Mortality risks associated with emergency admissions during weekends and public holidays: an analysis of electronic health records

Article (Published Version)


This version is available from Sussex Research Online: http://sro.sussex.ac.uk/id/eprint/68155/

This document is made available in accordance with publisher policies and may differ from the published version or from the version of record. If you wish to cite this item you are advised to consult the publisher’s version. Please see the URL above for details on accessing the published version.

Copyright and reuse:
Sussex Research Online is a digital repository of the research output of the University.

Copyright and all moral rights to the version of the paper presented here belong to the individual author(s) and/or other copyright owners. To the extent reasonable and practicable, the material made available in SRO has been checked for eligibility before being made available.

Copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.
Mortality risks associated with emergency admissions during weekends and public holidays: an analysis of electronic health records

A Sarah Walker*, Amy Mason*, T Phuong Quan, Nicola J Fawcett, Peter Watkinson, Martin Llewelyn, Nicole Stoesser, John Finney, Jim Davies, David H Wyllie, Derrick W Crook, Tim E A Peto

Summary

Background Weekday hospital admission is associated with increased mortality, but the contributions of varying illness severity and admission time to this weekend effect remain unexplored.

Methods We analysed unselected emergency admissions to four Oxford University National Health Service hospitals in the UK from Jan 1, 2006, to Dec 31, 2014. The primary outcome was death within 30 days of admission (in or out of hospital), analysed using Cox models measuring time from admission. The primary exposure was day of the week of admission. We adjusted for multiple confounders including demographics, comorbidities, and admission characteristics, incorporating non-linearity and interactions. Models then considered the effect of adjusting for 15 common haematology and biochemistry test results or proxies for hospital workload.

Findings 257 596 individuals underwent 503 938 emergency admissions. 18 313 (4·7%) patients admitted as weekday emergency admissions and 6070 (5·1%) patients admitted as weekend emergency admissions died within 30 days (p<0·0001). 9347 individuals underwent 9707 emergency admissions on public holidays. 559 (5·8%) died within 30 days (p<0·0001 vs weekday). 15 routine haematology and biochemistry test results were highly prognostic for mortality. In 271 465 (53·9%) admissions with complete data, adjustment for test results explained 33% (95% CI 21 to 70) of the excess mortality associated with emergency admission on Saturdays compared with Wednesdays, 52% (lower 95% CI 34) on Sundays, and 87% (lower 95% CI 45) on public holidays after adjustment for standard patient characteristics. Excess mortality was predominantly restricted to admissions between 1100 h and 1500 h (pinteraction=0·04). No hospital workload measure was independently associated with mortality (all p values >0·06).

Interpretation Adjustment for routine test results substantially reduced excess mortality associated with emergency admission at weekends and public holidays. Adjustment for patient-level factors not available in our study might further reduce the residual excess mortality, particularly as this clustered around midday at weekends. Hospital workload was not associated with mortality. Together, these findings suggest that the weekend effect arises from patient-level differences at admission rather than reduced hospital staffing or services.

Funding NIHR Oxford Biomedical Research Centre.

Copyright © The Author(s). Published by Elsevier Ltd. This is an Open Access article under the CC BY-NC-ND 4.0 license.

Introduction Substantial medical and public attention has been paid to the so-called weekend effect, namely that patients admitted to hospital at the weekend have greater mortality than do patients admitted on weekdays. This independent effect has been demonstrated in large national and international studies, in elective, emergency and all admissions.

Although the excess mortality risk associated with weekend admission appears clear, the underlying causal mechanisms are not. Many hospitals are widely assured to have fewer staff and resources at weekends than on weekdays, affecting patient care. Findings from studies into the weekend effect have led the UK Government to commit to providing National Health Service (NHS) hospital care as a 7-day service.

However, it is being admitted at weekends, rather than merely being in hospital at weekends, that has been consistently associated with higher mortality risk; reduced weekend staffing and resources should affect all patients in hospital at weekends, not just those newly admitted. Alternative explanations for the weekend effect include variation in patient factors (eg, presenting illness severity, delayed presentation, frailty) that are not completely captured in administrative datasets used in many studies to date. In such studies the factor most closely reflective of the severity of presenting illness is the intrinsic mortality risk score based on clinical classifications software, which leaves substantial potential for residual confounding of admission-day effects by the individual patient’s illness severity (appendix p 24). Findings from a 2016 study showing increased mortality risk only in patients admitted at weekends from general practitioners (rather than via the emergency room) provide indirect evidence supporting this notion.
Studies using clinical datasets with more detailed prognostic data have generally been restricted to specific conditions or have been much smaller. It is also unclear how the excess risk is distributed across the 48 h of weekend admissions (with time of admission unavailable in hospital episode statistics). Here, we use information from common haematology and biochemistry tests done around admission, and admission time, from the Infections in Oxfordshire Research Database (IORD) to investigate explanations for the mortality weekend effect in emergency admissions to one large hospital group.

**Methods**

**Study design and participants**

IORD contains anonymised data from all admissions to the four hospitals that make up the Oxford University Hospitals NHS Foundation Trust from April 1, 1997, linked to haematology, biochemistry, and microbiology test results. These hospitals (which include a district general hospital, a large teaching hospital, a specialist orthopaedic hospital, and a major cancer centre) provide all acute care and pathology services in the region, supplying a population of about 600,000 individuals. Out-of-hospital mortality is determined by regular updates from the national information system that records all UK deaths, the National Health Service clinical spine application.

We analysed data from all emergency admissions (defined by all codes with prefix 2 for the variable “admission method”), including patients admitted via the accident and emergency department, general practitioners, consultant clinics, and other methods from Jan 1, 2006, to Dec 31, 2014. We excluded elective admissions because different factors might affect risks associated with weekend admission (eg, restriction of specific surgery lists to particular weekdays). IORD has Research Ethics Committee and Health Research Authority approval (14/SC/1069, ECC5-07[a]/2009).

**Evidence before this study**

We searched PubMed for publications from inception up until June 15, 2016, with the terms “weekend” AND “admission” AND “mortality”, with no language restrictions, and also reviewed references from retrieved articles. Weekend emergency admissions have been associated with an excess risk of dying in the next 30 days compared with weekday admissions (after adjusting for patient-level factors available in administrative datasets) in large national and international studies, in all admissions and in subgroups defined by elective admissions, emergency admissions, and clinical subgroups (eg, stroke). The excess mortality is often attributed to differences in staffing levels or service provision at the weekends. However, there is indirect evidence that the excess mortality could be attributed to inadequate adjustment for how sick the patients admitted at weekends are.

**Added value of this study**

We used a large comprehensive warehouse of electronic health records to adjust individual-level analyses for factors not previously considered, including haematology, biochemistry, and microbiology tests, and time of admission. We found that adjustment for 15 routinely measured haematology and biochemistry test results could explain a substantial proportion of the excess mortality effect associated with weekend emergency admission. The remaining excess deaths predominantly occurred in patients admitted as emergencies between 1100 h and 1500 h at the weekend. The excess mortality was not associated with multiple measures of hospital workload.

**Implications of all available evidence**

These results are not consistent with staffing or service provision being the primary driver of the weekend effect, and suggest that much of the remaining excess mortality could be accounted for by other characteristics of the patients, their health-seeking behaviour, or availability of services outside the hospital.

**Outcomes**

The primary outcome was 30-day mortality (in hospital or after discharge) for consistency with previous studies, censoring at the earliest of the following three dates: 30 days after admission, last routine vital status update, or last subsequent admission or discharge. Cox regression (which implicitly adjusts for days at risk) considered days from admission.

**Statistical analysis**

As exposures, we first considered all admission factors adjusted for in previous NHS studies (appendix p 24). Of 504,563 total emergency admissions, we excluded 69 admissions with missing age, one with negative age, seven admissions with missing sex or intersex, and 548 admissions with missing diagnostic codes (total 625 [0.1%]), leaving 503,938 admissions in regression analyses. The primary exposure was admission day of the week, prespecified to be included irrespective of statistical significance; as in previous studies, the reference category was Wednesday because this is the middle of the week. For other factors, model selection used backwards elimination based on minimisation of the Bayesian information criterion, using natural cubic splines for non-linear effects in continuous factors. We then identified pairwise interactions between included factors using forward selection based on the Bayesian information criterion to produce the final model (model A), also fitted to 7-day, 14-day, and 21-day mortality as secondary outcomes. Admission day of week was categorised as weekend (Saturday or Sunday) versus...
weekday to increase power to identify interactions. Secondary analyses investigated mortality risk for admission on public holidays. Sensitivity analyses included current day of the week at risk in a time-updated Cox model. Full details are provided in the appendix (p 4).

We then investigated the subgroup with 15 commonly performed haematology and biochemistry test results (haemoglobin, platelets, lymphocytes, neutrophils, eosinophils, monocytes, C-reactive protein, urea, bilirubin, creatinine, albumin, alanine aminotransferase, alkaline phosphatase, sodium, and potassium, using the closest result to admission time within 2 calendar days before or after admission). Several of these tests reflect the presence of underlying infection. We chose tests on the basis of the percentage of these tests reflect the presence of underlying infection. We chose tests on the basis of the percentage of test results, ranging from 53·0% to 54·5% across admission days (18244 [74·8%] of 24383 admissions after which patients were not known to have died within 30 days; appendix p 6).

Values for nine of the 15 test results were markedly exceeded 100%. We estimated excess hazards associated with admission day over time from admission using the closest result to admission time within 2 calendar days before or after admission). Several of these tests reflect the presence of underlying infection. We chose tests on the basis of the percentage of these tests reflect the presence of underlying infection. We chose tests on the basis of the percentage of test results, ranging from 53·0% to 54·5% across admission days (18244 [74·8%] of 24383 admissions after which patients were not known to have died within 30 days; appendix p 6).

Using model A, all the factors adjusted for in previous published analyses or studies of administrative datasets had an independent effect on 30-day mortality (C-statistic 0·88; appendix pp 9, 12), as did weekend emergency admission (adjusted relative risk [aRR] for Saturday vs Wednesday 1·09 [95% CI 1·03–1·14]; figure 2). This excess mortality was slightly larger when we fitted the identical model to emergency admissions with all 15 test results, aRR for Saturday vs Wednesday 1·11 [95% CI 1·05–1·17], aRR for Sunday vs Wednesday 1·11 [1·05–1·18]; C-statistic 0·84; figure 2, appendix p 12), but we found no evidence of heterogeneity (Pinteraction =0·18). There was no evidence that admissions with complete test results had higher adjusted mortality than those without all test results (aRR 1·01 [95% CI 0·98–1·04], p=0·40). Absolute mortality risks, and excess risks associated with weekend admission, were greatest in the first 2–5 days after admission (figure 3).

Values for nine of the 15 test results were markedly different for weekend versus weekday emergency admissions (eg, median neutrophil count and C-reactive protein; figure 1, appendix p 26). This difference was predominantly due to proportionately fewer patients with normal results being admitted at weekends than on weekdays, although the absolute numbers of...
admissions with abnormal results also fell (appendix p 27–28). In model B, each test result independently predicted 30-day mortality after adjustment for model A factors (appendix p 30). Several test results, notably lymphocyte count and sodium and urea concentrations, affected mortality risk even within normal ranges. Eight interactions with test results added predictive information (C-statistic 0·89; appendix pp 10, 30).

Figure 1: Characteristics of emergency admissions

(A) Mean total number of admissions over 8 years by day of the week. (B) Total number of admissions by calendar year and weekday vs weekend. (C) Median age at admission. (D) Mean Charlson Comorbidity Index (68·6% of admissions had Charlson score 0, so mean rather than median is shown). (E) Median neutrophils at admission (×10⁹/L). (F) Median C-reactive protein concentration at admission (mg/L).
In admissions with complete data, test results accounted for 33% (95% CI 21 to 70) of the excess mortality risk for emergency admission on Saturday and 52% (lower 95% CI 34) of the risk for Sunday, compared with emergency admission on Wednesday (figure 2). The adjusted relative risk for residual excess mortality (ie, after adjusting for test results) fell to 1.07 (95% CI 1.01–1.13) for Saturday and 1.05 (1.00–1.11) for Sunday, compared with Wednesday. The residual excess mortality associated with weekend emergency admission was not restricted to any patient or clinical subgroup defined by model A factors, and did not vary by calendar year.

<table>
<thead>
<tr>
<th>Day of admission</th>
<th>Emergency admissions (n=503,938)</th>
<th>Emergency admissions on weekdays (n=285,647)</th>
<th>Emergency admissions on weekends (n=118,291)</th>
<th>Deaths within 30 days (n=24,383)*</th>
<th>Emergency admissions with complete test results (n=271,465)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>80,950 (16.1%)</td>
<td>49,465 (17.2%)</td>
<td>31,485 (16.1%)</td>
<td>3900 (4.8%)</td>
<td>41,662 (16.1%)</td>
</tr>
<tr>
<td>Tuesday</td>
<td>75,596 (15.0%)</td>
<td>45,755 (16.0%)</td>
<td>29,841 (15.0%)</td>
<td>3611 (4.4%)</td>
<td>41,101 (15.1%)</td>
</tr>
<tr>
<td>Wednesday</td>
<td>75,732 (15.0%)</td>
<td>45,967 (16.0%)</td>
<td>29,765 (15.0%)</td>
<td>3607 (4.4%)</td>
<td>41,050 (15.1%)</td>
</tr>
<tr>
<td>Thursday</td>
<td>74,975 (14.9%)</td>
<td>44,250 (15.6%)</td>
<td>30,725 (15.9%)</td>
<td>3541 (4.7%)</td>
<td>40,867 (15.1%)</td>
</tr>
<tr>
<td>Friday</td>
<td>78,194 (15.6%)</td>
<td>46,204 (16.2%)</td>
<td>32,090 (16.0%)</td>
<td>3564 (4.7%)</td>
<td>41,579 (15.3%)</td>
</tr>
<tr>
<td>Saturday</td>
<td>59,242 (11.8%)</td>
<td>32,607 (11.4%)</td>
<td>26,635 (12.7%)</td>
<td>3100 (5.2%)</td>
<td>31,469 (11.6%)</td>
</tr>
<tr>
<td>Sunday</td>
<td>59,049 (11.7%)</td>
<td>32,295 (11.3%)</td>
<td>26,754 (13.1%)</td>
<td>2970 (5.0%)</td>
<td>31,728 (11.7%)</td>
</tr>
<tr>
<td>Calendar year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010 (2008–2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012 (2008–2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014 (2008–2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010 (2008–2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012 (2008–2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014 (2008–2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Table continues on next page)
(Continued from previous page)

<table>
<thead>
<tr>
<th>Emergency admissions (n=503 938)</th>
<th>Emergency admissions on weekdays (n=385 647)</th>
<th>Emergency admissions on weekends (n=118 291)</th>
<th>Deaths within 30 days (n=24 383)*</th>
<th>Emergency admissions with complete test results (n=27 1465)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td>127 254 (25.3%)</td>
<td>99 668 (25.8%)</td>
<td>27 586 (23.3%)</td>
<td>10 850 (8.5%)</td>
</tr>
<tr>
<td>Low-risk</td>
<td>85 321 (16.9%)</td>
<td>66 260 (17.2%)</td>
<td>19 061 (16.1%)</td>
<td>203 (0.2%)</td>
</tr>
<tr>
<td>Non-specific chest pain</td>
<td>20 802 (4.1%)</td>
<td>16 176 (4.2%)</td>
<td>4 626 (3.9%)</td>
<td>119 (0.6%)</td>
</tr>
<tr>
<td>Abdominal pain</td>
<td>18 486 (3.7%)</td>
<td>14 392 (3.7%)</td>
<td>4 094 (3.5%)</td>
<td>158 (0.9%)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>12 582 (2.5%)</td>
<td>9 336 (2.4%)</td>
<td>3 246 (2.7%)</td>
<td>256 (2.0%)</td>
</tr>
<tr>
<td>Acute bronchitis</td>
<td>11 675 (2.3%)</td>
<td>8 809 (2.3%)</td>
<td>2 866 (2.4%)</td>
<td>77 (6.6%)</td>
</tr>
<tr>
<td>Superficial injury, contusion</td>
<td>11 236 (2.2%)</td>
<td>7 737 (2.0%)</td>
<td>3 499 (3.0%)</td>
<td>173 (1.5%)</td>
</tr>
<tr>
<td>Urinary tract infection</td>
<td>11 182 (2.2%)</td>
<td>8 218 (2.1%)</td>
<td>2 964 (2.5%)</td>
<td>57 (5.1%)</td>
</tr>
<tr>
<td>Fracture of upper limb</td>
<td>10 194 (2.0%)</td>
<td>7 347 (1.9%)</td>
<td>2 847 (2.4%)</td>
<td>87 (6.9%)</td>
</tr>
<tr>
<td>Skin and subcutaneous tissue infection</td>
<td>9 874 (2.0%)</td>
<td>7 750 (2.0%)</td>
<td>2 124 (1.8%)</td>
<td>127 (3.3%)</td>
</tr>
</tbody>
</table>

Data are n (%) or median (IQR). Details about other categories, other clinical classification software groups, and relative risk estimates from unadjusted and adjusted models are provided in the appendix (p 12). NHS-National Health Service. *Column shows number of deaths as a proportion of emergency admissions.

Table: Cohort characteristics

(Continued from previous page)

In sensitivity analyses, the addition of an indicator that blood had been taken for culture (suggesting doctors suspected bacterial infection) or for blood gas analysis improved model B ($p_{\text{interaction}}=0.004$) and bilirubin ($p_{\text{interaction}}=0.002$) were small in magnitude and did not explain the weekend effect (appendix p 40; $p_{\text{interaction}}>0.10$ for other interactions between weekend versus weekday admission and test results).

In sensitivity analyses, the addition of an indicator that blood had been taken for culture (suggesting doctors suspected bacterial infection) or for blood gas analysis improved model B ($p_{\text{interaction}}=0.004$) and bilirubin ($p_{\text{interaction}}=0.002$) were small in magnitude and did not explain the weekend effect (appendix p 40; $p_{\text{interaction}}>0.10$ for other interactions between weekend versus weekday admission and test results).

In sensitivity analyses, the addition of an indicator that blood had been taken for culture (suggesting doctors suspected bacterial infection) or for blood gas analysis improved model B ($p_{\text{interaction}}=0.004$) and bilirubin ($p_{\text{interaction}}=0.002$) were small in magnitude and did not explain the weekend effect (appendix p 40; $p_{\text{interaction}}>0.10$ for other interactions between weekend versus weekday admission and test results).

In sensitivity analyses, the addition of an indicator that blood had been taken for culture (suggesting doctors suspected bacterial infection) or for blood gas analysis improved model B ($p_{\text{interaction}}=0.004$) and bilirubin ($p_{\text{interaction}}=0.002$) were small in magnitude and did not explain the weekend effect (appendix p 40; $p_{\text{interaction}}>0.10$ for other interactions between weekend versus weekday admission and test results).

In sensitivity analyses, the addition of an indicator that blood had been taken for culture (suggesting doctors suspected bacterial infection) or for blood gas analysis improved model B ($p_{\text{interaction}}=0.004$) and bilirubin ($p_{\text{interaction}}=0.002$) were small in magnitude and did not explain the weekend effect (appendix p 40; $p_{\text{interaction}}>0.10$ for other interactions between weekend versus weekday admission and test results).

In sensitivity analyses, the addition of an indicator that blood had been taken for culture (suggesting doctors suspected bacterial infection) or for blood gas analysis improved model B ($p_{\text{interaction}}=0.004$) and bilirubin ($p_{\text{interaction}}=0.002$) were small in magnitude and did not explain the weekend effect (appendix p 40; $p_{\text{interaction}}>0.10$ for other interactions between weekend versus weekday admission and test results).

In sensitivity analyses, the addition of an indicator that blood had been taken for culture (suggesting doctors suspected bacterial infection) or for blood gas analysis improved model B ($p_{\text{interaction}}=0.004$) and bilirubin ($p_{\text{interaction}}=0.002$) were small in magnitude and did not explain the weekend effect (appendix p 40; $p_{\text{interaction}}>0.10$ for other interactions between weekend versus weekday admission and test results).
except in the middle of the day (1100–1500 h). Between 1100 h and 1500 h at weekends, evidence of a 1·18-times increase (95% CI 1·10–1·27) in relative mortality risk for emergency admission remained.

**Discussion**

Findings from large-scale studies of hospital episode statistics have shown that admission to hospital at weekends is associated with increased risk of death within 30 days compared with admission during the week.1–10,16 We used a comprehensive warehouse of electronic health records from four hospitals within a large NHS trust to examine the effect of accounting for illness severity and admission time on this excess risk. Results of common haematology and biochemistry tests, not available in previous studies,3–5,7 often differed markedly between weekend and weekday admissions and by admission hour. These test results strongly and independently predicted 30-day mortality. In admissions with complete data, adjustment for these results accounted for 33–52% of the excess mortality associated with weekend emergency admission. Furthermore, the residual so-called weekend effect was predominantly restricted to the middle of the day on Saturdays and Sundays, with no excess mortality remaining for weekend nights. No patient or clinical subgroups had more or less pronounced residual risk of excess mortality.

Previous findings have been interpreted as suggesting that reduced staffing is a major driver of the excess mortality risk associated with weekend admissions (not necessarily the authors' conclusion).7 However, our measures of hospital workload, reflecting adequacy of staffing levels and service provision relative to each specific day of the week, were not associated with mortality. Further, the excess mortality associated with admission on public holidays was almost completely removed by adjusting for test results reflecting physiological dysregulation on admission. That is, the increased unadjusted risk was mostly explained by increased intrinsic mortality risk in patients who presented to hospital during public holidays. Because staffing levels and services are more similar on public holidays and weekends, it seems unlikely that differences in staffing levels or services alone would explain the excess mortality associated with weekend versus weekday admission.

---

**Figure 2:** Mortality risk associated with day of admission with and without adjustment for admission test results

(A) Mortality risk by day of week of admission in all emergency admissions. (B) Mortality risk by day of week of admission in emergency admissions with complete test results. (C) Mortality risk by public holiday vs Saturday vs Sunday. Freemantle results are reported to two decimal places, and therefore plotted 95% CIs are not symmetrical.
previous study\textsuperscript{11} that showed that the weekend effect was unaffected by adjustment for several highly prognostic factors reflecting staffing and service provision in 294 602 emergency admissions for specific surgical procedures, and from another study\textsuperscript{21} showing no evidence of association between hospital specialist staffing at weekends and mortality for emergency admissions.

Our data support previous findings\textsuperscript{7} that the main effect is not of current day of the week (Monday–Sunday) the patient is in hospital, only the day of the week of admission. This finding could suggest that effective early management is crucial (the so-called golden hour), supported by the excess mortality risk being greatest in the first 2 days after admission (figure 3). However, failure to manage patients optimally in this golden hour at the weekend (eg, due to reduced staffing or services) could not account for our observation that the weekend effect was restricted to admissions in the middle of the day (1100 h to 1500 h).

Restrictions in access to senior staff, imaging, or other diagnostic tests are similar across the weekend. Other factors we could not account for might explain this mortality excess in the middle of the day. Examples might be reduced access to primary and social care for vulnerable people (eg, at weekends, frail elderly people are more likely to be admitted than referred to more appropriate services), or differences in health-seeking behaviour at weekends (eg, delays in access to primary care, reduced availability of other services, or reluctance to attend emergency departments on Friday or Saturday nights).

Although generally recognised in the literature that the case mix of patients admitted at weekends differs from that of patients admitted on weekdays and that administrative data are inadequate for measurement of illness acuity, these datasets have nevertheless been widely used to investigate the weekend effect. Our ability to investigate the effect of test results, admission time,
and hospital workload are major strengths of this study. Previous studies have considered overnight versus daytime, or shift patterns in small studies,\textsuperscript{21} in specific conditions,\textsuperscript{22} or did not adjust for illness severity.\textsuperscript{23} We analysed data from unselected emergency admissions, avoiding potential coding bias by restricting our analysis to specific subgroups.\textsuperscript{24} We considered overall mortality because it is most relevant to patients, it incorporates discharge for palliative care, and because being discharged alive is a competing risk for in-hospital mortality.\textsuperscript{25} We did many sensitivity analyses to assess the robustness of our results.

A major limitation is that we did not have access to patients’ vital signs or direct measures of acute illness severity (eg, National Early Warning Score, Sequential Organ Failure Score) or frailty (Barthel score). Blood lactate and blood gases were not measured in most patients. In view of the reductions in the weekend effect we found by adjusting for haematology and biochemistry test results, it is plausible that much of the remaining excess risk could be explained by accounting for other patient-level factors. For example, some study findings suggest that adjustment for National Early Warning System score\textsuperscript{26} or arrival by ambulance\textsuperscript{27} (also unavailable in our study) might help to explain the weekend effect. Not all admissions had complete test results; this aspect might limit the generalisability of our model B findings. Completeness was greater in patients who died within 30 days of admission. However, admissions with complete test results were broadly representative of the full dataset (table 1, appendix p 12), model A provided similar results in all admissions and in admissions with complete test results, and there was no statistical evidence that individuals with complete test results had increased mortality after adjustment. Modest oversampling of more severe cases with more abnormal results, and undersampling of less severe cases with normal results, would (if anything) lead to dilution bias, meaning the genuine effect of test results would be larger, potentially further attenuating the weekend effect. Staffing data were not available, so we used proxies for hospital workload. We might not have found an effect of hospital workload because these were inadequate proxies.

Our study was done in a single hospital group; however, it consists of four large hospitals (including a district general hospital, a large teaching hospital, a specialist orthopaedic hospital, and a major cancer centre), with substantial numbers of emergency admissions to three of the four hospitals, serving a diverse urban and rural local population and accounting for about 1% of the UK population. Both our hospital mix and the similarity of

Figure 4: 30-day mortality by time and day of admission
(a) Unadjusted 30-day mortality. (B) Model A, including admission hour as a factor. (C) Model A with grouped admission hour. (D) Model B with grouped admission hour. p values for pairwise comparisons of weekend vs weekday admission are shown for parts C and D.
our results to previous multicentre or England-wide studies5,14 suggest broad generalisability of our findings in terms of the potential for residual confounding from presenting illness severity, with important implications for future studies. For example, investigations of the effect of organisation of health-care services on patient outcomes might be irrevocably biased without adequate adjustment for severity of the presenting illness. Whether the clustering of excess weekend mortality in the middle of the day is generalisable depends on its underlying mechanism, which requires further investigation. Investigators of one large study28 of stroke care noted several patterns of weekly variation, probably with different underlying causes. Lastly, standardised mortality ratios, our primary outcome, might not be the most appropriate way to measure quality of hospital care.29

In summary, we found that 33–52% of the residual excess mortality associated with weekend emergency admission after adjustment for standard patient characteristics, and 87% of the excess mortality associated with emergency admission during public holidays, can be explained by results from 15 commonly measured blood test results. The residual excess is predominantly restricted to weekend admissions between 1100 h and 1500 h. Mortality is not associated with relative hospital workload. Levels of staffing and services available in hospitals therefore seem unlikely to explain differences in mortality associated with weekend emergency admission. Other more plausible explanations include differences in patients who attend hospitals at these times (eg, in oximetry or vital signs), factors determining their health-care-seeking behaviour, and availability of services outside the hospital at weekends. As such, increased mortality in patients admitted between 1100 h and 1500 h at weekends might not be preventable through implementation of 7-day hospital services.176 By contrast, the unintended consequence of patients delaying presenting to hospital because of fears of worse care at the weekends poses a clear, avoidable danger.30

Contributors
AM planned the statistical analysis, cleaned and analysed the data, and drafted and revised the paper. ASW initiated the project, planned the statistical analysis, cleaned and analysed the data, interpreted the data, and drafted and revised the paper. ASW and AM are the guarantors and their contribution is considered equal. TPQ acquired the data from IORD and revised the paper. NJF advised on medical research ethics and revised the paper. TEAP and DWC are NIHR Senior Investigators. The views expressed are those of the authors and not necessarily those of the NHS, the NIHR, the Department of Health, or Public Health England. IORD has Research Ethics Committee and Health Research Authority approval as a generic electronic research database (I4/SC/1069, ECCS-017/a/2009).

References
12 Academy of Medical Royal Colleges. Seven day consultant present care. London: Academy of Medical Royal Colleges, 2012.


25 Wolkewitz M, Cooper BS, Bonten MJM, Barnett AG, Schumacher M. Interpreting and comparing risks in the presence of competing events. *BMJ* 2014; 349: g4060.

26 Mohammed MA, Faisal M, Richardson D, et al. Adjusting for illness severity shows there is no difference in patient mortality at weekends or weekdays for emergency medical admissions. *QJM* 2016; published online July 11. DOI:10.1093/qimnd/hcw104.


