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National trends in emergency readmission rates: A longitudinal analysis of administrative data for England between 2006 and 2016.

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National trends in emergency readmission rates: A longitudinal analysis of administrative data for England between 2006 and 2016.

Rocco Friebel[1 2], Katharina Hauck[1], Paul Aylin[1] and Adam Steventon[2]

[1] School of Public Health, Imperial College London, South Kensington Campus, London, SW7 2AZ

[2] Data Analytics, The Health Foundation, 90 Long Acre, London, WC2E 9RA

Rocco Friebel, Doctoral Researcher; Data Analyst

Katharina Hauck, Senior Lecturer in Health Economics

Paul Aylin, Professor of Epidemiology and Public Health

Adam Steventon, Director of Data Analytics

Correspondence to: rocco.friebel@health.org.uk, 0207 257 8000

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ABSTRACT

Objective: To assess trends in 30-day emergency readmission rates across England over one decade.

Design: Retrospective study design.

Setting: 150 non-specialist hospital trusts in England.

Participants: 22,979,374 patients above 18 years of age who were readmitted following an initial admission (n = 68,648,640) between April 2006 and February 2016.

Primary and secondary outcomes: We examined emergency admissions that occurred within 30 days of discharge from hospital ("emergency readmissions") as a measure of healthcare quality. Presented are overall readmissions, and disaggregated by type of admission and by clinical condition at first admission. All rates were risk-adjusted for patient age, gender, ethnicity, socioeconomic status, comorbidities and length of stay.

Results: The average risk-adjusted, 30-day readmission rate decreased from 6.37% in 2006/07 to 6.00% in 2015/16 (p<0.01), peaking at 6.57% in 2011/12. Emergency readmissions for patients discharged following elective procedures decreased by 0.58% (p<0.01), while those following emergency admission increased slightly by 0.30% (p<0.01). Readmission rates for hip- or knee replacements decreased (-1.64%; p <0.001), for COPD (-0.72%; p <0.001), heart failure -0.07%; p <0.01), and acute myocardial infarction (+0.47%; p <0.001) remained stable, and for diabetes (+6.07%; p <0.001), pneumonia (+2.93%; p<0.001), cholecystectomy (+1.46; p <0.001), stroke (+1.39%; p<0.001), and hysterectomy (+1.42%; p <0.001) increased.

Conclusions: There were encouraging signs of improvements in healthcare quality provided to patients across England. However, there were large variations in trends across clinical areas, with some experiencing marked increases in readmission rates. This highlights the need for targeted interventions to achieve highest standards of care quality for all patients.

Keywords: Quality of Care; Readmission Rates; Variation in Quality of Care

Strengths and limitations of this study

- This study uses a large administrative health data source, possibly capturing all patients entering the English NHS between 2006 and 2016.
- Unlike previous studies, we provider an overview of changes in readmission rates and variation for all patients, and for nine clinical subgroups.
- In this study, we provide an estimation of the unobservable part of the variation that is due to hospital characteristics.
- Wile readmission rates have been previously used as a measure for healthcare quality due to being associated with quality of care provided along the patient pathway, their validity as a quality metric is contested, and other measures should be considered.
- This study examines trends in readmissions and variation over time, but provides no impact assessment of policies aimed at reducing readmission rates across the observation period.

INTRODUCTION

Ensuring that patients receive appropriate and high-quality care in hospitals followed by an efficient discharge in a way that leads to the best possible outcomes is a priority for the English National Health Service (NHS).[1] Despite this objective, care received by patients remains variable in quality across England,[2] and while some of this variation may be explained by differences in patients' complexity and medical needs;[3] the unwarranted variation due to suboptimal care quality is associated with unnecessary harm to patients.[4] It is a key priority of the NHS to close this 'quality gap', which was outlined in the NHS Five Year Forward View[5] and addressed through initiatives such as the Right Care Programme[6] and Getting it Right First Time.[7]

Emergency hospital readmission rates are widely used for measuring health system performance.[8–10] Despite their limitations,[11] there is now mounting evidence that they are correlated with quality of care provided to patients along the clinical pathway. This includes quality of care at the initial hospital stay,[12] transitional care services[13–15] and post-discharge support.[16,17] Emergency readmission rates were incorporated into quality frameworks across several health care systems (e.g. United States, Denmark, Germany, and England),[18] with numerous national-level policies aimed at reducing readmissions in an attempt to improve quality of care. For example, in England, the governmental white paper: *Equity and Excellence: Liberating the English NHS*,[19] led to the implementation of policies directly aiming at reducing readmission rates, including via financial penalties for hospitals reporting excess emergency readmissions.

Previous research on readmissions analysed trends at the national level by aggregating across all hospitals.[20] While national readmission trends can indicate whether progress was made in improving quality of care overall in the healthcare systems, an aggregate analysis masks differences in the rate of progress for specific hospitals and patient groups. Analyses in the aggregate offer little value for the identification of providers and clinical areas that require specific policy attention, and works counter the government's credo to provide high quality health care for all patients no matter what hospitals they attend. Therefore, in addition to investigating national trends in readmissions, examining variation in health care quality between providers and for different patient groups helps to uncover additional dimensions in care quality, which can direct policy makers in implementing future improvement efforts in a more targeted fashion. To measure variation in readmission rates across hospitals we used the systematic component of variation (SCV).[21] This is a commonly applied measure of variation in health system performance.[22–24] To measure variation in readmission rates across clinical areas, we undertook separate analyses of 9 patient groups with specific conditions and procedures. We used a large dataset consisting of the medical records of all patients admitted to the population of English hospitals over 10 years. This study provides one of the most comprehensive assessments of trends in readmission rates in England.

METHODS

Study population

Our analysis included a total of 22,979,374 patients admitted between April 2006 and February 2016 to 150 non-specialist NHS trusts. Trusts are healthcare providers that typically manage multiple hospital sites. We obtained the patients' health care records from the administrative Hospital Episode Statistics (HES) database. HES contains information on patient demographics, diagnoses and treatment. For each patient, we constructed linked health records from the patients' admission to discharge, even when patients changed hospital as part of the hospital stay.[25,26] We studied all adult patients discharged from a non-specialist NHS trust between 1 April 2006 and 29 February 2016, following any elective (*i.e.* planned) or emergency (*i.e.* unplanned) indexed (*i.e.* original or first) admission. This included patients admitted with an indexed admission as a day-case to account for health system trends that shifted care from an inpatient to an outpatient setting during the 10 years.[27] Patients discharged in March 2016 were removed from the study sample to allow for a sufficient follow-up period required to calculate 30-day readmission rates within the scope of available data. We also excluded the following patients (n= 17,702,522/40,972,164): below 18 years of age, without complete records of variables required for risk-adjustment (see below), and maternity cases. We also excluded any patient not surviving their stay in hospital (n= 290,268/23,269,642). Where a patient experienced multiple admissions, we treated each admission as an indexed admission provided they occurred more than 30 days from each other.

We followed the definition used by policy makers in England for identifying emergency readmissions from administrative health records,[28] which are described as any all-cause, emergency admission with a method of admission via Accident and Emergency department (A&E); general practitioner; Bed Bureau; consultant outpatient clinic; other means, such as arriving via A&E of another provider where the patient had not been admitted, and occurring within 30-days of discharge from an indexed admission. We focussed on a period of 30-days following discharge from any indexed admission as this reflects common practice in policy evaluation, and we only counted the first emergency readmission for patients experiencing multiple emergency readmissions within the 30-day period. Emergency readmissions may have comprised of readmissions for conditions unrelated to the indexed admission.

We first calculated yearly national readmission rates by averaging across hospital-specific readmission rates. We then examined yearly trends in readmissions for patients with 9 specific conditions. Patients' experience with the health care system is likely to differ with medical condition. For example long-term conditions are usually managed in primary care settings, while acute conditions require hospital admissions and rehabilitative care. We used the HES recorded primary diagnoses codes (International Classification of Diseases 10th edition, or ICD-10) and procedure codes (Classification of Intervention and Procedure Codes, or OPCS-4) to identify patients for subgroup analyses. The selection of acute conditions and chronic conditions was based on research identifying the leading causes for hospital bed use in the NHS,[29] and as a result we included acute myocardial infarction, stroke and pneumonia as acute conditions; we chose congestive heart failure, chronic obstructive pulmonary disease (COPD) and diabetes mellitus as chronic conditions. For surgical interventions, we focussed on commonly performed surgeries in the English NHS, which also capture several surgical subsections.[30] Thus, we selected cholecystectomy, total hip and knee replacement and hysterectomy. The full list of applied ICD-10 codes and OPCS-4 codes is presented in the Supplementary Appendix A.

Statistical analysis

We first estimated the average observed emergency readmission rate (OR) for each trust and financial year by aggregating from the patient-level. To remove variation in readmission rates that is not due to suboptimal care, we adjusted for systematic differences in patient complexity across trusts based on clinical conditions recorded in each patients' record. We then estimated the predicted emergency readmission rates (ER) for each trust and financial year by performing a logistic regression at the patient-level. We used patient case-mix information, including patient age on admission, gender, ethnicity, socioeconomic deprivation score (Index of Multiple Deprivation version 2010 based on small geographic areas, each containing on average 1,500 residents),[31] length of stay, and comorbidities measured by the Charlson Index.[32] This index was constructed based on diagnoses codes recorded at the indexed admission and during previous admissions that occurred within one year. Because the Charlson index may be affected by changes in how health conditions are recorded in HES,[33] we entered interaction terms between the Charlson index and financial year into our logistic regression model. To calculate the risk-adjusted, 30-day emergency readmission rate for each trust and financial year, we divided *OR* by *ER* to assess whether the trust performed below or above what would be expected given patient case-mix. We then multiplied this ratio for each trust and financial year by the average emergency readmission rate observed at the national-level in that financial year.

The amount of variation in 30-day, emergency readmission rates in England for each financial year was calculated with the SCV methodology developed by [21] (see Appendix B). The SCV can be described as the variance of the ratios of *OR* and *ER*, minus the random component caused by Poisson variability,[34] times 100. This provided us with one SCV measure for each financial year. The SCV measures the degree of variation caused by time-invariant unobservable characteristics related to the hospitals or the populations in their catchment area that are leading some hospitals to diverge from the average national emergency readmission rate. A high SCV means that hospitals in that year have very different readmission rates due to unobservable characteristics that we cannot explain. These can be interpreted as unobservable characteristics that are constant over time, and make a hospital perform above or below the national average in terms of readmissions. Unobservable hospital characteristics could be good or bad management practices, staff satisfaction, whereas unobservable population characteristics could be socioeconomic factors that affect medical need.[26] The estimated SCV score can be categorised into three distinct groups. A SCV score below 3 indicates small variation in emergency readmission rates; a score between 5.4 and 10.0 indicates high variation in emergency readmission rates; and a score above 10.0 indicates very high variation in emergency readmission rates.[22,35,36] Other studies have suggested a value above 16 to indicate high variability,[37] while one study that investigated variation in access to health services commissioned by the National Specialised Commissioning Team in England, suggested high variability above a cut-off point of 20.[38]

To test whether trends in risk-adjusted, 30-day emergency readmission rates and the SCV changed across financial years, we estimated two separate regression models with ordinary least squares estimators. For each model, we used the risk-adjusted, 30-day emergency readmission rate and the SCV as dependent variable, respectively and entered time dummies for each financial year, omitting financial year 2006/07 as the baseline case. The direction of the coefficient estimates showed whether the readmission rate and SCV score in a respective financial year is significantly different from the values observed in financial year 2006/07.

We conducted sensitivity analyses using alternative time-windows for emergency readmissions within 7 days and 90 days. In addition to the SCV, we also report the standard deviation as an alternative measure of variation. We used SAS Enterprise Miner for the initial data extraction and the statistical analysis was conducted using STATA version 13.

RESULTS

Study sample

Our analysis included a total of 68,648,640 (n = 22,979,374 patients) indexed admissions (corresponding to 47,606 indexed admissions per trust per year, with a range from 1,144 to 121,699), suggesting that several patients experienced multiple indexed admissions across the observation period. The characteristics of all patients admitted to hospital changed slightly between 2006/07 and 2015/16 (see Table 1). For example, the average patient age increased across the study period, from 54.8 years in 2006/7 to 59.8 years in 2015/16 (p <0.001). Similarly, the average number of comorbidities measured by the Charlson index increased from 0.29 in 2006/07 to 0.51 in 2015/16 (p <0.001). This increase may reflect improvements in coding practice over time rather than a real increase in medical complexity of patients. Patients remained in hospital for a shorter period, with the average length of stay decreasing from 3.30 days in 2006/07 to 2.29 days in 2015/16 (p <0.001).

Table 1: Summary statistics of all patients in the study sample by financial year

Variable	FY 2006/07 *Mean (No)*	FY 2015/16 *Mean (No)*
No of index discharges	5734330	6857904
Patient age (years)	57.80	59.80
Female (%)	54.72 (3 138 043)	54.63 (3 746 817)
White (%)	89.32 (5 122 453)	87.72 (6 016 161)
Black (%)	2.31 (132 649)	2.54 (174 207)
Asian (%)	4.10 (235 324)	4.96 (340 217)
Other (%)	1.49 (85 648)	2.17 (149 376)
Length of stay in days (Total days per year)	3.30 (18 954 667)	2.29 (15 762 967)
No of patients discharged per day from quintile 1 - IMD score (least deprived)	20.71 (1187633)	19.11 (1310716)
No of patients discharged per day from quintile 2 - IMD score	19.96 (1165254)	19.61 (1344866)
No of patients discharged per day from quintile 3 - IMD score	19.59 (1144370)	20.17 (1383483)
No of patients discharged per day from quintile 4 - IMD score	19.59 (1123612)	20.30 (1391953)
No of patients discharged per day from quintile 5 - IMD score (most deprived)	19.42 (1113461)	20.81 (1426886)
Charlson comorbidities	0.29	0.51
Crude 30-day readmission rate (%)	6.31 (362 323)	6.18 (424 067)
Number of NHS trusts	150	149

Note: Summary statistics across all patients for each financial year

Trends and variation in national emergency readmission rates for all NHS patients

The total number of indexed admissions per year increased by 1,123,574 from 5,734,330 in 2006/07 to 6,857,904 in 2015/16 (note: 2015/16 is exclusive of March 2016) (p <0.001). A total of 362,323 discharges following an indexed admission resulted in an emergency readmission in 2006/07, whereas a total of 424,067 discharges following an indexed admission resulted in an emergency readmission in 2015/16 (see table 1). The observed crude emergency readmission remained relatively stable across the study period, increasing slightly from 6.31% in 2006/07 to 6.54% in 2012/13 (p <0.001), and then decreasing to 6.18% in 2015/16 (p <0.001). Similarly, reductions in risk-adjusted, 30-day emergency readmission rates increased slightly from 6.37% in 2006/07 to 6.57% in 2011/12, followed by a slight decrease to 6.00% in 2015/16 (p<0.01). The standard deviation of risk-adjusted readmissions showed a small decrease from 0.84% in 2006/07 to 0.79% in 2015/16 (see table 1) (p <0.05).

The average SCV for readmissions following any indexed admission and across the entire observation period was 15.75, and we observed a small decrease in the SCV score from 15.99 in 2006/07 to 15.58 in 2015/16 (p <0.01). Specifically, the SCV increased initially to 16.08 in 2007/08 (p <0.01), followed by a decrease to 15.27 in 2012/13 (p<0.001), but increased again thereafter (see figure 1). This means that although readmission rates decreased overall, the variation across providers did not decrease substantially.

We then performed two regression analyses, using ordinary least squares estimators to test first, whether risk-adjusted, 30-day emergency readmission rates across the observation period differed from the baseline case (risk-adjusted, 30-day emergency readmission rates in 2006/07) and second, whether the SCV score in the years succeeding the baseline case (SCV in 2006/07) were significantly different. We found a statistically significant decrease in risk-adjusted, 30-day emergency readmission rates across the observation period, with the emergency readmission rate being 0.37% (p<0.01) below the baseline emergency readmission rate in 2006/07. While the SCV in 2012/13 was smaller by 0.35 (*p<0.13)* compared with the baseline SCV in 2006/07, it was not significant, however the SCV in 2014/15 was significantly smaller by 0.64 (p<0.07). Regression output is presented in Supplementary Appendix C.

Trends and variation in emergency readmission rates for patient subgroups

While overall risk-adjusted, 30-day emergency readmission rates decreased, sub-analyses by type and clinical condition of indexed admission reveals heterogeneous trends that would remain concealed in an aggregate analysis (see Table 2). Risk-adjusted, 30-day emergency readmissions for all elective procedures decreased by 0.58% (p<0.01), from 3.16% in 2006/07 to 2.58% in 2015/16. Similarly, the SCV decreased from 33.53 in 2006/07 to 33.47 in 2015/16 (p <0.05). On the other hand, risk-adjusted, 30-day emergency readmissions following any emergency (*i.e.* unplanned) indexed admission did not decrease but stayed about constant, or may have even increased slightly by 0.30% (p<0.01), from 11.00% in 2006/07 to 11.30% in 2015/16. Over the same period, the SCV decreased from 8.78 in 2006/07 to 8.45 in 2015/16 (p<0.01).

Out of the analysed elective procedures, a reduction in risk-adjusted, 30-day emergency readmissions was observed for patients undergoing total hip and knee replacements (-1.64%; p <0.001), Constant or slightly reduced readmission rates are seen for patients with indexed admissions for COPD and heart failure. For the other six conditions, readmission rates have increased. For patients admitted with a primary diagnosis of acute myocardial infarction (+0.47%; p <0.001) readmission rates were constant or slightly increased. The other five clinical areas saw increases in 30-day readmission rates by above 1%. Diabetes patients experienced the largest increase in rates at (+6.07%; p <0.001), followed by patients admitted for pneumonia (+2.93%; p<0.001), cholecystectomy (+1.46; p <0.001), patients admitted for stroke (+1.39%; p<0.001), and hysterectomy (+1.42%; p <0.001).

Except for emergency readmissions following stroke, total hip and knee replacement, cholecystectomy and hysterectomy, the SCV reduced across all conditions, indicating lower levels of variation in quality of care received by patients across the country. However, all investigated conditions showed either high or very high levels of variation, with lowest levels observed in patients with COPD (6.48) and heart failure (6.72). Moreover, whilst the SCV reduced slightly for patient readmitted within 7-days (-0.13) and 90-days (-0.15), 7-day readmission rates were found to increase slightly from 2.72% in 2006/07 to 2.79% in 2015/16, and 90-day readmission rates decreased from 10.03% in 2006/07 to 8.15% in 2015/16 (see Supplementary Appendix D).

Table 2: Descriptive statistics of risk-adjusted, 30-day readmission rates and SCV for selected patient subgroups

	FY 2006/07			FY 2015/16		
Type of indexed admission	*No of indexed admissions*	*Mean readmission rate (Std. Dev.)*	*SCV*	*No of indexed admissions*	*Mean readmission rate (Std. Dev.)*	*SCV*
All	5 734 330	6.37 (0.84)	15.99	6 857 904	6.00 (0.78)	15.68
Emergency	2 275 642	11.00 (1.05)	8.78	2 653 162	11.30 (0.91)	8.45
Elective	3 458 686	3.16 (0.43)	33.53	4 204 272	2.58 (0.34)	33.47
Acute myocardial infarction	44 821	12.94 (2.45)	7.43	38 540	13.41 (3.13)	7.16
Stroke	46 182	6.64 (2.78)	12.14	53 795	8.03 (1.94)	12.25
Pneumonia	60 210	9.34 (1.84)	9.24	124 219	12.27 (1.72)	8.45
Chronic obstructive pulmonary disease	98 670	15.38 (1.88)	6.58	105 525	14.66 (1.92)	6.48
Heart failure	36 609	14.35 (2.73)	6.83	42 205	14.28 (2.66)	6.72
Diabetes	30 132	8.24 (3.45)	10.15	25 743	14.31 (3.66)	9.32
Hip and knee replacement	60 844	7.67 (1.99)	14.53	65 087	6.03 (1.68)	14.64
Cholecystectomy	37 741	5.64 (1.66)	14.42	44 559	7.10 (1.86)	14.97
Hysterectomy	22 108	6.08 (2.32)	12.57	18 264	7.50 (3.27)	14.90

Note: [1]The table depicts risk-adjusted, 30-day emergency readmission rates; [2]Abbreviation Std. Dev. refers to standard deviation.

DISCUSSION

Despite an enhanced focus on policies aimed at reducing readmissions, which saw the introduction of national-level policies, including financial penalties for readmission reduction in hospitals reporting excess readmission rates[19] and a number of local-level initiatives, little is known about the development of readmission rates over the past decade and the overall effect of interventions to improve this aspect of healthcare quality. We examined readmissions for all non-specialists NHS trusts in England between 2006/07 and 2015/16, and showed that risk-adjusted, 30-day emergency readmission rates following discharge from any indexed admission decreased slightly from 6.37% in 2006/07 to 6.00% in 2015/16, while the degree of variation measured by the SCV decreased slightly from 15.99 to 15.68 over the same period. Decreases in both metrics suggest overall quality improvements in the NHS across all providers and over the study period. However, when we disaggregated results by type of admission and clinical condition, we observed heterogeneous trends with decreasing trends for some patient groups, but increasing ones for others. Disaggregating findings by type of admission shows that emergency readmissions following any elective surgery decreased, reflecting positively on quality of care with changes potentially attributable to initiatives that focussed on improving metrics such as infection rates (e.g. Commissioning for Quality and Innovation scheme in the 2008 NHS Stage Review).[39] However, emergency readmissions following an indexed emergency admission increased slightly over the observation period. Disaggregation by clinical areas shows that readmissions rates decreased for patients initially admitted for hip- or knee replacements. Readmission rates stayed about constant for patients initially admitted for COPD, heart failure, and acute myocardial infarction. Readmission rates actually increased for patients initially admitted for diabetes, pneumonia, cholecystectomy, stroke, and hysterectomy.

While previous studies examined trends in emergency readmission rates for different types of hospitals[40] and surgical emergency readmission rates for selected patient subgroups as a measure for quality of care in the United States,[41] this is the first study that provides a comprehensive overview of trends in risk-adjusted, 30-day emergency readmissions and variation in England over a ten year period and disaggregated for nine clinical conditions. One study that had reported on trends of English emergency readmission rates reported before, focussed on a period up to May 2010, but did not disaggregate by clinical condition.[42] However, our study provides an updated overview of these changes in emergency readmissions until February 2016, and for 9 subgroups. Expanding the previous observation period further is particularly important, since the NHS has focused considerable efforts into reducing readmission rates following the publication of *Equity and Excellence* in April 2010. While our study found similar patterns in trends of emergency readmission rates to [42] the magnitude of emergency readmission rates was slightly smaller, 6.5% compared with 7.0%. This is likely to be caused by differences in the methodology used for linking information from HES. Large variations in the reporting of readmission rates for specific clinical subgroups exist in the literature. For example, while one study reported the readmission rate for chronic obstructive pulmonary disease to be approximately 10.2% in the NHS,[43] the Royal College of Physicians reported much higher rates of approximately 31% to 34%, over a 90-day period.[44] In comparison, we found a readmission rate of 14.6% in 2015/16. Moreover, research from the Unites States suggested readmission rates of 19.9% and 18.3% for acute myocardial infarction and pneumonia, respectively.[45] We found readmissions to be lower in the NHS, 13.41% for acute myocardial infarction and 12.27% for pneumonia in 2015/16. Other research focussed primarily on the examination of quality of care provided at singular pathway points, which includes the investigation into mortality rates to assess variation of in-hospital quality between providers[46] and the evaluation of policies with emergency readmissions as an outcome indicator.[14,35,36]

Strengths and limitations

We used trends in 30-day emergency readmission rates across all non-specialists trusts, to examine whether quality improvement initiatives that were introduced in England between 2006 and 2016, led to benefits for patients. We chose unplanned, emergency readmissions as an outcome measure, as they are mostly undesirable for patients and also add potentially avoidable strain on services. A 30-day follow-up period was chosen to capture the impact of quality along the clinical pathway, including the initial hospital stay, transitional care, post-discharge support, and community and social care. However, poor quality may also affect emergency readmissions after 30-days, with studies showing that a follow-up of 90-days may be more appropriate when assessing quality of care provided to older patients with debility, after discharge from rehabilitation services.[47] Other studies have suggested that

7-day emergency readmission rates are more closely related to the quality provided at the initial hospital stay.[48] To investigate this potential threat to the validity of this study, we conducted sensitivity analysis that in addition to 30-day emergency readmissions also investigated changes in trends and variation for 7-day emergency readmissions and 90-day emergency readmissions. Outcomes from the sensitivity analyses did not materially change our findings, confirming a statistically significant overall reduction in emergency readmission rates and decrease in level of SCV (see Supplementary Appendix C). Findings from sensitivity analyses also provided some indication about quality improvements at the hospital-level (measured by 7-day emergency readmissions), and post-discharge level (measured by 90-day emergency readmissions).

The validity of emergency readmission rates as an appropriate measure for quality of care had been questioned before, mainly due to their sensitivity to changes in patient case-mix, random variation, and the poor correlation with other indicators of hospital quality.[49] While this might be a relevant concern for direct provider comparisons, such as in the case of imposing financial penalties for hospitals with high readmission rates and associated fears about unintended consequences,[50] in this study we aimed to assess overall trends in readmission rates for all trusts and across ten years. This approach helped to deal with random variation and presented longitudinal changes in quality of care in the English NHS.

We used a large administrative data source that included all hospital inpatients in England and risk-adjusted emergency readmission rates at the patient-level, accounting for systematic differences in observed patient characteristics between trusts. We adjusted for patient demographics, including socio-economic status. Thus, we treated any variation in emergency readmissions that correlates with socioeconomic status as being ‘unavoidable, on the assumption that it is outside of the direct control of the health care system. However, it is possible that the higher emergency readmission rates observed amongst patients living in more deprived areas is in part due to lower quality health care - a possibility that has been extensively discussed.[50] Another concern relates to omitting variable bias in the risk-adjustment for emergency readmission rates, such as by the lack of information on clinical severity, which may dilute the true predicted likelihood (i.e. upward or downward depending on the severity of disease) of a patient having to return to hospital. We were not able to address this limitation within our dataset, but we used the Charlson index to capture some of the patient's clinical complexity[51] and further accounted for improvements in recording practices by including interaction terms of the Charlson index in each financial years into our risk-adjustment model.

We constructed the SCV, a measure that represented 'avoidable' variation that can be attributed to differences in quality of care, provided our controls for patient characteristics that are not under the influence of the health system within the prediction model. However, it is possible that other factors explained the variation in emergency readmission rates. In particular, the subgroup analysis showed rises in emergency readmission rates for many of the selected acute conditions. These changes might be explained by reductions in patient mortality, triggered through technological advancements, which have been found to inversely correlate with emergency readmission rates,[52] and in fact, may suggest quality improvements. Our findings are also susceptible to time varying confounders, such as the establishment of Hyper Acute Stroke Units in London and Greater Manchester in 2010,[53,54] leading to a shift in quality that is provided to stroke patients across different parts of the country.

While our study was able to describe overall changes in emergency readmission rates over time, we were not able to make inferences about the effectiveness of individual policies. Future research should therefore evaluate the mechanism of local-level and national-level policies aimed at improving quality of care in England, such as the introduction of financial penalties,[19] or improvements in access to general practitioners.[55] Linkages of secondary care data with information on care received during the post-discharge period would allow establishing causal relationships along the patient pathway. Future research might also benefit from additional exploration of audit data that could hold information on quality, which is not commonly available within large administrative health datasets.

Conclusions

Declines in hospital emergency readmissions after discharge following any indexed admission were accompanied by reductions in variation. These reductions fall into a period of an enhanced focus on quality improvement in the English NHS, thereby suggesting an overall success of local-level and national-level efforts to reduce emergency readmission rates. However, changes in both metrics were only modest and they varied widely by clinical area, which might have several possible causes. For example, while reductions in readmissions for chronic conditions may indicate improvements in quality provided outside the hospital (*i.e.* in primary care settings), observed increases in readmissions for acute conditions in stroke or pneumonia patients may be linked to possible reductions in mortality. However, this paper looked at emergency readmission rates, but other measures of care quality are important too. In particular, because emergency readmission rates were found to not closely relate to patient reported outcomes in hip and knee replacement patients,[56] emphasising the need to investigate variation on other quality indicators, for example total number of bed days over a defined period of time.

While the focus on reducing emergency readmission rates across several health care systems may yield certain benefits, policy makers are required to further develop an understanding about changes in variation of care quality over time before introducing targeted and effective improvement strategies. It should be the aim of any health system to provide care at the highest quality standard and equally to all patients regardless of where they access the health system.

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Contributions

RF had the idea for this study. RF and AS came up with the statistical analysis plan. RF carried out the analysis. RF, AS, KH and PA drafted and finalised the paper.

Competing interests

All authors have completed the ICMJE uniform disclosure from at www.icmje.org/coi_disclosure.pdf and declare: RF is the recipient of a studentship from Imperial Patient Safety Translational Research Centre; no financial relationships with any other organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submission.

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England (PHE), and by the MRC Centre for Outbreak Analysis and Modelling (funding reference: MR/K010174/1B).

Conflict of interest

The authors declare no conflict of interest.

Data sharing

The data controller of the data analysed is NHS Digital. Patient-level data is available subject to their information governance requirements.

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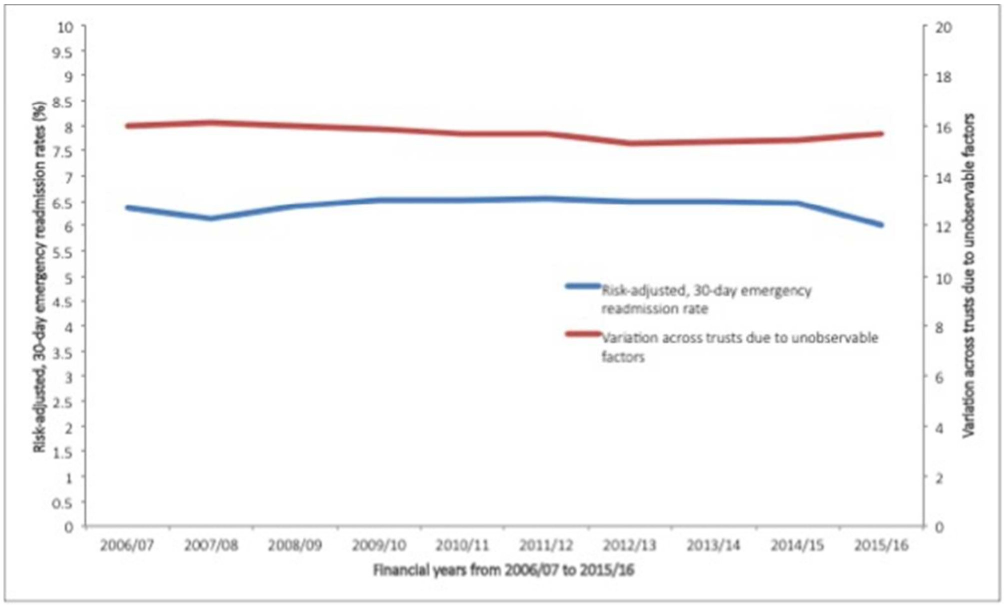

Figure 1: Trends in risk-adjusted, 30-day emergency readmission rates and variation in England from 2006/07 to 2015/16

215x129mm (72 x 72 DPI)

Appendix A: List of ICD-10 codes and OPSC-4 codes used for subgroup analyses

Condition	ICD-10	OPCS-4
Acute Myocardial Infarction	I21, I210, I211, I212, I213, I214, I219 I22, I220, I221, I228, I229	- -
Stroke	I60, I61, I62, I63, I64	-
Pneumonia	J12, J13, J14, J15, J16, J17, J18	-
Chronic Obtructive Pulmonary Disease	I278, I279, J40, J41, J42, J43, J44, J45, J46, J47, J61, J62, J63, J64, J65, J66, J67, J684, J701, J703	- - -
Heart failure	I110, I130, I132, I50, I501, I509, J81X	-
Diabetes	E10, E11, E12, E13, E14	-
Hip and knee replacement	- - - - - - -	W371 W378 W379 W381 W388 W389 W391 W398 W399 W461 W468 W469 W471 W478 W479 W481 W488 W489 W931 W938 W939 W941 W948 W949 W951 W958 W959 W521 W528 W529 W531 W538 W539 W541 W548 W371 W378 W379 W381 W388 W389 W391 W398 W399 W521 W528 W529 W531 W538 W539 W541 W548 W549 O181 O188 O189 W400 W402 W403 W404 W410 W412 W413 W414 W420 W422 W423 W581 W582 W424 W425 W426 W520 W522 W523 W530 W532 W533 W540 W542 W543 W544 O180 O182 O183 O184
Cholecystectomy	-	J18
Hysterectomy	-	Q07

Appendix B: Computation formula for calculating the systematic component of variation

$$\text{SCV} = \left[\frac{\sum_i \frac{(OR_i - ER_i)^2}{ER_i^2} - \sum_i \frac{1}{ER_i}}{n-1}\right] \text{x } 100$$

Appendix C: Ordinary least squares regression analysis

	30-day emergency readmission rates (risk-adj)			*Systematic component of variation*		
Variable	Coefficient	Std. Err.	t-statistics	Coefficient	Std. Err.	t-statistics
Constant	6.37***	0.08	81.93	15.99***	0.45	356.33
FY 2006/07		Baseline			Baseline	
FY 2007/08	-0.21**	0.11	-1.99	0.09	0.07	0.91
FY 2008/09	0.03	0.11	0.27	-0.01	0.07	-0.71
FY 2009/10	0.16	0.11	1.57	-0.14	0.07	-2.37
FY 2010/11	0.24**	0.10	2.35	-0.32	0.07	-4.68
FY 2011/12	0.14	0.10	1.38	-0.36	0.07	-5.2
FY 2012/13	0.20**	0.10	1.99	-0.72*	0.07	-9.81
FY 2013/14	0.12	0.10	1.15	-0.66*	0.07	-9.05
FY 2014/15	0.10	0.10	1.00	-0.64*	0.07	-8.28
FY 2015/16	-0.37***	0.11	-4.11	-0.35	0.07	-4.55
N	1472			10		
R-squared	0.05			1		

Note: *** indicates that the variable has robust impact on dependent variable at 1% significance level, ** for 5% and * for 10%.

Appendix D: Sensitivity analysis for 7-day and 90-day emergency readmission rates

	FY 2006/07			FY 2015/16		
	No of indexed admissions	*Mean (Std. Dev.)*	*SCV*	*No of indexed admissions*	*Mean (Std. Dev.)*	*SCV*
7-day emergency readmission (any indexed admission)	6 623 148	2.72 (0.49)	35.14	8 361 220	2.79 (0.49)	35.01
30-day emergency readmission (any indexed admission)	5 734 330	6.37 (0.84)	15.99	6 857 904	6.00 (0.79)	15.68
90-day emeregency readmission (any indexed admission)	5 008 977	10.03 (1.21)	10.70	5 577 445	8.15 (0.99)	10.55

STROBE Statement—checklist of items that should be included in reports of observational studies

National trends in emergency readmission rates: A longitudinal analysis of administrative data for England between 2006 and 2016.

Rocco Friebel[1 2], Katharina Hauck[1], Paul Aylin[1] and Adam Steventon[2]

[1] School of Public Health, Imperial College London, South Kensington Campus, London, SW7 2AZ

[2] Data Analytics, The Health Foundation, 90 Long Acre, London, WC2E 9RA

Rocco Friebel, Doctoral Researcher; Data Analyst

Katharina Hauck, Senior Lecturer in Health Economics

Paul Aylin, Professor of Epidemiology and Public Health

Adam Steventon, Director of Data Analytics

Correspondence to: rocco.friebel@health.org.uk, 0207 257 8000

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1/2	
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2	
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3+4	
Objectives	3	State specific objectives, including any prespecified hypotheses	3+4	

Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5+6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—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 *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5+6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5+6+7
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	5+6+7
Bias	9	Describe any efforts to address potential sources of bias	7
Study size	10	Explain how the study size was arrived at	5+6+7

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6+7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7+8
		(*b*) Describe any methods used to examine subgroups and interactions	6+8
		(*c*) Explain how missing data were addressed	5
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5+9
		(b) Give reasons for non-participation at each stage	5+9
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	5
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	11
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	

Continued on next page

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13+13 (Table 2)	
Discussion				
Key results	18	Summarise key results with reference to study objectives	14	1st Paragraph
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	15+16+17	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	15+16+17+18	
Generalisability	21	Discuss the generalisability (external validity) of the study results	15+16+17	
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	19	

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

National trends in emergency readmission rates: A longitudinal analysis of administrative data for England between 2006 and 2016.

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Primary Subject Heading:	Health services research
Secondary Subject Heading:	Health policy
Keywords:	Quality in health care < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Readmission Rates, Variation in Quality of Care

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Rocco Friebel[1 2], Katharina Hauck[1], Paul Aylin[1] and Adam Steventon[2]

[1] School of Public Health, Imperial College London, South Kensington Campus, London, SW7 2AZ

[2] Data Analytics, The Health Foundation, 90 Long Acre, London, WC2E 9RA

Rocco Friebel, Doctoral Researcher; Data Analyst

Katharina Hauck, Senior Lecturer in Health Economics

Paul Aylin, Professor of Epidemiology and Public Health

Adam Steventon, Director of Data Analytics

Correspondence to: rocco.friebel@health.org.uk, 0207 257 8000

Word count: 4622

ABSTRACT

Objective: To assess trends in 30-day emergency readmission rates across England over one decade.

Design: Retrospective study design.

Setting: 150 non-specialist hospital trusts in England.

Participants: 23,069,134 patients above 18 years of age who were readmitted following an initial admission (n = 62,584,297) between April 2006 and February 2016.

Primary and secondary outcomes: We examined emergency admissions that occurred within 30 days of discharge from hospital ("emergency readmissions") as a measure of health care quality. Presented are overall readmissions, and disaggregated by type of admission and by clinical condition at first admission. All rates were risk-adjusted for patient age, gender, ethnicity, socioeconomic status, comorbidities and length of stay.

Results: The average risk-adjusted, 30-day readmission rate increased from 6.56% in 2006/07 to 6.76% (p<0.01) in 2012/13, followed by a small decrease to 6.64% (p<0.01) in 2015/16. Emergency readmissions for patients discharged following elective procedures decreased by 0.13% (p<0.05), while those following emergency admission increased by 1.27% (p<0.001). Readmission rates for hip- or knee replacements decreased (-1.29%; p <0.001), for acute myocardial infarction (-0.04; p<0.49), stroke (+0.62; p<0.05), COPD (+0.41%; p<0.05) and heart failure (+0.15%; p<0.05) remained stable, and pneumonia (+2.72%; p<0.001), diabetes (7.09%; p<0.001), cholecystectomy (+1.86; p<0.001) and hysterectomy (+2.54%; p<0.001) increased.

Conclusions: Overall emergency readmission rates in England remained relatively stable across the observation period, with trends of slight increases contained post 2012/13. However, there were large variations in trends across clinical areas, with some experiencing marked increases in readmission rates. This highlights the need to better understand variations in outcomes across clinical subgroups to allow for targeted interventions that will ensure highest standards of care provided for all patients.

Keywords: Quality of Care; Readmission Rates; Variation in Quality of Care

Strengths and limitations of this study

- The use of a large administrative health data source allowed capturing all patients entering the English National Health Service between 2006 and 2016.
- This study extended the scope of the previous literature, by examining changes in readmission trends and variation for all patients, and for nine clinical subgroups.
- Our analysis employed the systematic component of variation, which provides an estimation of the unobservable part of the variation that is due to hospital characteristics.
- The risk-adjusted, 30-day readmission rate and the systematic component of variation assume that all patient-level predictors of a readmission are controlled for by the information entered into the logistic regression model.
- There may be other dimensions of quality of care that we were not able to measure through readmission rates.

INTRODUCTION

Ensuring that patients receive appropriate and high-quality care in hospitals followed by an efficient discharge in a way that leads to the best possible outcomes is a priority for the English National Health Service (NHS).[1] Despite this objective, care received by patients remains variable in quality across England,[2] and while some of this variation may be explained by differences in patients' complexity and medical needs;[3] some variation may be unwarranted by the characteristics of patients and point to opportunities to improve care.[4] It is a key priority of the NHS to close this 'quality gap', which was outlined in the NHS Five Year Forward View[5] and addressed through initiatives such as the Right Care Programme[6] and Getting it Right First Time.[7]

Emergency hospital readmission rates are widely used for measuring health system performance.[8–10] They have important and well-known limitations,[11] which include the difficulty in distinguishing readmissions avoidable through actions of health care providers from those caused by other factors such as the patient complexity, a sensitivity to omitted variable bias in risk-adjustment models, a link with competing outcome measures of quality (i.e. mortality rates, or length of stay), and their link to factors outside the control of hospitals (e.g. primary care, or social isolation). Nevertheless, there is now mounting evidence that they are correlated with quality of care provided to patients along the clinical pathway. This includes quality of care at the initial hospital stay,[12] transitional care services[13–15] and post-discharge support.[16,17] Emergency readmission rates were incorporated into quality frameworks across several health care systems (e.g. United States, Denmark, Germany, and England),[18] with numerous national-level policies aimed at reducing readmissions in an attempt to improve quality of care. For example, in England, the governmental white paper: *Equity and Excellence: Liberating the English NHS*,[19] led to the implementation of policies directly aiming at reducing readmission rates, including via financial penalties for hospitals reporting excess emergency readmissions.

Previous research on readmissions analysed trends at the national-level by aggregating across all hospitals.[20] While national readmission trends can indicate whether progress was made overall in the health care systems, an aggregate analysis masks differences in the rate of progress for specific hospitals and patient groups. Analyses in the aggregate offer little value for the identification of providers and clinical areas that require specific policy attention, and works counter the ambition to provide high quality health care for all patients no matter what hospitals they attend. Therefore, in addition to investigating national trends in readmissions, examining variation between providers and for different patient groups helps to uncover additional dimensions in care quality, which can direct policy makers in implementing future improvement efforts in a more targeted fashion. To measure variation in readmission rates across hospitals we used the systematic component of variation (SCV).[21] This is a commonly applied measure of variation in health system performance.[22–24] To measure variation in readmission rates across clinical areas, we undertook separate analyses of 9 patient groups with specific conditions and procedures. We used a large dataset consisting of the medical records of all patients admitted to the population of English hospitals over 10 years. This study provides one of the most comprehensive assessments of trends in readmission rates in England.

METHODS

Study population

Our analysis included a total of 23,069,134 patients between April 2006 and February 2016 to 150 non-specialist NHS trusts. Trusts are health care providers that typically manage multiple hospital sites. We obtained pseudonomized and unidentifiable patient health care records from the administrative Hospital Episode Statistics (HES) database. HES contains information on patient demographics, diagnoses and treatment. For each patient, we constructed linked health records from the patients' admission to discharge, even when patients changed hospital as part of the hospital stay.[25,26] We studied all adult patients discharged from a non-specialist NHS trust between 1 April 2006 and 29 February 2016, following any elective (*i.e.* planned) or emergency (*i.e.* unplanned) indexed (*i.e.* original or first) admission. This included patients admitted with an indexed admission as a day-case to account for health system trends that shifted care from an inpatient to an outpatient setting during the 10 years.[27] Patients discharged in March 2016 were removed from the study sample to allow for a sufficient follow-up period required to calculate 30-day readmission rates within the scope of available data. We also excluded the following elective and emergency admissions from the study sample (total exclusions: 56,401,750 out of 140,709,025 admissions): below 18 years of age (n=17,860,079), without complete records of variables required for risk-adjustment (n=11,173,561), maternity cases (n=12,085,711), and any admission related to cancer or chemotherapy (n=13,985,696). We also excluded any indexed admission that was not survived by the patient (n=1,296,703), because they could not result in a readmission. Where a patient experienced multiple admissions, we treated each admission as an indexed admission provided they occurred more than 30 days from each other.

We followed the definition used by policy makers in England for identifying emergency readmissions from administrative health records,[28] which are described as any all-cause, emergency admission with a method of admission via Accident and Emergency department (A&E); general practitioner; Bed Bureau; consultant outpatient clinic; other means, such as arriving via A&E of another provider where the patient had not been admitted, and occurring within 30-days of discharge from an indexed admission. We focussed on a period of 30-days following discharge from any indexed admission as this reflects common practice when assessing care quality, and we only counted the first emergency readmission for patients experiencing multiple emergency readmissions within the 30-day period. Emergency readmissions may have comprised of readmissions for conditions unrelated to the indexed admission.

We first calculated yearly national readmission rates by averaging across hospital-specific readmission rates. We then examined yearly trends in readmissions for patients with nine specific conditions, following the hypothesis that the patients' experience with the health care system is likely to differ with health condition. For example long-term conditions are usually managed in primary care settings,[29] while acute conditions require hospital admissions and rehabilitative care. We used the HES recorded primary diagnoses codes (International Classification of Diseases 10th edition, or ICD-10) and procedure codes (Classification of Intervention and Procedure Codes, or OPCS-4) to identify patients for subgroup analyses. The selection of acute conditions and chronic conditions was based on publicly available statistics on health service utilisation based on primary diagnosis in 2015/16,[30] and as a result we included acute myocardial infarction, stroke and pneumonia as acute conditions; we chose congestive heart failure, chronic obstructive pulmonary disease (COPD) and diabetes mellitus as long-term conditions. For surgical interventions, we focussed on commonly performed surgeries in the English NHS, which also capture several surgical subsections.[31] Thus, we selected cholecystectomy, total hip and knee replacement and hysterectomy. The full list of applied ICD-10 codes and OPCS-4 codes is presented in the Supplementary Appendix A.

Statistical analysis

We first estimated the average observed emergency readmission rate (OR) for each trust and financial year by aggregating from the patient-level. We adjusted for systematic differences in patient complexity across trusts based on clinical conditions recorded in each patients' record. We then estimated the predicted emergency readmission rates (ER) for each trust and financial year by performing a logistic regression at the patient-level. We used patient case-mix information, including patient age on admission, gender, ethnicity, socioeconomic deprivation score (Index of Multiple Deprivation version 2010 based on small geographic areas, each containing on average 1,500 residents),[32] comorbidities measured by the Charlson Index [33], and length of stay. This Charlson index was constructed based on diagnoses codes recorded at the indexed admission and during previous admissions that occurred within one year. Because the Charlson index may be affected by changes in how health conditions are recorded in HES,[34] we entered interaction terms between the Charlson index and financial year into our logistic regression model. Length of stay was entered into the risk-adjustment process, as every extra day spent in hospital was found to be associated with an increased risk of incurring an adverse health event,[35] possibly affecting the patients' likelihood of recovery, but it might also indicate disease severity in the absence of any other adequate measures recorded within the HES database. However, because length of stay is also used as a measure of quality,[36] it is possible that adjusting for it might remove some of the variation in readmission rates. To calculate the risk-adjusted, 30-day emergency readmission rate for each trust and financial year, we divided *OR* by *ER* to assess whether the trust performed below or above what would be expected given patient case-mix. We then multiplied this ratio for each trust and financial year by the average emergency readmission rate observed at the national-level in that financial year.

The amount of trust-level variation in 30-day, emergency readmission rates in England for each financial year was calculated with the SCV methodology developed by [21] (see Appendix B). The SCV can be described as the variance of the ratios of *OR* and *ER*, minus the random component caused by Poisson variability,[37] times 100. Since hospital readmissions are relatively rare events, we assumed that *ER* approximates a Poisson distribution. This provided us with one SCV measure for each financial year, and each category of readmission. The SCV measures the degree of variation caused by time-invariant unobservable characteristics related to the hospitals or the populations in their catchment area that are leading some hospitals to diverge from the average national emergency readmission rate. A high SCV means that hospitals in that year have very different readmission rates due to unobservable characteristics that we cannot explain by the information entered into the prediction model. These unobservable characteristics make a hospital perform above or below the national average in terms of readmissions. Unobservable hospital characteristics could be good or bad management practices, staff satisfaction, whereas unobservable population characteristics could be socioeconomic factors that affect medical need, but are not captured by the socioeconomic deprivation score in HES.[26] The estimated SCV score can be categorised into three distinct groups. A SCV score below 3 indicates small variation in emergency readmission rates; a score between 5.4 and 10.0 indicates high variation in emergency readmission rates; and a score above 10.0 indicates very high variation in emergency readmission rates.[22,38,39] Other studies have suggested a value above 16 to indicate high variability,[40] while one study that investigated variation in access to health services commissioned by the National Specialised Commissioning Team in England, suggested high variability above a cut-off point of 20.[41]

To test whether trends in risk-adjusted, 30-day emergency readmission rates changed across financial years, we estimated a regression model with ordinary least squares estimators. We used the risk-adjusted, 30-day emergency readmission rate as dependent variable, and entered time dummies for each financial year, omitting financial year 2006/07 as the baseline case. The direction of the coefficient estimates showed whether the readmission rate in a respective financial year is significantly different from the values observed in financial year 2006/07.

We conducted sensitivity analyses using alternative time-windows for emergency readmissions within 7 days and 90 days. In addition to the SCV, we also report the standard deviation as an alternative measure of variation. We used SAS Enterprise Miner for the initial data extraction and the statistical analysis was conducted using STATA version 13.

RESULTS

Study sample

Our analysis included a total of 62,584,297 (n = 23,069,134 patients) indexed admissions (corresponding to 43,551 indexed admissions per trust per year, with a range from 1,195 to 121,500), suggesting that several patients experienced multiple indexed admissions across the observation period. The characteristics of all patients admitted to hospital changed slightly between 2006/07 and 2015/16 (see table 1). For example, the average patient age increased across the study period, from 57.4 years in 2006/7 to 59.5years in 2015/16 (p <0.001). Similarly, the average number of comorbidities measured by the Charlson index increased from 0.23 in 2006/07 to 0.45 in 2015/16 (p <0.001). However, this increase may reflect improvements in coding practice over time, rather than a real increase in medical complexity of patients. Patients remained in hospital for a shorter period, with the average length of stay decreasing from 3.16 days in 2006/07 to 2.25 days in 2015/16 (p <0.001).

Table 1: Summary statistics of all patients in the study sample by financial year

Variable	FY 2006/07 *Mean (No)*	FY 2015/16 *Mean (No)*
No of index discharges	5 204 263	6 219 153
Patient age (years)	57.42	59.46
Female (%)	54.02 (2 811 559)	54.48 (3 391 862)
White (%)	89.40 (4 652 641)	87.76 (5 463 584)
Black (%)	2.26 (118 127)	2.55 (158 949)
Asian (%)	4.13 (215 017)	5.03 (313 120)
Other (%)	1.48 (77 369)	2.17 (135 425)
Length of stay in days (Total days per year)	3.16 (16 461 340)	2.25 (14 029 556)
No of patients discharged per day from quintile 1 - IMD score (least deprived)	20.90 (1 087 857)	19.33 (120 3376)
No of patients discharged per day from quintile 2 - IMD score	20.39 (1 061 572)	19.74 (1 229 077)
No of patients discharged per day from quintile 3 - IMD score	19.93 (1 037 591)	20.15 (1 254 540)
No of patients discharged per day from quintile 4 - IMD score	19.49 (1 014 601)	20.17 (1 255 631)
No of patients discharged per day from quintile 5 - IMD score (most deprived)	19.26 (1 002 642)	20.60 (1 282 480)
Charlson comorbidities	0.23	0.45
Crude 30-day readmission rate (%)	6.50 (338 565)	6.73 (418 949)
Number of NHS trusts	150	139

Note: Summary statistics across all patients for each financial year

Trends and variation in national emergency readmission rates for all NHS patients

The total number of indexed admissions per year increased by 1,014,890 from 5,204,263 in 2006/07 to 6,219,153 in 2015/16 (p <0.001). A total of 338,565 discharges following an indexed admission resulted in an emergency readmission in 2006/07, whereas a total of 418,949 discharges following an indexed admission resulted in an emergency readmission in 2015/16 (p <0.001) (see table 1). The observed crude emergency readmission remained stable across the study period, increasing slightly from 6.50% in 2006/07 to 6.75% in 2012/13 (p <0.001), and then remaining constant until 2015/16 (p <0.001). The standard deviation of crude readmissions was also constant from 0.95% in 2006/07 to 0.93% in 2015/16 (p <0.30). The risk-adjusted, 30-day emergency readmission rates increased slightly from 6.56% in 2006/07 to 6.76% in 2012/13 (p<0.01), followed by a small decrease to 6.64% in 2015/16 (p<0.01) (see figure 1). While percentage changes in risk-adjusted, 30-day emergency readmission rates appear insubstantial, when calculating the total number of patients readmitted per year from the number of indexed admissions per year, the small decrease in readmissions between 2012/13 and 2015/16 translated into approximately 7000 fewer readmissions per year.

The average SCV for readmissions following any indexed admission and across the entire observation period was 15.11, and we observed a continuous decrease in the SCV score from 15.60 in 2006/07 to 14.54 in 2015/16 (p<0.001) (see figure 1). This means that although readmission rates were higher in 2015/16 compared with 2006/07, the variation across providers reduced significantly. This is confirmed by observed reductions in the standard deviation (see table 2).

We then performed a regression analysis, using ordinary least squares estimators to test whether risk-adjusted, 30-day emergency readmission rates across the observation period differed from the baseline case (risk-adjusted, 30-day emergency readmission rates in 2006/07). We found a statistically significant increase in risk-adjusted, 30-day emergency readmission rates across the observation period, with the emergency readmission rate in 2010/11 being 0.21% (p<0.05) above the baseline emergency readmission rate in 2006/07. The risk-adjusted, 30-day emergency readmission rate for any other year was not significantly different from the baseline. Regression output is presented in Supplementary Appendix C.

Trends and variation in emergency readmission rates for patient subgroups

While overall risk-adjusted, 30-day emergency readmission rates remained relatively stable, sub-analyses by type and clinical condition of indexed admission reveals heterogeneous trends that would remain concealed in an aggregate analysis (see table 2). Risk-adjusted, 30-day emergency readmissions for all elective procedures did not decrease substantially – a reduction from 2.88% in 2006/07 to 2.61% in 2015/16 (p <0.05). Similarly, the SCV reduced from 35.91 in 2006/07 to 35.30 in 2015/16 (p <0.05). On the other hand, risk-adjusted, 30-day emergency readmissions following any emergency (*i.e.* unplanned) indexed admission increased by 1.27% (p<0.001), from 11.49% in 2006/07 to 12.76% in 2015/16. Over the same period, the SCV decreased by 0.61, from 8.41 in 2006/07 to 7.90 in 2015/16 (p<0.01).

Out of the analysed elective procedures, a reduction in risk-adjusted, 30-day emergency readmissions was observed for patients undergoing total hip and knee replacements (-1.29%; p <0.001). Constant or slightly reduced readmission rates are seen for patients with indexed admissions for acute myocardial infarction (-0.04; p<0.49), stroke (+0.62; p<0.05), COPD (+0.41%; p<0.05) and heart failure (+0.15%; p<0.05). For the other four conditions, readmission rates have increased, including pneumonia (+2.72%; p<0.001), diabetes (7.09%; p<0.001), cholecystectomy (+1.86; p<0.001) and hysterectomy (+2.54%; p<0.001) (see figure 2).

Except for emergency readmissions following cholecystectomy and hysterectomy, the SCV reduced across all conditions, indicating lower levels of variation in quality of care received by patients across the country. However, all investigated conditions showed either medium or high levels of variation, with lowest levels of SCV observed in patients with heart failure (5.60) and COPD (5.97). Moreover, whilst the SCV reduced for patient readmitted within 7-days (-1.84) and 90-days (-0.57), 7-day emergency readmission rates were found to increase slightly from 3.20% in 2006/07 to 3.37% in 2015/16, and 90-day readmission rates decreased slightly from 9.99% in 2006/07 to 9.78% in 2015/16 (see Supplementary Appendix D).

Table 2: Descriptive statistics of crude, 30-day readmission rates and SCV for selected patient subgroups

	FY 2006/07			FY 2015/16		
Type of indexed admission	*No of indexed admissions*	*Mean readmission rate (Std. Dev.)*	*SCV*	*No of indexed admissions*	*Mean readmission rate (Std. Dev.)*	*SCV*
All	5 204 263	6.50 (0.95)	15.60	6 219 153	6.73 (0.93)	14.58
Emergency	2 146 898	11.70 (1.07)	8.41	2 505 047	12.68 (0.97)	7.90
Elective	3 057 365	2.85 (0.46)	35.91	3 718 858	2.72 (0.39)	35.30
Acute myocardial infarction	43 416	15.07 (2.70)	6.74	39 037	15.32 (3.32)	6.37
Stroke	34 835	9.88 (2.45)	9.43	45 601	10.45 (2.07)	9.37
Pneumonia	46 224	13.73 (2.60)	7.14	106 554	15.76 (2.03)	6.48
Chronic obstructive pulmonary disease	97 306	16.54 (2.06)	6.15	103 871	16.91 (2.37)	5.97
Heart failure	32 051	17.47 (3.12)	5.76	38 349	17.77 (3.22)	5.60
Diabetes	30 280	9.56 (4.48)	9.61	25 574	13.58 (3.45)	8.67
Hip and knee replacement	59 267	7.56 (2.11)	13.94	64 155	7.06 (2.15)	13.48
Cholecystectomy	37 627	6.34 (1.88)	14.17	44 488	7.18 (1.92)	14.70
Hysterectomy	18 355	7.09 (2.85)	12.30	13 897	7.59 (3.30)	14.85

Note: [1]The table depicts crude 30-day emergency readmission rates; [2]Abbreviation Std. Dev. refers to standard deviation.

DISCUSSION

Despite an enhanced policy focus aimed at reducing readmissions, which saw the introduction of national-level policies, including financial penalties for readmission reduction in hospitals reporting excess readmission rates[19] and a number of local-level initiatives, little is known about the development of readmission rates over the past decade, as well as the overall effect of interventions to improve this aspect of health care quality. We examined readmissions for all non-specialists NHS trusts in England between 2006/07 and 2015/16, and showed that risk-adjusted, 30-day emergency readmission rates following discharge from any indexed admission increased slightly from 6.56% in 2006/07 to 6.76% in 2012/13, followed by a small decrease to 6.64% in 2015/16. At the same time, the degree of variation measured by the SCV decreased from 15.60 in 2006/07 to 14.54 in 2015/16. However, when we disaggregated results by type of admission and clinical condition, we observed heterogeneous trends with decreasing trends for some patient groups, but increasing ones for others. Disaggregating findings by type of admission showed that emergency readmissions following any elective surgery decreased slightly, which could be attributable to initiatives that focussed on improving metrics such as infection rates (e.g. Commissioning for Quality and Innovation scheme in the 2008 NHS Stage Review).[42] However, emergency readmissions following an indexed emergency admission increased over the observation period. Disaggregation by clinical areas showed that readmission rates decreased for patients initially admitted for hip- or knee replacements. Readmission rates stayed about constant for patients initially admitted for heart failure, acute myocardial infarction, stroke and COPD, but increased for patients initially admitted for diabetes, pneumonia, cholecystectomy and hysterectomy. We observed particularly large rises in risk-adjusted, emergency readmission rates in diabetes patients, which could have several possible explanations. For example, it is possible that the coding of diabetes has improved across the observation period. Moreover, it could be linked to significant reductions in mortality from diabetes and rises in the number of socio-economically deprived populations,[43] but has previously also been linked to side effects of diabetic drugs.[44]

While previous studies examined trends in emergency readmission rates for different types of hospitals[45] and surgical emergency readmission rates for selected patient subgroups as a measure for quality of care in the United States,[46] this is the first study that provides a comprehensive overview of trends in risk-adjusted, 30-day emergency readmissions and variation in England over a ten year period and disaggregated for nine clinical conditions. One study that had reported on trends of English emergency readmission rates before, focussed on a period up to May 2010, but did not disaggregate by clinical condition.[47] Our study provides an updated overview of these changes in emergency readmissions until February 2016, and for nine subgroups. Expanding the previous observation period further is particularly important, since the NHS has focused considerable efforts into reducing readmission rates following the publication of *Equity and Excellence* in April 2010. While our study found similar patterns in trends of emergency readmission rates to [47], the magnitude of emergency readmission rates was slightly smaller, 6.67% compared with 7.0%. This is likely to be caused by differences in the methodology used for linking information from HES, and differences in defining indexed admissions.

Large variations in the reporting of readmission rates for specific clinical subgroups exist in the literature. For example, while one study reported the 30-day readmission rate for COPD to be approximately 10.2% in the NHS,[48] the Royal College of Physicians reported much higher rates of approximately 31% to 34%, over a 90-day period.[49] In comparison, we found a readmission rate of 17.0% in 2015/16. Moreover, research from the Unites States suggested readmission rates of 19.9% and 18.3% for acute myocardial infarction and pneumonia, respectively.[50] We found readmissions to be lower in the NHS, 15.2% for acute myocardial infarction and 16.0% for pneumonia in 2015/16. Other research focussed primarily on the examination of care provided at singular pathway points, which included the investigation into mortality rates to assess variation of in-hospital quality between providers[51] and the evaluation of health care policies with emergency readmissions as an outcome indicator.[14,35,36]

Strengths and limitations

We examined changes in 30-day emergency readmission rates across all non-specialist trusts in England between 2006 and 2016. We chose unplanned, emergency readmissions as an outcome measure, as they are mostly undesirable for patients and also add potentially avoidable strain on services. A 30-day follow-up period was chosen to capture the impact of quality along the clinical pathway, including the initial hospital stay,[12] transitional care,[13–15] and post-discharge support.[16,17] However, health service quality may also affect emergency readmissions after 30-days, with studies showing that a follow-up of 90-days may be more appropriate when assessing quality of care provided to older patients with debility, after discharge from rehabilitation services.[52] Other studies have suggested that 7-day emergency readmission rates are more closely related to the quality provided at the initial hospital stay.[53] To investigate this potential threat to the validity of this study, we conducted sensitivity analysis that in addition to 30-day emergency readmissions also investigated changes in trends and variation for 7-day emergency readmissions and 90-day emergency readmissions. Outcomes from the sensitivity analyses did not materially change our findings, with small increases found for 7-day readmission rates, but small decreases in 90-day readmission rates. The SCV for both outcome measures decreased (see Supplementary Appendix C). While our findings present statistically significant differences in readmission rates across financial years, the relative magnitude of change was small, with their clinical meaningfulness depending on the distribution of their incremental changes across trusts.

The validity of emergency readmission rates as a measure for quality of care had been questioned before, mainly due to their sensitivity to changes in patient case-mix, random variation, and the poor correlation with other indicators of hospital quality.[54,55] Since quality is multidimensional, several metrics are needed to provide a comprehensive picture of changes occurred in health care systems and over time, for example total number of bed days over a defined period of time. While the limitations of readmission rates as a metric might be a particularly relevant concern for direct provider comparisons, such as in the case of imposing financial penalties for hospitals with high readmission rates and associated fears about unintended consequences,[56] in this study we aimed to assess overall trends in readmission rates for all trusts and across ten years. This approach helped to deal with random variation and presented longitudinal changes in readmission rates in the English NHS.

We used a large administrative data source that included all hospital inpatients in England and risk-adjusted emergency readmission rates at the patient-level, accounting for systematic differences in observed patient characteristics between trusts. We adjusted for patient demographics, including socio-economic status. Thus, we assumed that any variation in emergency readmissions that correlates with socioeconomic status was outside of the direct control of the health care system. While it is common practice in England to adjust for socio-economic status, however, it is possible that the higher emergency readmission rates observed amongst patients living in more deprived areas is in part due to lower quality health care - a possibility that has been extensively discussed.[56] Another concern relates to omitting variable bias in the risk-adjustment for emergency readmission rates, such as by the lack of information on clinical severity (i.e. acuity determined through laboratory test results) that was found to be highly predictive of a readmission.[57] Our study may therefore dilute the true predicted likelihood (i.e. upward or downward depending on the severity of disease) of a patient having to return to hospital. We were not able to address this limitation within our dataset, but we used the Charlson index to capture some of the patients' clinical complexity[58] and further accounted for improvements in recording practices by including interaction terms of the Charlson index in each financial years into our risk-adjustment model.

We constructed the SCV, a measure that represented potentially 'avoidable' variation that can be attributed to differences in quality of care, provided our controls for patient characteristics that are not under the influence of the health system within the prediction model. Similar to the risk-adjusted readmission rates, the interpretation of the SCV follows the assumption that all 'unavoidable' variation in readmissions was sufficiently addressed by the information that was entered into the prediction model. However, it is possible that other factors explained the variation in emergency readmission rates. In particular, the subgroup analysis showed rises in emergency readmission rates for many of the selected acute conditions. These changes might be explained by reductions in patient mortality, triggered through technological advancements, which have been found to inversely correlate with emergency readmission rates for patient with hip fracture. [59] In fact, increases in readmission rates may reflect positively on the care provided to patients in the NHS. Our findings are also susceptible to time varying confounders, such as the establishment of Hyper Acute Stroke Units in London and Greater Manchester in 2010,[60,61] leading to a step change in quality provided to stroke patients across different parts of the country.

While our study was able to describe overall changes in emergency readmission rates over time, we were not able to make inferences about the effectiveness of specific health care interventions. Future research should therefore evaluate the mechanism of local-level and national-level policies aimed at improving quality of care in England, such as the introduction of financial penalties,[19] or improvements in access to general practitioners.[62] Linkages of secondary care data with information on care received during the post-discharge period would allow establishing causal relationships along the patient pathway. Populating risk-adjustment models with information other than those currently available from secondary care data sets would allow for more precise estimates of risk-adjusted, emergency readmission rates. Future research might also benefit from additional exploration of audit data that could hold information on quality, which is not commonly available within large administrative health datasets.

Conclusions

Small initial rises in emergency readmission rates after discharge from any indexed admission was followed by stable, or even slightly decreasing emergency readmission rates after 2012/13. We also found a decrease in variation from 2006/07 to 2015/16. These changes in readmission rates fall into a period of an enhanced focus on reducing readmission rates in the English NHS, thereby suggesting possible impacts of local-level and national-level efforts to stabilise, or even contain rises emergency readmission rates since 2010. However, changes in both metrics were only modest and they varied widely by clinical area, which might have several possible causes. For example, while reductions in readmissions for long-term conditions may indicate changes in quality provided outside the hospital (*i.e.* in primary care settings), increases in readmissions for acute conditions such as pneumonia patients might be linked to factors in quality not captured through readmission rates, such as improvements in patient survival at the indexed admission. Lastly, and importantly, changes in readmission rates may be related to changes in other factors that we could not adjust for in our analysis.

While the focus on reducing emergency readmission rates across several health care systems may yield certain benefits, policy makers are required to further develop an understanding about changes in variation of care quality over time before introducing targeted and effective improvement strategies. It should be the aim of any health system to provide care at the highest quality standard and equally to all patients regardless of where they access the health system.

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Contributions

RF had the idea for this study. RF and AS came up with the statistical analysis plan. RF carried out the analysis. RF, AS, KH and PA drafted and finalised the paper.

Competing interests

All authors have completed the ICMJE uniform disclosure from at www.icmje.org/coi_disclosure.pdf and declare: RF is the recipient of a studentship from Imperial Patient Safety Translational Research Centre; no financial relationships with any other organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submission.

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Conflict of interest

The authors declare no conflict of interest.

Data sharing

The data controller of the data analysed is NHS Digital. Patient-level data is available subject to their information governance requirements.

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FIGURE LEGENDS

Figure 1: Trends in risk-adjusted, 30-day emergency readmission rates and variation in England from 2006/07 to 2015/16

Figure 2: Trends in risk-adjusted, 30-day emergency readmission rates for a) indexed acute conditions, b) indexed chronic conditions, and c) surgical interventions from 2006/07 to 2015/16.

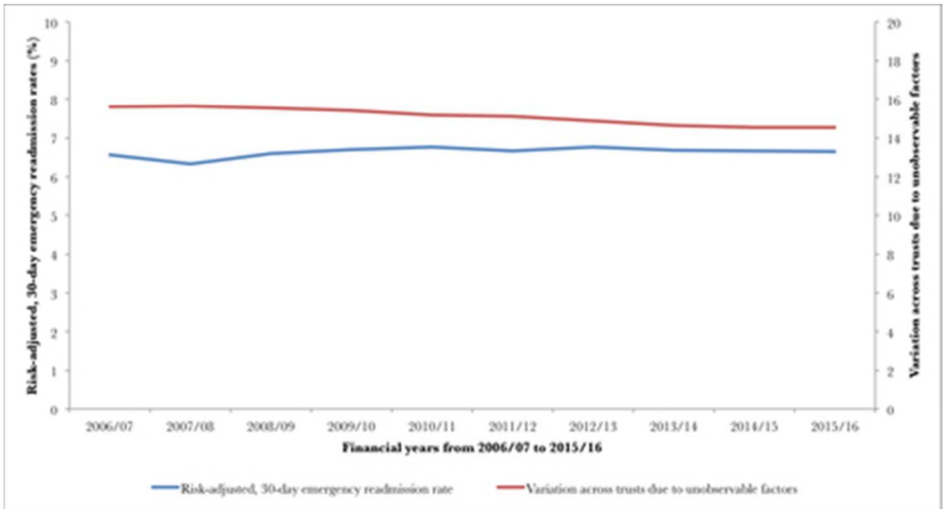

Figure 1: Trends in risk-adjusted, 30-day emergency readmission rates and variation in England from 2006/07 to 2015/16

39x21mm (300 x 300 DPI)

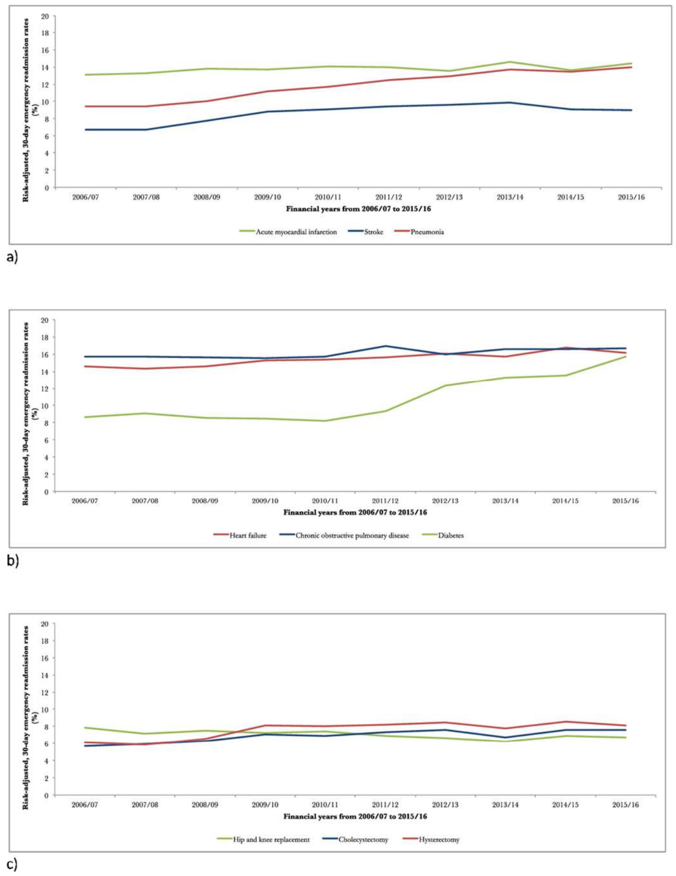

Figure 2:Trends in risk-adjusted, 30-day emergency readmission rates for a) indexed acute conditions, b) indexed chronic conditions, and c) surgical interventions from 2006/07 to 2015/16.

118x168mm (300 x 300 DPI)

Appendix A: List of ICD-10 codes and OPSC-4 codes used for subgroup analyses

Condition	ICD-10	OPCS-4
Acute Myocardial Infarction	I21, I210, I211, I212, I213, I214, I219 I22, I220, I221, I228, I229	- -
Stroke	I60, I61, I62, I63, I64	-
Pneumonia	J12, J13, J14, J15, J16, J17, J18	-
Chronic Obtructive Pulmonary Disease	I278, I279, J40, J41, J42, J43, J44, J45, J46, J47, J61, J62, J63, J64, J65, J66, J67, J684, J701, J703	- - -
Heart failure	I110, I130, I132, I50, I501, I509, J81X	-
Diabetes	E10, E11, E12, E13, E14	-
Hip and knee replacement	- - - - - - -	W371 W378 W379 W381 W388 W389 W391 W398 W399 W461 W468 W469 W471 W478 W479 W481 W488 W489 W931 W938 W939 W941 W948 W949 W951 W958 W959 W521 W528 W529 W531 W538 W539 W541 W548 W371 W378 W379 W381 W388 W389 W391 W398 W399 W521 W528 W529 W531 W538 W539 W541 W548 W549 O181 O188 O189 W400 W402 W403 W404 W410 W412 W413 W414 W420 W422 W423 W581 W582 W424 W425 W426 W520 W522 W523 W530 W532 W533 W540 W542 W543 W544 O180 O182 O183 O184
Cholecystectomy	-	J18
Hysterectomy	-	Q07

Appendix B: Computation formula for calculating the systematic component of variation

$$SCV = \left[\frac{\sum_i \frac{(OR_i - ER_i)^2}{ER_i^2} - \sum_i \frac{1}{ER_i}}{n-1}\right] x\ 100$$

Appendix C: Ordinary least squares regression analysis

	30-day emergency readmission rates (risk-adj)		
Variable	Coefficient	Std. Err.	t-statistics
Constant	6.56***	0.08	80.95
FY 2006/07		Baseline	
FY 2007/08	-0.23 **	0.11	-2.05
FY 2008/09	0.03	0.11	0.32
FY 2009/10	0.13	0.10	1.20
FY 2010/11	0.21**	0.10	1.95
FY 2011/12	0.10	0.10	0.96
FY 2012/13	0.20*	0.10	1.88
FY 2013/14	0.12	0.10	1.13
FY 2014/15	0.09	0.10	0.89
FY 2015/16	0.08	0.10	0.75
N	1446		
R-squared	0.01		

Note: *** indicates that the variable has robust impact on dependent variable at 1% significance level, ** for 5% and * for 10%.

Appendix D: Sensitivity analysis for 7-day and 90-day emergency readmission rates

	FY 2006/07			FY 2015/16		
	No of indexed admissions	*Mean (Std. Dev.)*	*SCV*	*No of indexed admissions*	*Mean (Std. Dev.)*	*SCV*
7-day emergency readmission (any indexed admission)	5 728 882	3.20 (0.56)	31.11	7 123 792	3.37 (0.58)	29.27
30-day emergency readmission (any indexed admission)	5 204 263	6.50 (0.95)	15.60	6 219 153	6.73 (0.93)	14.58
90-day emeregency readmission (any indexed admission)	4 597 361	9.99 (1.33)	10.42	5 088 164	9.78 (1.22)	9.85

Note: Crude readmission rates weighted by the number of indexed admissions per trust.

STROBE Statement—checklist of items that should be included in reports of observational studies

National trends in emergency readmission rates: A longitudinal analysis of administrative data for England between 2006 and 2016.

Rocco Friebel[1 2], Katharina Hauck[1], Paul Aylin[1] and Adam Steventon[2]

[1] School of Public Health, Imperial College London, South Kensington Campus, London, SW7 2AZ

[2] Data Analytics, The Health Foundation, 90 Long Acre, London, WC2E 9RA

Rocco Friebel, Doctoral Researcher; Data Analyst

Katharina Hauck, Senior Lecturer in Health Economics

Paul Aylin, Professor of Epidemiology and Public Health

Adam Steventon, Director of Data Analytics

Correspondence to: rocco.friebel@health.org.uk, 0207 257 8000

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1/2	
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2	
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3+4	
Objectives	3	State specific objectives, including any prespecified hypotheses	3+4	

Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5+6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—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 *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5+6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5+6+7
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	5+6+7
Bias	9	Describe any efforts to address potential sources of bias	7
Study size	10	Explain how the study size was arrived at	5+6+7

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6+7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7+8
		(*b*) Describe any methods used to examine subgroups and interactions	6+8
		(*c*) Explain how missing data were addressed	5
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5+9
		(b) Give reasons for non-participation at each stage	5+9
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	5
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	11
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	

Continued on next page

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13+13 (Table 2)	
Discussion				
Key results	18	Summarise key results with reference to study objectives	14	1st Paragraph
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	15+16+17	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	15+16+17+18	
Generalisability	21	Discuss the generalisability (external validity) of the study results	15+16+17	
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	19	

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.