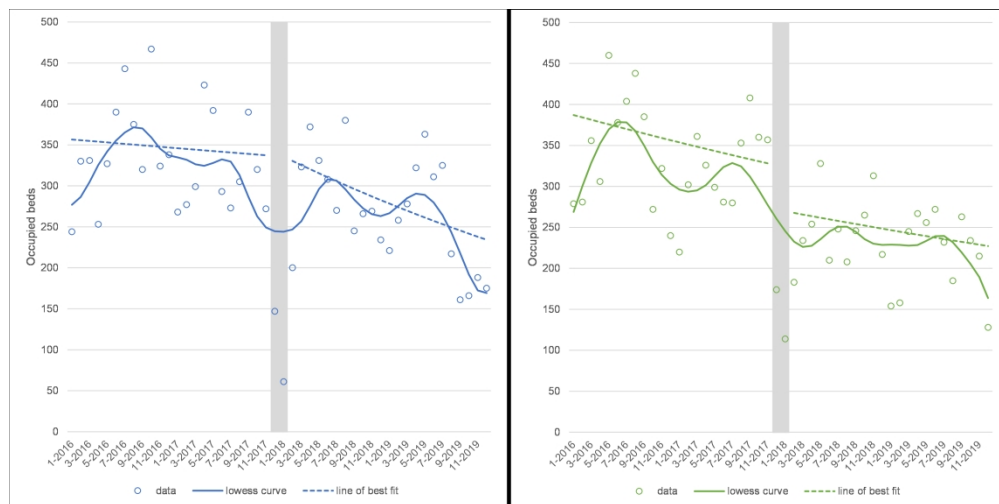
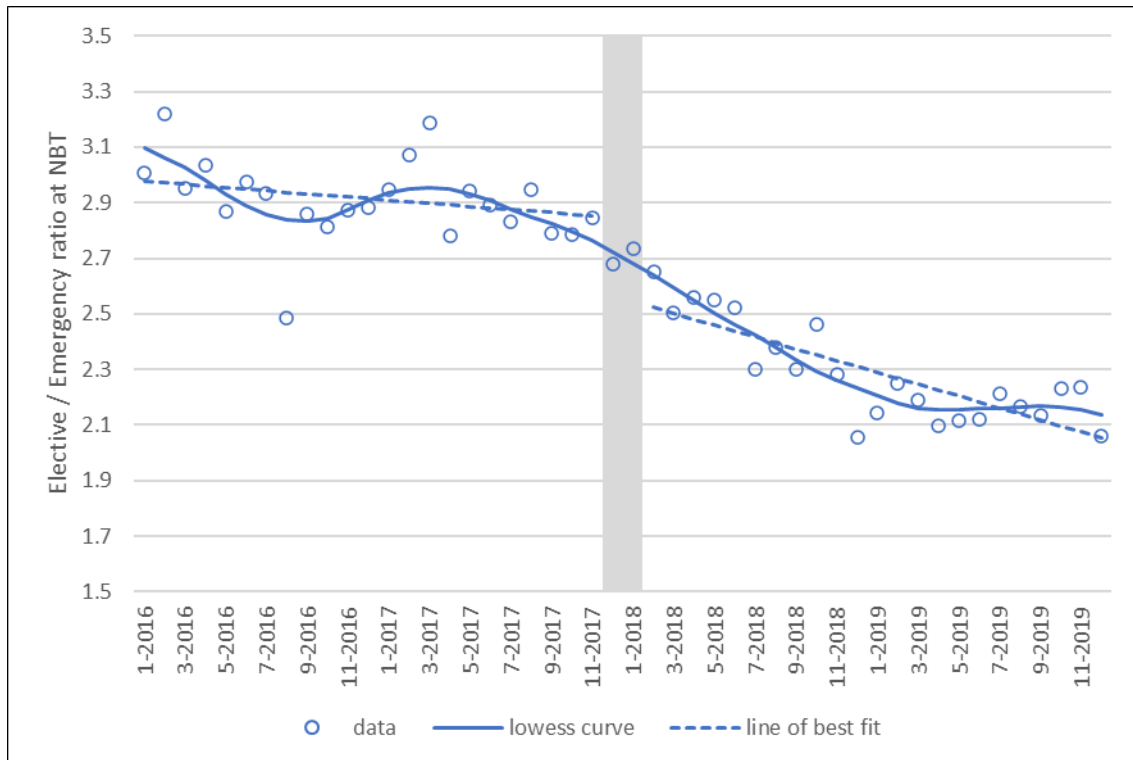


Figure 5. Bed occupancy for hip (left panel) and knee (right panel) replacements at the Trust
 Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

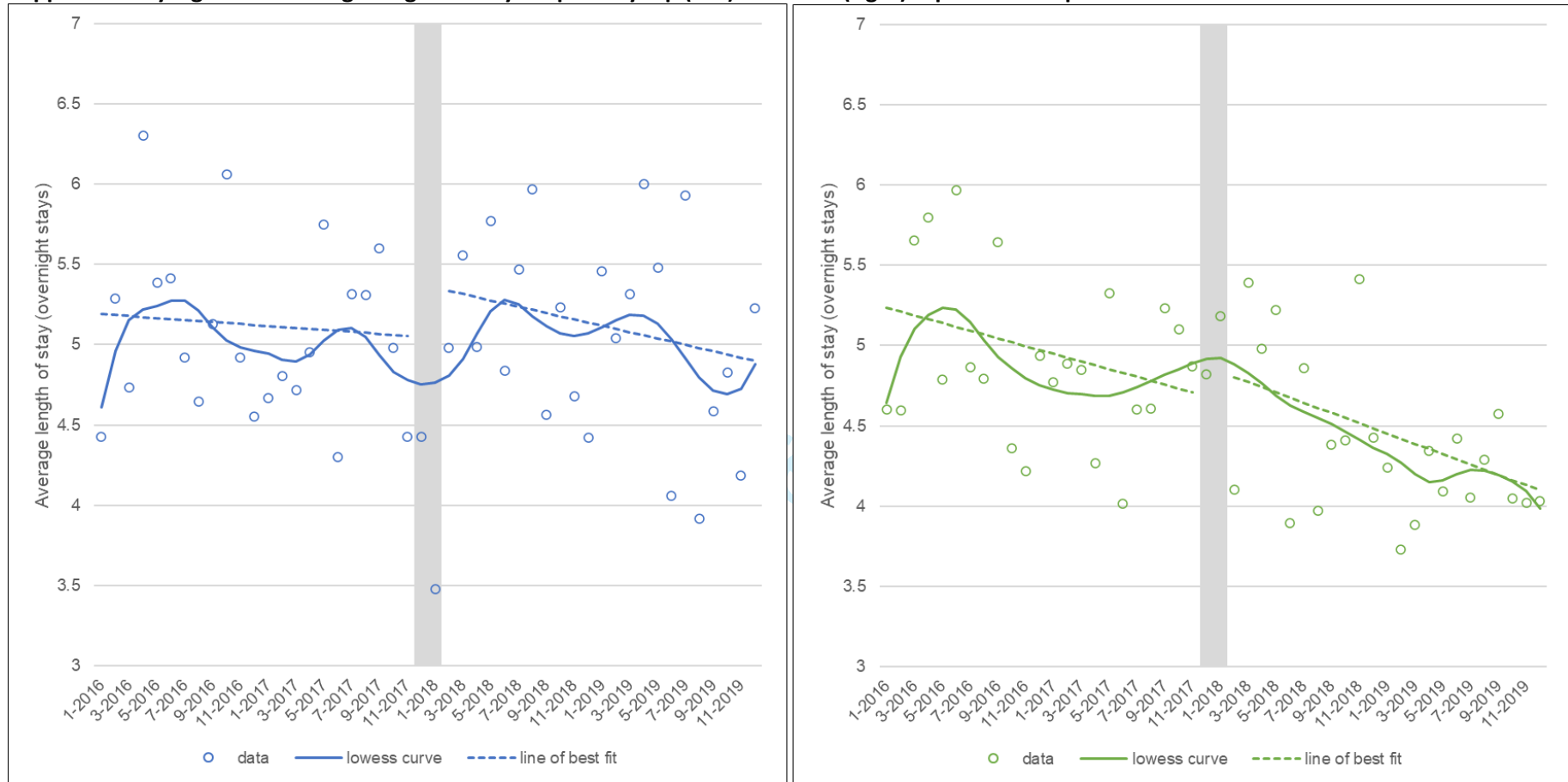
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Supplementary Figure F1. Ratio of elective to emergency hospital admissions for any reason at the Trust



Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

Supplementary Figure F2. Average length of stay for primary hip (left) and knee (right) replacement operations at NBT



Note: grey area shows the winter 2017 cancellations and is excluded from the analysis

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Supplementary Table T1. OPCS-4 codes used to identify primary hip and knee replacement operations

Category	Code	Description	Notes
<i>Primary Total Hip Replacement</i>	W37.1	Primary total prosthetic replacement of hip joint using cement	
	W37.8	Other specified total prosthetic replacement of hip joint using cement	
	W37.9	Unspecified total prosthetic replacement of hip joint using cement	
	W38.1	Primary total prosthetic replacement of hip joint not using cement	
	W38.8	Other specified total prosthetic replacement of hip joint not using cement	
	W38.9	Unspecified total prosthetic replacement of hip joint not using cement	
	W39.1	Primary total prosthetic replacement of hip joint NEC	
	W39.8	Other specified other total prosthetic replacement of hip joint	
	W39.9	Unspecified other total prosthetic replacement of hip joint	
	W43.1	Primary total prosthetic replacement of other joint using cement NEC	
	W43.8	Other specified total prosthetic replacement of other joint using cement NEC	
	W43.9	Unspecified total prosthetic replacement of other joint using cement NEC	
	W44.1	Primary total prosthetic replacement of other joint not using cement NEC	
	W44.8	Other specified total prosthetic replacement of other joint not using cement NEC	
	W44.9	Unspecified total prosthetic replacement of other joint not using cement NEC	
W45.1	Other primary total prosthetic replacement of other joint NEC		
W45.8	Other specified total prosthetic replacement of other joint NEC		
W45.9	Unspecified total prosthetic replacement of other joint NEC		
W52.1	Primary prosthetic replacement of articulation of bone using cement NEC		

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3 W52.8 Other specified prosthetic replacement of articulation of bone using
4 cement NEC
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6 W52.9 Unspecified prosthetic replacement of articulation of bone using
7 cement NEC
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9 W53.1 Primary prosthetic replacement of articulation of bone not using
10 cement NEC
11
12 W53.8 Other specified prosthetic replacement of articulation of bone not
13 using cement NEC
14
15 W53.9 Unspecified prosthetic replacement of articulation of bone not using
16 cement NEC
17
18 W54.1 Primary prosthetic replacement of articulation of bone NEC
19
20 W54.8 Other specified prosthetic replacement of articulation of bone NEC
21
22 W54.9 Unspecified prosthetic replacement of articulation of bone NEC
23
24 W93.1 Primary hybrid prosthetic replacement of hip joint using cemented
25 acetabular component
26
27 W93.8 Other specified hybrid prosthetic replacement of hip joint using
28 cemented acetabular component
29
30 W93.9 Unspecified hybrid prosthetic replacement of hip joint using cemented
31 acetabular component
32
33 W94.1 Primary hybrid prosthetic replacement of hip joint using cemented
34 femoral component
35
36 W94.8 Other specified hybrid prosthetic replacement of hip joint using
37 cemented femoral component
38
39 W94.9 Unspecified hybrid prosthetic replacement of hip joint using cemented
40 femoral component
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42 W95.1 Primary hybrid prosthetic replacement of hip joint using cement NEC
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44 W95.8 Other specified hybrid prosthetic replacement of hip joint using
45 cement
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47 W95.9 Unspecified hybrid prosthetic replacement of hip joint using cement
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3	<i>Primary Total Knee</i>	W40.1	Primary total prosthetic replacement of knee joint using cement
4	<i>Replacement</i>		
5			
6		W40.8	Other specified total prosthetic replacement of knee joint using cement
7			
8		W40.9	Unspecified total prosthetic replacement of knee joint using cement
9		W41.1	Primary total prosthetic replacement of knee joint not using cement
10			
11		W41.8	Other specified total prosthetic replacement of knee joint not using cement
12			
13		W41.9	Unspecified total prosthetic replacement of knee joint not using cement
14			
15		W42.1	Primary total prosthetic replacement of knee joint NEC
16		W42.8	Other specified other total prosthetic replacement of knee joint
17		W42.9	Unspecified other total prosthetic replacement of knee joint
18		O18.1	Primary hybrid prosthetic replacement of knee joint using cement
19		O18.8	Other specified hybrid prosthetic replacement of knee joint using cement
20			
21		O18.9	Unspecified hybrid prosthetic replacement of knee joint using cement
22			
23	<i>Resurfacing / Reconstruction</i>	W58.1	Primary resurfacing arthroplasty of joint
24			Require combination with site + combination codes to ID
25		W58.8	Other specified reconstruction of joint
26			Require combination with site + combination codes to ID
27			
28		W58.9	Unspecified other reconstruction of joint
29			Require combination with site + combination codes to ID
30			
31	<i>Primary unicondylar /</i>	W52.1	Primary prosthetic replacement of articulation of bone using cement
32	<i>unicompartmental knee</i>		Require combination with site + combination codes to ID
33	<i>operations</i>	W52.8	Other specified prosthetic replacement of articulation of other bone using cement
34			Require combination with site + combination codes to ID
35			
36		W52.9	Unspecified prosthetic replacement of articulation of other bone using cement
37			Require combination with site + combination codes to ID
38		W53.1	Primary prosthetic replacement of articulation of bone not using cement NEC
39			Require combination with site + combination codes to ID
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W53.9	Unspecified prosthetic replacement of articulation of other bone not using cement	Require combination with site + combination codes to ID
W54.0	Conversion from previous prosthetic replacement of articulation of bone NEC	Require combination with site + combination codes to ID
W54.1	Primary prosthetic replacement of articulation of bone NEC	Require combination with site + combination codes to ID
W54.8	Other specified other prosthetic replacement of articulation of other bone	Require combination with site + combination codes to ID
W54.9	Unspecified other prosthetic replacement of articulation of other bone	Require combination with site + combination codes to ID

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Supplementary Table T2. Interrupted time series model results with maximum auto-correlation lag 2

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.986,1.004)	0.300	1.055 (0.912,1.221)	0.469	0.991 (0.977,1.006)	0.239	1.19 (1.034,1.37)	0.015	1.207 (1.094,1.332)	0.000	1.101 (0.982,1.234)	0.099
Hip Average Age	-0.015 (-0.102,0.072)	0.737	1.571 (-0.1,3.242)	0.065	-0.06 (-0.175,0.055)	0.307	1.52 (-0.07,3.111)	0.061	2.09 (0.811,3.368)	0.001	1.031 (-0.598,2.66)	0.215
Hip Prop Women	0.999 (0.995,1.003)	0.582	0.966 (0.861,1.083)	0.549	1.007 (0.999,1.016)	0.089	1.023 (0.941,1.111)	0.596	1.088 (1.001,1.183)	0.048	0.981 (0.888,1.083)	0.700
Hip Prop 2+ Charlson	0.994 (0.982,1.007)	0.380	1.411 (1.064,1.873)	0.017	1.01 (0.994,1.027)	0.220	1.195 (0.982,1.455)	0.075	1.306 (1.096,1.557)	0.003	1.003 (0.788,1.276)	0.982
Hip Prop High Deprivation	1.003 (0.993,1.013)	0.587	1.027 (0.869,1.214)	0.754	1.004 (0.986,1.022)	0.660	0.937 (0.815,1.076)	0.358	0.877 (0.752,1.022)	0.093	0.996 (0.84,1.18)	0.963
Hip LoS	-0.006 (-0.034,0.021)	0.660	0.312 (-0.193,0.818)	0.225	-0.014 (-0.047,0.02)	0.425	0.502 (0.214,0.79)	0.001	0.135 (-0.194,0.463)	0.422	0.1 (-0.288,0.488)	0.613
Hip LoS Age 16-59	-0.003 (-0.028,0.021)	0.788	0.379 (-0.094,0.851)	0.116	-0.026 (-0.065,0.013)	0.190	0.223 (-0.156,0.602)	0.249	0.384 (0.065,0.703)	0.018	0.219 (-0.183,0.622)	0.285
Hip LoS Age 60-69	-0.004 (-0.034,0.026)	0.818	0.013 (-0.807,0.832)	0.976	0 (-0.053,0.052)	0.988	0.107 (-0.44,0.654)	0.702	0.158 (-0.468,0.783)	0.621	0.162 (-0.487,0.811)	0.625
Hip LoS Age 70-79	0.006 (-0.058,0.069)	0.862	-0.753 (-2.003,0.497)	0.238	0.007 (-0.06,0.073)	0.847	-0.433 (-1.416,0.549)	0.387	-0.842 (-1.93,0.246)	0.129	-0.865 (-1.991,0.262)	0.132
Hip LoS Age 80+	-0.068 (-0.171,0.036)	0.199	2.109 (0.683,3.535)	0.004	-0.002 (-0.128,0.123)	0.971	1.506 (0.515,2.497)	0.003	0.222 (-0.773,1.217)	0.662	1.003 (-0.229,2.235)	0.111
Hip LoS Men	-0.007 (-0.055,0.041)	0.776	0.347 (-0.583,1.278)	0.464	-0.02 (-0.083,0.043)	0.536	0.293 (-0.126,0.712)	0.170	0.289 (-0.196,0.774)	0.243	0.458 (-0.111,1.026)	0.114
Hip LoS Women	-0.004 (-0.041,0.033)	0.842	0.235 (-0.308,0.778)	0.396	-0.014 (-0.055,0.027)	0.505	0.693 (0.309,1.077)	0.000	0.009 (-0.428,0.446)	0.966	-0.203 (-0.728,0.323)	0.449
Hip LoS Charlson 0	-0.011 (-0.042,0.019)	0.469	0.297 (-0.288,0.882)	0.319	-0.005 (-0.042,0.031)	0.782	0.912 (0.549,1.276)	0.000	0.178 (-0.148,0.503)	0.285	0.222 (-0.065,0.509)	0.129
Hip LoS Charlson 1	0.034 (-0.012,0.08)	0.146	0.238 (-0.709,1.184)	0.623	-0.077 (-0.145,-0.01)	0.024	0.191 (-0.418,0.801)	0.538	0.312 (-0.405,1.029)	0.393	0.014 (-0.578,0.606)	0.963
Hip LoS Charlson 2+	-0.123 (-0.259,0.013)	0.077	0.172 (-2.224,2.569)	0.888	0.116 (-0.016,0.249)	0.085	-0.789 (-2.141,0.563)	0.253	-0.783 (-2.087,0.521)	0.239	0.188 (-2.051,2.427)	0.869
Hip LoS Dep 1	0.004 (-0.032,0.04)	0.829	0.553 (-0.391,1.496)	0.251	-0.017 (-0.068,0.035)	0.529	0.784 (0.107,1.462)	0.023	0.42 (-0.024,0.863)	0.064	0.299 (-0.358,0.956)	0.373
Hip LoS Dep 2	-0.038 (-0.083,0.006)	0.092	0.822 (-0.392,2.035)	0.184	-0.015 (-0.086,0.055)	0.670	1.509 (0.759,2.258)	0.000	0.66 (-0.246,1.567)	0.154	0.589 (-0.417,1.594)	0.251
Hip LoS Dep 3	-0.034 (-0.107,0.038)	0.353	0.617 (-0.897,2.131)	0.424	0.01 (-0.076,0.095)	0.827	-0.216 (-1.224,0.792)	0.675	-0.424 (-1.378,0.53)	0.384	-0.701 (-1.536,0.135)	0.100
Hip LoS Dep 4	0.081 (-0.005,0.166)	0.064	-0.473 (-2.181,1.236)	0.588	-0.112 (-0.215,-0.009)	0.034	-0.374 (-1.65,0.903)	0.566	-1.204 (-2.351,-0.057)	0.040	-0.491 (-1.918,0.935)	0.500
Hip LoS Dep 5	0.015 (-0.086,0.116)	0.773	-0.72 (-2.059,0.62)	0.292	0 (-0.098,0.099)	0.999	0.621 (-0.084,1.327)	0.084	0.689 (-0.31,1.689)	0.176	0.816 (-0.784,2.416)	0.317
Hip Bed Occ	0.997 (0.987,1.008)	0.643	1 (0.844,1.186)	0.997	0.987 (0.97,1.005)	0.149	1.291 (1.11,1.501)	0.001	1.283 (1.125,1.463)	0.000	1.146 (0.988,1.328)	0.071
Hip Public Private	0.013 (-0.015,0.041)	0.377	-0.741 (-1.237,-0.245)	0.003	-0.019 (-0.05,0.011)	0.218	-0.008 (-0.212,0.196)	0.939	0.308 (0.154,0.463)	0.000	0.038 (-0.166,0.241)	0.718
Knee Admissions	0.995 (0.99,1.001)	0.106	0.843 (0.728,0.976)	0.022	1.005 (0.996,1.014)	0.256	1.308 (1.157,1.479)	0.000	1.26 (1.138,1.396)	0.000	1.286 (1.164,1.42)	0.000
Knee Average Age	-0.078 (-0.157,0.001)	0.054	-1.632 (-2.988,-0.276)	0.018	0.211 (0.117,0.305)	0.000	0.926 (-0.112,1.965)	0.080	0.953 (-0.021,1.927)	0.055	0.354 (-0.531,1.24)	0.433
Knee Prop Women	1.004 (0.998,1.01)	0.150	0.96 (0.85,1.084)	0.513	0.994 (0.986,1.003)	0.193	1.037 (0.963,1.117)	0.336	1.017 (0.924,1.118)	0.735	1.036 (0.958,1.12)	0.375
Knee Prop 2+ Charlson	1.009 (0.993,1.026)	0.249	0.638 (0.455,0.894)	0.009	1.042 (1.017,1.067)	0.001	1.156 (0.911,1.467)	0.234	1.074 (0.849,1.359)	0.551	0.909 (0.628,1.315)	0.612
Knee Prop High Deprivation	1.005 (0.997,1.013)	0.189	0.968 (0.786,1.191)	0.758	0.986 (0.974,0.998)	0.021	1.224 (1.077,1.39)	0.002	1.075 (0.942,1.227)	0.282	1.031 (0.902,1.178)	0.656
Knee LoS	-0.024 (-0.049,0.001)	0.058	0.176 (-0.279,0.63)	0.449	-0.008 (-0.036,0.02)	0.566	0.422 (0.073,0.771)	0.018	0.15 (-0.166,0.467)	0.352	0.396 (0.015,0.777)	0.042

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Knee LoS Age 16-59	-0.016 (-0.037,0.006)	0.151	0.403 (-0.045,0.852)	0.078	-0.028 (-0.06,0.005)	0.096	0.484 (0.13,0.839)	0.007	0.422 (-0.021,0.866)	0.062	0.475 (0.19,0.76)	0.001
Knee LoS Age 16-59	0.007 (-0.028,0.043)	0.684	-0.295 (-1.015,0.426)	0.423	-0.026 (-0.072,0.02)	0.262	0.069 (-0.46,0.599)	0.797	-0.194 (-0.687,0.3)	0.441	-0.096 (-0.725,0.532)	0.764
Knee LoS Age 70-79	-0.009 (-0.057,0.038)	0.705	0.77 (0.002,1.538)	0.049	-0.054 (-0.11,0.003)	0.061	-0.086 (-0.715,0.542)	0.787	-0.552 (-1.163,0.059)	0.077	0.367 (-0.352,1.085)	0.317
Knee LoS Age 80+	-0.051 (-0.118,0.015)	0.131	-0.562 (-2.298,1.173)	0.525	0.028 (-0.081,0.137)	0.612	1.521 (0.03,3.011)	0.046	1.37 (0.169,2.57)	0.025	1.361 (0.496,2.227)	0.002
Knee LoS Men	-0.007 (-0.031,0.018)	0.581	0.096 (-0.405,0.597)	0.708	-0.033 (-0.068,0.002)	0.064	0.082 (-0.367,0.531)	0.720	0.157 (-0.262,0.575)	0.464	0.205 (-0.221,0.631)	0.346
Knee LoS Women	-0.042 (-0.084,0)	0.052	0.252 (-0.461,0.966)	0.488	0.017 (-0.029,0.063)	0.478	0.635 (0.048,1.223)	0.034	0.15 (-0.397,0.698)	0.590	0.49 (-0.17,1.151)	0.146
Knee LoS Charlson 0	-0.021 (-0.046,0.004)	0.095	0.067 (-0.362,0.495)	0.760	-0.011 (-0.045,0.024)	0.545	0.645 (0.334,0.956)	0.000	0.193 (-0.111,0.497)	0.213	0.415 (0.069,0.76)	0.019
Knee LoS Charlson 1	-0.03 (-0.074,0.015)	0.191	0.47 (-0.391,1.331)	0.284	-0.029 (-0.083,0.025)	0.298	0.455 (-0.043,0.953)	0.073	0.324 (-0.297,0.945)	0.307	1.058 (0.367,1.748)	0.003
Knee LoS Charlson 2+	-0.04 (-0.107,0.028)	0.247	0.407 (-2.28,3.095)	0.766	-0.022 (-0.196,0.151)	0.802	-0.627 (-1.698,0.443)	0.251	-0.949 (-2.342,0.444)	0.182	-1.433 (-2.229,-0.637)	0.000
Knee LoS Dep 1	-0.009 (-0.06,0.041)	0.712	-0.035 (-0.726,0.656)	0.920	-0.008 (-0.073,0.056)	0.800	0.257 (-0.47,0.985)	0.488	0.096 (-0.619,0.811)	0.793	-0.127 (-0.725,0.472)	0.678
Knee LoS Dep 2	-0.019 (-0.06,0.022)	0.358	0.199 (-0.699,1.097)	0.664	-0.043 (-0.098,0.012)	0.124	0.018 (-0.776,0.812)	0.965	-0.731 (-1.49,0.029)	0.059	0.05 (-0.822,0.922)	0.911
Knee LoS Dep 3	0.014 (-0.036,0.064)	0.586	-0.426 (-1.355,0.503)	0.369	-0.036 (-0.106,0.033)	0.302	0.976 (0.061,1.892)	0.036	0.909 (-0.034,1.852)	0.059	0.547 (-0.217,1.312)	0.160
Knee LoS Dep 4	-0.064 (-0.123,-0.004)	0.035	0.634 (-0.293,1.56)	0.180	0.033 (-0.039,0.105)	0.373	0.669 (-0.187,1.525)	0.126	0.617 (0.02,1.214)	0.043	0.852 (-0.208,1.912)	0.115
Knee LoS Dep 5	-0.035 (-0.09,0.021)	0.224	0.709 (-0.303,1.721)	0.170	0.015 (-0.046,0.076)	0.628	0.123 (-0.73,0.976)	0.778	-0.387 (-1.281,0.507)	0.397	1.104 (0.077,2.131)	0.035
Knee Bed Occ	0.993 (0.984,1.002)	0.103	0.834 (0.704,0.989)	0.037	1 (0.989,1.011)	0.993	1.42 (1.297,1.556)	0.000	1.373 (1.218,1.547)	0.000	1.465 (1.312,1.635)	0.000
Knee Public Private	0.006 (-0.02,0.031)	0.667	-0.476 (-1.026,0.074)	0.090	-0.015 (-0.04,0.009)	0.225	0.113 (-0.089,0.314)	0.274	0.276 (0.035,0.517)	0.025	0.131 (-0.071,0.332)	0.205
Elec Emerg Ratio	-0.005 (-0.013,0.002)	0.171	-0.322 (-0.446,-0.198)	0.000	-0.016 (-0.026,-0.005)	0.003	-0.008 (-0.12,0.103)	0.886	-0.053 (-0.182,0.077)	0.424	-0.028 (-0.151,0.096)	0.661

Supplementary Table T3. Interrupted time series model results with maximum auto-correlation lag 0

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.985,1.005)	0.323	1.055 (0.902,1.235)	0.503	0.991 (0.978,1.005)	0.220	1.19 (1.036,1.367)	0.014	1.207 (1.088,1.339)	0.000	1.101 (0.983,1.234)	0.098
Hip Average Age	-0.015 (-0.134,0.104)	0.806	1.571 (-0.863,4.004)	0.206	-0.06 (-0.208,0.088)	0.427	1.52 (-0.079,3.119)	0.062	2.09 (0.685,3.494)	0.004	1.031 (-0.505,2.567)	0.188
Hip Prop Women	0.999 (0.993,1.004)	0.674	0.966 (0.826,1.13)	0.662	1.007 (0.997,1.017)	0.158	1.023 (0.937,1.116)	0.617	1.088 (0.995,1.189)	0.064	0.981 (0.878,1.096)	0.730
Hip Prop 2+ Charlson	0.994 (0.98,1.009)	0.455	1.411 (0.969,2.055)	0.072	1.01 (0.989,1.031)	0.344	1.195 (0.971,1.471)	0.092	1.306 (1.043,1.637)	0.020	1.003 (0.734,1.37)	0.986
Hip Prop High Deprivation	1.003 (0.991,1.014)	0.631	1.027 (0.846,1.247)	0.787	1.004 (0.983,1.025)	0.704	0.937 (0.819,1.072)	0.342	0.877 (0.746,1.03)	0.110	0.996 (0.831,1.193)	0.965
Hip LoS	-0.006 (-0.038,0.026)	0.704	0.312 (-0.262,0.887)	0.287	-0.014 (-0.058,0.03)	0.542	0.502 (0.132,0.872)	0.008	0.135 (-0.292,0.562)	0.537	0.1 (-0.287,0.487)	0.612
Hip LoS Age 16-59	-0.003 (-0.033,0.026)	0.821	0.379 (-0.165,0.922)	0.172	-0.026 (-0.067,0.015)	0.210	0.223 (-0.17,0.617)	0.266	0.384 (0.053,0.715)	0.023	0.219 (-0.168,0.607)	0.267
Hip LoS Age 60-69	-0.004 (-0.046,0.039)	0.871	0.013 (-1.026,1.052)	0.981	0 (-0.069,0.068)	0.990	0.107 (-0.592,0.805)	0.765	0.158 (-0.514,0.829)	0.645	0.162 (-0.588,0.912)	0.672
Hip LoS Age 70-79	0.006 (-0.067,0.078)	0.879	-0.753 (-2.031,0.525)	0.248	0.007 (-0.069,0.082)	0.865	-0.433 (-1.583,0.716)	0.460	-0.842 (-2.028,0.344)	0.164	-0.865 (-2.164,0.435)	0.192
Hip LoS Age 80+	-0.068 (-0.193,0.058)	0.291	2.109 (0.536,3.682)	0.009	-0.002 (-0.16,0.155)	0.977	1.506 (-0.007,3.018)	0.051	0.222 (-1.036,1.48)	0.729	1.003 (-0.375,2.38)	0.154
Hip LoS Men	-0.007 (-0.056,0.042)	0.783	0.347 (-0.58,1.275)	0.463	-0.02 (-0.084,0.044)	0.543	0.293 (-0.283,0.87)	0.319	0.289 (-0.314,0.892)	0.347	0.458 (-0.15,1.066)	0.140
Hip LoS Women	-0.004 (-0.048,0.041)	0.868	0.235 (-0.563,1.033)	0.564	-0.014 (-0.071,0.043)	0.634	0.693 (0.164,1.222)	0.010	0.009 (-0.543,0.562)	0.973	-0.203 (-0.727,0.322)	0.448
Hip LoS Charlson 0	-0.011 (-0.047,0.024)	0.532	0.297 (-0.428,1.023)	0.422	-0.005 (-0.049,0.039)	0.817	0.912 (0.522,1.302)	0.000	0.178 (-0.232,0.587)	0.396	0.222 (-0.135,0.579)	0.223
Hip LoS Charlson 1	0.034 (-0.023,0.091)	0.240	0.238 (-0.704,1.179)	0.621	-0.077 (-0.157,0.002)	0.056	0.191 (-0.562,0.945)	0.619	0.312 (-0.397,1.022)	0.388	0.014 (-0.544,0.572)	0.960
Hip LoS Charlson 2+	-0.123 (-0.266,0.02)	0.092	0.172 (-2.155,2.5)	0.885	0.116 (-0.04,0.273)	0.144	-0.789 (-2.218,0.64)	0.279	-0.783 (-2.108,0.541)	0.246	0.188 (-1.779,2.156)	0.851
Hip LoS Dep 1	0.004 (-0.039,0.047)	0.857	0.553 (-0.509,1.614)	0.307	-0.017 (-0.078,0.045)	0.599	0.784 (0.118,1.451)	0.021	0.42 (-0.084,0.923)	0.102	0.299 (-0.356,0.954)	0.371
Hip LoS Dep 2	-0.038 (-0.087,0.01)	0.124	0.822 (-0.528,2.172)	0.233	-0.015 (-0.103,0.072)	0.730	1.509 (0.797,2.22)	0.000	0.66 (-0.225,1.546)	0.144	0.589 (-0.26,1.437)	0.174
Hip LoS Dep 3	-0.034 (-0.096,0.027)	0.275	0.617 (-1.066,2.3)	0.472	0.01 (-0.09,0.109)	0.851	-0.216 (-1.343,0.912)	0.708	-0.424 (-1.475,0.627)	0.429	-0.701 (-1.667,0.266)	0.155
Hip LoS Dep 4	0.081 (-0.023,0.185)	0.129	-0.473 (-2.643,1.698)	0.670	-0.112 (-0.258,0.034)	0.134	-0.374 (-1.695,0.947)	0.579	-1.204 (-2.409,0.001)	0.050	-0.491 (-1.978,0.995)	0.517
Hip LoS Dep 5	0.015 (-0.112,0.142)	0.819	-0.72 (-2.66,1.221)	0.467	0 (-0.135,0.135)	0.999	0.621 (-0.412,1.655)	0.239	0.689 (-0.485,1.864)	0.250	0.816 (-0.891,2.524)	0.349
Hip Bed Occ	0.997 (0.987,1.009)	0.653	1 (0.824,1.215)	0.997	0.987 (0.972,1.002)	0.097	1.291 (1.125,1.48)	0.000	1.283 (1.129,1.458)	0.000	1.146 (0.984,1.334)	0.080
Hip Public Private	0.013 (-0.015,0.041)	0.377	-0.741 (-1.237,-0.245)	0.003	-0.019 (-0.05,0.011)	0.218	-0.008 (-0.212,0.196)	0.939	0.308 (0.154,0.463)	0.000	0.038 (-0.166,0.241)	0.718
Knee Admissions	0.995 (0.987,1.004)	0.274	0.843 (0.702,1.013)	0.068	1.005 (0.993,1.017)	0.422	1.308 (1.154,1.483)	0.000	1.26 (1.114,1.426)	0.000	1.286 (1.147,1.441)	0.000
Knee Average Age	-0.078 (-0.157,0.001)	0.053	-1.632 (-3.299,0.035)	0.055	0.211 (0.102,0.32)	0.000	0.926 (-0.129,1.981)	0.085	0.953 (-0.257,2.163)	0.123	0.354 (-0.777,1.485)	0.540
Knee Prop Women	1.004 (0.998,1.011)	0.182	0.96 (0.84,1.097)	0.551	0.994 (0.986,1.003)	0.184	1.037 (0.939,1.146)	0.474	1.017 (0.908,1.138)	0.776	1.036 (0.928,1.157)	0.529
Knee Prop 2+ Charlson	1.009 (0.988,1.031)	0.384	0.638 (0.392,1.037)	0.070	1.042 (1.008,1.077)	0.015	1.156 (0.891,1.501)	0.276	1.074 (0.829,1.393)	0.589	0.909 (0.636,1.299)	0.600
Knee Prop High Deprivation	1.005 (0.997,1.014)	0.237	0.968 (0.784,1.195)	0.761	0.986 (0.974,0.998)	0.023	1.224 (1.099,1.363)	0.000	1.075 (0.956,1.209)	0.225	1.031 (0.911,1.166)	0.631
Knee LoS	-0.024 (-0.052,0.004)	0.089	0.176 (-0.352,0.703)	0.515	-0.008 (-0.041,0.025)	0.625	0.422 (0.117,0.726)	0.007	0.15 (-0.174,0.475)	0.364	0.396 (0.027,0.765)	0.036

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Knee LoS Age 16-59	-0.016 (-0.048,0.017)	0.352	0.403 (-0.286,1.093)	0.252	-0.028 (-0.074,0.019)	0.246	0.484 (0.111,0.857)	0.011	0.422 (-0.111,0.956)	0.121	0.475 (0.056,0.893)	0.026
Knee LoS Age 16-59	0.007 (-0.026,0.041)	0.664	-0.295 (-1.22,0.63)	0.532	-0.026 (-0.085,0.033)	0.384	0.069 (-0.465,0.604)	0.799	-0.194 (-0.754,0.366)	0.497	-0.096 (-0.673,0.48)	0.743
Knee LoS Age 70-79	-0.009 (-0.072,0.054)	0.775	0.77 (-0.267,1.807)	0.145	-0.054 (-0.128,0.02)	0.154	-0.086 (-0.782,0.609)	0.808	-0.552 (-1.267,0.163)	0.130	0.367 (-0.528,1.261)	0.421
Knee LoS Age 80+	-0.051 (-0.154,0.051)	0.327	-0.562 (-2.568,1.443)	0.583	0.028 (-0.105,0.161)	0.678	1.521 (-0.076,3.118)	0.062	1.37 (-0.178,2.918)	0.083	1.361 (-0.071,2.794)	0.063
Knee LoS Men	-0.007 (-0.037,0.023)	0.656	0.096 (-0.512,0.704)	0.758	-0.033 (-0.075,0.009)	0.121	0.082 (-0.382,0.547)	0.729	0.157 (-0.272,0.585)	0.474	0.205 (-0.265,0.675)	0.392
Knee LoS Women	-0.042 (-0.088,0.004)	0.071	0.252 (-0.495,1)	0.508	0.017 (-0.036,0.07)	0.536	0.635 (0.107,1.164)	0.019	0.15 (-0.365,0.666)	0.567	0.49 (-0.022,1.003)	0.061
Knee LoS Charlson 0	-0.021 (-0.054,0.012)	0.214	0.067 (-0.49,0.624)	0.814	-0.011 (-0.056,0.034)	0.643	0.645 (0.278,1.013)	0.001	0.193 (-0.146,0.533)	0.265	0.415 (-0.078,0.907)	0.099
Knee LoS Charlson 1	-0.03 (-0.081,0.022)	0.260	0.47 (-0.741,1.681)	0.447	-0.029 (-0.093,0.036)	0.384	0.455 (-0.111,1.021)	0.115	0.324 (-0.426,1.074)	0.398	1.058 (0.262,1.854)	0.009
Knee LoS Charlson 2+	-0.04 (-0.111,0.032)	0.276	0.407 (-2.137,2.951)	0.754	-0.022 (-0.184,0.14)	0.788	-0.627 (-1.883,0.628)	0.327	-0.949 (-2.145,0.247)	0.120	-1.433 (-2.278,-0.589)	0.001
Knee LoS Dep 1	-0.009 (-0.064,0.045)	0.733	-0.035 (-0.918,0.847)	0.937	-0.008 (-0.082,0.066)	0.826	0.257 (-0.443,0.958)	0.471	0.096 (-0.699,0.89)	0.813	-0.127 (-0.786,0.532)	0.706
Knee LoS Dep 2	-0.019 (-0.065,0.026)	0.413	0.199 (-1.031,1.429)	0.751	-0.043 (-0.116,0.031)	0.253	0.018 (-0.822,0.858)	0.967	-0.731 (-1.538,0.077)	0.076	0.05 (-0.819,0.919)	0.910
Knee LoS Dep 3	0.014 (-0.05,0.078)	0.670	-0.426 (-1.892,1.04)	0.569	-0.036 (-0.116,0.043)	0.369	0.976 (-0.09,2.043)	0.073	0.909 (-0.134,1.952)	0.088	0.547 (-0.408,1.503)	0.261
Knee LoS Dep 4	-0.064 (-0.143,0.015)	0.113	0.634 (-0.591,1.858)	0.310	0.033 (-0.057,0.123)	0.474	0.669 (-0.193,1.531)	0.128	0.617 (-0.032,1.266)	0.063	0.852 (-0.138,1.842)	0.092
Knee LoS Dep 5	-0.035 (-0.116,0.047)	0.405	0.709 (-0.701,2.119)	0.324	0.015 (-0.076,0.106)	0.745	0.123 (-0.882,1.128)	0.810	-0.387 (-1.379,0.606)	0.445	1.104 (-0.268,2.476)	0.115
Knee Bed Occ	0.993 (0.984,1.001)	0.074	0.834 (0.711,0.979)	0.027	1 (0.989,1.011)	0.993	1.42 (1.269,1.59)	0.000	1.373 (1.217,1.548)	0.000	1.465 (1.287,1.667)	0.000
Knee Public Private	0.006 (-0.02,0.031)	0.667	-0.476 (-1.026,0.074)	0.090	-0.015 (-0.04,0.009)	0.225	0.113 (-0.089,0.314)	0.274	0.276 (0.035,0.517)	0.025	0.131 (-0.071,0.332)	0.205
Elec Emerg Ratio	-0.005 (-0.013,0.002)	0.167	-0.322 (-0.451,-0.192)	0.000	-0.016 (-0.025,-0.006)	0.001	-0.008 (-0.117,0.101)	0.884	-0.053 (-0.174,0.068)	0.392	-0.028 (-0.128,0.073)	0.591

Supplementary Table T4. Interrupted time series model results with maximum auto-correlation lag 5

	pre-trend		level change		trend change		spring		summer		autumn	
	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p	estimate (95% CI)	p
Hip Admissions	0.995 (0.987,1.003)	0.249	1.055 (0.917,1.215)	0.454	0.991 (0.978,1.005)	0.217	1.19 (1.04,1.362)	0.012	1.207 (1.104,1.32)	0.000	1.101 (0.993,1.221)	0.069
Hip Average Age	-0.015 (-0.094,0.065)	0.714	1.571 (0.241,2.901)	0.021	-0.06 (-0.168,0.048)	0.277	1.52 (-0.178,3.218)	0.079	2.09 (0.818,3.361)	0.001	1.031 (-0.639,2.701)	0.226
Hip Prop Women	0.999 (0.995,1.002)	0.503	0.966 (0.895,1.042)	0.367	1.007 (1.001,1.014)	0.027	1.023 (0.932,1.122)	0.636	1.088 (1,1.184)	0.051	0.981 (0.879,1.094)	0.727
Hip Prop 2+ Charlson	0.994 (0.985,1.004)	0.261	1.411 (1.116,1.785)	0.004	1.01 (1,1.02)	0.042	1.195 (0.979,1.459)	0.079	1.306 (1.111,1.535)	0.001	1.003 (0.792,1.27)	0.981
Hip Prop High Deprivation	1.003 (0.994,1.012)	0.551	1.027 (0.883,1.195)	0.729	1.004 (0.99,1.018)	0.577	0.937 (0.805,1.091)	0.400	0.877 (0.752,1.022)	0.092	0.996 (0.847,1.171)	0.961
Hip LoS	-0.006 (-0.029,0.017)	0.605	0.312 (-0.12,0.745)	0.157	-0.014 (-0.042,0.015)	0.346	0.502 (0.286,0.718)	0.000	0.135 (-0.191,0.461)	0.418	0.1 (-0.332,0.532)	0.650
Hip LoS Age 16-59	-0.003 (-0.026,0.02)	0.773	0.379 (-0.046,0.803)	0.080	-0.026 (-0.062,0.01)	0.152	0.223 (-0.113,0.559)	0.193	0.384 (0.09,0.679)	0.011	0.219 (-0.191,0.63)	0.295
Hip LoS Age 60-69	-0.004 (-0.031,0.024)	0.799	0.013 (-0.766,0.791)	0.975	0 (-0.051,0.05)	0.987	0.107 (-0.33,0.543)	0.632	0.158 (-0.451,0.766)	0.611	0.162 (-0.352,0.676)	0.537
Hip LoS Age 70-79	0.006 (-0.054,0.065)	0.853	-0.753 (-1.944,0.438)	0.215	0.007 (-0.056,0.069)	0.836	-0.433 (-1.343,0.476)	0.350	-0.842 (-1.91,0.226)	0.122	-0.865 (-2.063,0.334)	0.157
Hip LoS Age 80+	-0.068 (-0.147,0.012)	0.097	2.109 (0.803,3.414)	0.002	-0.002 (-0.111,0.107)	0.967	1.506 (0.499,2.513)	0.003	0.222 (-0.799,1.243)	0.670	1.003 (-0.111,2.116)	0.078
Hip LoS Men	-0.007 (-0.047,0.033)	0.732	0.347 (-0.44,1.135)	0.387	-0.02 (-0.073,0.033)	0.458	0.293 (-0.117,0.704)	0.161	0.289 (-0.193,0.771)	0.239	0.458 (-0.163,1.079)	0.149
Hip LoS Women	-0.004 (-0.035,0.028)	0.816	0.235 (-0.271,0.741)	0.362	-0.014 (-0.046,0.018)	0.391	0.693 (0.395,0.991)	0.000	0.009 (-0.421,0.439)	0.966	-0.203 (-0.762,0.357)	0.477
Hip LoS Charlson 0	-0.011 (-0.039,0.016)	0.418	0.297 (-0.242,0.837)	0.280	-0.005 (-0.035,0.025)	0.738	0.912 (0.617,1.208)	0.000	0.178 (-0.123,0.478)	0.247	0.222 (-0.066,0.51)	0.131
Hip LoS Charlson 1	0.034 (0.003,0.065)	0.030	0.238 (-0.604,1.08)	0.580	-0.077 (-0.137,-0.018)	0.011	0.191 (-0.385,0.767)	0.515	0.312 (-0.431,1.056)	0.410	0.014 (-0.563,0.591)	0.962
Hip LoS Charlson 2+	-0.123 (-0.239,-0.007)	0.038	0.172 (-1.97,2.314)	0.875	0.116 (0.005,0.228)	0.040	-0.789 (-2.189,0.611)	0.269	-0.783 (-2.119,0.553)	0.250	0.188 (-2.176,2.552)	0.876
Hip LoS Dep 1	0.004 (-0.029,0.037)	0.814	0.553 (-0.303,1.408)	0.206	-0.017 (-0.065,0.032)	0.501	0.784 (0.131,1.437)	0.019	0.42 (-0.034,0.874)	0.070	0.299 (-0.401,0.999)	0.402
Hip LoS Dep 2	-0.038 (-0.083,0.006)	0.092	0.822 (-0.167,1.81)	0.103	-0.015 (-0.078,0.047)	0.630	1.509 (0.737,2.28)	0.000	0.66 (-0.202,1.522)	0.133	0.589 (-0.461,1.638)	0.272
Hip LoS Dep 3	-0.034 (-0.102,0.033)	0.319	0.617 (-0.789,2.023)	0.390	0.01 (-0.072,0.091)	0.819	-0.216 (-1.011,0.579)	0.595	-0.424 (-1.293,0.445)	0.339	-0.701 (-1.351,-0.05)	0.035
Hip LoS Dep 4	0.081 (0.017,0.144)	0.013	-0.473 (-1.858,0.913)	0.504	-0.112 (-0.189,-0.035)	0.004	-0.374 (-1.59,0.842)	0.547	-1.204 (-2.355,-0.053)	0.040	-0.491 (-1.989,1.007)	0.520
Hip LoS Dep 5	0.015 (-0.056,0.085)	0.682	-0.72 (-1.647,0.208)	0.128	0 (-0.07,0.07)	0.998	0.621 (-0.104,1.347)	0.093	0.689 (-0.25,1.629)	0.150	0.816 (-0.696,2.329)	0.290
Hip Bed Occ	0.997 (0.987,1.008)	0.627	1 (0.862,1.161)	0.996	0.987 (0.97,1.004)	0.128	1.291 (1.116,1.492)	0.001	1.283 (1.14,1.444)	0.000	1.146 (0.99,1.326)	0.068
Hip Public Private	0.013 (-0.015,0.041)	0.377	-0.741 (-1.237,-0.245)	0.003	-0.019 (-0.05,0.011)	0.218	-0.008 (-0.212,0.196)	0.939	0.308 (0.154,0.463)	0.000	0.038 (-0.166,0.241)	0.718
Knee Admissions	0.995 (0.992,0.999)	0.016	0.843 (0.761,0.934)	0.001	1.005 (0.998,1.012)	0.170	1.308 (1.154,1.482)	0.000	1.26 (1.16,1.369)	0.000	1.286 (1.178,1.403)	0.000
Knee Average Age	-0.078 (-0.152,-0.005)	0.037	-1.632 (-2.825,-0.439)	0.007	0.211 (0.128,0.293)	0.000	0.926 (-0.072,1.924)	0.069	0.953 (0.077,1.829)	0.033	0.354 (-0.422,1.13)	0.371
Knee Prop Women	1.004 (0.999,1.009)	0.086	0.96 (0.861,1.071)	0.465	0.994 (0.987,1.001)	0.097	1.037 (0.973,1.105)	0.260	1.017 (0.922,1.121)	0.743	1.036 (0.966,1.111)	0.319
Knee Prop 2+ Charlson	1.009 (0.993,1.026)	0.250	0.638 (0.468,0.869)	0.004	1.042 (1.021,1.064)	0.000	1.156 (0.931,1.436)	0.190	1.074 (0.841,1.372)	0.567	0.909 (0.626,1.321)	0.617
Knee Prop High Deprivation	1.005 (0.999,1.011)	0.107	0.968 (0.835,1.122)	0.664	0.986 (0.977,0.995)	0.003	1.224 (1.082,1.384)	0.001	1.075 (0.95,1.217)	0.251	1.031 (0.924,1.149)	0.586
Knee LoS	-0.024 (-0.047,-0.001)	0.042	0.176 (-0.2,0.551)	0.360	-0.008 (-0.031,0.015)	0.490	0.422 (0.033,0.81)	0.033	0.15 (-0.199,0.499)	0.398	0.396 (-0.011,0.803)	0.057

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Knee LoS Age 16-59	-0.016 (-0.032,0.001)	0.068	0.403 (0.008,0.799)	0.046	-0.028 (-0.059,0.003)	0.081	0.484 (0.198,0.77)	0.001	0.422 (-0.01,0.855)	0.056	0.475 (0.216,0.734)	0.000
Knee LoS Age 16-59	0.007 (-0.018,0.033)	0.571	-0.295 (-0.854,0.265)	0.302	-0.026 (-0.062,0.009)	0.147	0.069 (-0.455,0.593)	0.795	-0.194 (-0.652,0.265)	0.407	-0.096 (-0.713,0.52)	0.759
Knee LoS Age 70-79	-0.009 (-0.045,0.027)	0.616	0.77 (0.101,1.439)	0.024	-0.054 (-0.096,-0.012)	0.012	-0.086 (-0.736,0.563)	0.794	-0.552 (-1.116,0.012)	0.055	0.367 (-0.3,1.034)	0.281
Knee LoS Age 80+	-0.051 (-0.097,-0.006)	0.026	-0.562 (-1.849,0.724)	0.391	0.028 (-0.062,0.119)	0.541	1.521 (0.119,2.923)	0.034	1.37 (0.391,2.349)	0.006	1.361 (0.617,2.106)	0.000
Knee LoS Men	-0.007 (-0.028,0.014)	0.514	0.096 (-0.297,0.488)	0.633	-0.033 (-0.062,-0.004)	0.024	0.082 (-0.416,0.58)	0.746	0.157 (-0.244,0.558)	0.444	0.205 (-0.149,0.559)	0.256
Knee LoS Women	-0.042 (-0.079,-0.005)	0.027	0.252 (-0.356,0.861)	0.416	0.017 (-0.018,0.052)	0.350	0.635 (-0.036,1.307)	0.064	0.15 (-0.454,0.754)	0.625	0.49 (-0.258,1.239)	0.199
Knee LoS Charlson 0	-0.021 (-0.044,0.002)	0.077	0.067 (-0.312,0.446)	0.730	-0.011 (-0.036,0.015)	0.419	0.645 (0.331,0.959)	0.000	0.193 (-0.129,0.516)	0.240	0.415 (0.075,0.754)	0.017
Knee LoS Charlson 1	-0.03 (-0.064,0.005)	0.092	0.47 (-0.199,1.139)	0.169	-0.029 (-0.067,0.01)	0.145	0.455 (-0.097,1.007)	0.106	0.324 (-0.341,0.988)	0.340	1.058 (0.384,1.731)	0.002
Knee LoS Charlson 2+	-0.04 (-0.092,0.012)	0.134	0.407 (-1.956,2.771)	0.736	-0.022 (-0.184,0.14)	0.789	-0.627 (-1.625,0.37)	0.218	-0.949 (-2.374,0.476)	0.192	-1.433 (-2.175,-0.691)	0.000
Knee LoS Dep 1	-0.009 (-0.05,0.031)	0.644	-0.035 (-0.656,0.586)	0.911	-0.008 (-0.059,0.043)	0.750	0.257 (-0.541,1.056)	0.527	0.096 (-0.581,0.772)	0.782	-0.127 (-0.724,0.47)	0.677
Knee LoS Dep 2	-0.019 (-0.055,0.017)	0.300	0.199 (-0.57,0.968)	0.612	-0.043 (-0.086,0)	0.049	0.018 (-0.731,0.767)	0.962	-0.731 (-1.507,0.046)	0.065	0.05 (-0.887,0.987)	0.917
Knee LoS Dep 3	0.014 (-0.031,0.059)	0.544	-0.426 (-1.102,0.25)	0.217	-0.036 (-0.095,0.022)	0.220	0.976 (0.281,1.672)	0.006	0.909 (-0.067,1.886)	0.068	0.547 (-0.12,1.215)	0.108
Knee LoS Dep 4	-0.064 (-0.127,-0.001)	0.047	0.634 (-0.165,1.432)	0.120	0.033 (-0.04,0.106)	0.380	0.669 (-0.076,1.414)	0.079	0.617 (0.007,1.227)	0.047	0.852 (-0.274,1.978)	0.138
Knee LoS Dep 5	-0.035 (-0.087,0.018)	0.194	0.709 (-0.225,1.643)	0.137	0.015 (-0.042,0.072)	0.606	0.123 (-0.701,0.947)	0.770	-0.387 (-1.304,0.531)	0.409	1.104 (0.188,2.02)	0.018
Knee Bed Occ	0.993 (0.986,0.999)	0.032	0.834 (0.728,0.956)	0.009	1 (0.991,1.009)	0.991	1.42 (1.308,1.542)	0.000	1.373 (1.213,1.553)	0.000	1.465 (1.318,1.627)	0.000
Knee Public Private	0.006 (-0.02,0.031)	0.667	-0.476 (-1.026,0.074)	0.090	-0.015 (-0.04,0.009)	0.225	0.113 (-0.089,0.314)	0.274	0.276 (0.035,0.517)	0.025	0.131 (-0.071,0.332)	0.205
Elec Emerg Ratio	-0.005 (-0.013,0.003)	0.198	-0.322 (-0.455,-0.189)	0.000	-0.016 (-0.026,-0.005)	0.004	-0.008 (-0.107,0.091)	0.872	-0.053 (-0.18,0.074)	0.414	-0.028 (-0.163,0.108)	0.690

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract P2 L35-37 Abstract P2 L35-38
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Introduction P4-5 L76-113
Objectives	3	State specific objectives, including any prespecified hypotheses			Introduction P5 L107-113
Methods					
Study Design	4	Present key elements of study design early in the paper			Methods P5 L116-119
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Methods P5 L116-119 Methods P7-8 L70-176

<p>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27</p> <p>Participants</p>	<p>6</p>	<p>(a) <i>Cohort study</i> - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> - Give the eligibility criteria, and the sources and methods of selection of participants</p> <p>(b) <i>Cohort study</i> - For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> - For matched studies, give matching criteria and the number of controls per case</p>		<p>RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided.</p> <p>RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided.</p> <p>RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.</p>	<p>Methods P6 L141-147 Supplementary Table T1</p>
<p>28 29 30 31 32 33 34</p> <p>Variables</p>	<p>7</p>	<p>Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.</p>		<p>RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.</p>	<p>Methods P6-7 L141-169</p>
<p>35 36 37 38 39 40 41 42</p> <p>Data sources/ measurement</p>	<p>8</p>	<p>For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group</p>			<p>Methods P5-6 L120-140</p>

1 2 3 4	Bias	9	Describe any efforts to address potential sources of bias		Methods P7-8 L170-185,
5 6 7 8 9	Study size	10	Explain how the study size was arrived at		Methods P6 L141-147
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why		Methods P6-7 L141-169
35 36 37 38 39 40 41 42 43 44 45 46 47	Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) <i>Cohort study</i> - If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses		Methods P7-8 L170-185
	Data access and cleaning methods		..	RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	Data Sharing P17 L392-400

				RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	Methods P6-7 L141-169
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (<i>e.g.</i> , numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (<i>i.e.</i> , study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Methods P6 L141-147 Results P8 L191-194
Descriptive data	14	(a) Give characteristics of study participants (<i>e.g.</i> , demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) <i>Cohort study</i> - summarise follow-up time (<i>e.g.</i> , average and total amount)			Results P8 L191-194
Outcome data	15	<i>Cohort study</i> - Report numbers of outcome events or summary measures over time <i>Case-control study</i> - Report numbers in each exposure			Results P8-9 L195-206

		category, or summary measures of exposure <i>Cross-sectional study</i> - Report numbers of outcome events or summary measures			
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Results P9-11 L196-267
Other analyses	17	Report other analyses done— e.g., analyses of subgroups and interactions, and sensitivity analyses			Results P9-11 L196-267
Discussion					
Key results	18	Summarise key results with reference to study objectives			Discussion P11-12, L268-288
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	Discussion P12-13 L289-303
Interpretation	20	Give a cautious overall interpretation of results considering objectives,			Discussion P13-14 L317-340

		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			
Generalisability	21	Discuss the generalisability (external validity) of the study results			Discussion P13 L294-303
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based			Funding Statement P16 L375-380
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Methods P8 L186-188 Data Sharing P17 L392-400

*Reference: Benchimol EI, Smeeth L, Guttman A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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