Original Article

The economic impact of acute kidney injury in England

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ABSTRACT

Background. Acute kidney injury (AKI) is one of the most common complications affecting hospital inpatients around the world. It is associated with high mortality and adverse long-term outcomes, but there is uncertainty regarding its prevalence and cost. We estimate the prevalence of AKI in hospital inpatients in a universal health-care system, and the immediate and long-term impacts on survival, quality of life and health-care costs.

Methods. We examined prevalence of AKI in inpatients using both routine national data for the National Health Service (NHS) in England, and laboratory data from East Kent Hospitals. We used regression analyses to estimate the impact of AKI on mortality and length of hospital stay, and a Markov model to estimate the impact on quality-adjusted life years and NHS costs.

Results. AKI was recorded in 2.43% of hospital admissions in Hospital Episode Statistics (HES), but age- and gender-standardized estimates derived from laboratory data suggest the true prevalence may be more than five times as high (14.15%). We estimate that the annual number of excess inpatient deaths associated with AKI in England may be above 40,000. The annual cost of AKI-related inpatient care in England is estimated at £1.02 billion, just over 1% of the NHS budget. The lifetime cost of post-discharge care for people who had AKI during hospital admission in 2010–11 is estimated at £179 million.

Conclusions. AKI prevalence in inpatients may be considerably higher than previously thought, and up to four fifths of cases may not be captured in routine hospital data. AKI is associated with large numbers of in-hospital deaths and with high NHS costs. Comparison of HES and East Kent data suggests that most of the cases recorded in HES may be relatively severe AKI (AKIN 2–3).

Keywords: acute kidney injury, cost, economics, mortality

INTRODUCTION

Acute kidney injury (AKI) is one of the most serious and common complications affecting hospital inpatients, and incidence is believed to be rising [1–4]. It is associated with adverse outcomes and high mortality, independent of other risk factors [5–7]. Even mild cases of AKI are associated with increased in-hospital mortality risk [8], and patients who recover kidney function after AKI are at increased risk of developing chronic kidney disease (CKD) and of death [9]. There is evidence that deficiencies in clinical care may contribute to the development and progression of the condition. In the UK, a recent report by the National Confidential Enquiry into Patient Outcome and Death (NCEPOD) [10] found that 30% of AKI cases occurring during hospital admission were avoidable, and that only 50% of patients with AKI received an overall standard of care that was considered good.

Measurement of the incidence and prevalence of AKI, and analysis of outcomes, have in the past been hampered by the lack of an agreed definition. Most studies have focused on relatively severe AKI [11, 12], on AKI in intensive care units [13–16] or on patients who require renal replacement therapy (RRT) [17, 18]. A 2002 study found that 7.2% of patients at a US centre acquired some degree of renal impairment during hospital admission [19]. Newly developed classification systems in recent years have focused on AKI as a spectrum of disease, and create the potential for more robust measurement of prevalence and outcomes [20–22].

This study examines AKI among inpatients, estimating prevalence, mortality, outcomes and the cost to the National Health Service (NHS) in England. The analysis is based, in the
first instance, on Hospital Episode Statistics (HES), which provide details of patient demographics and health-care activity, including recorded diagnoses, procedures, length of stay and in-hospital mortality for all individual hospital admissions in the English NHS. The national dataset is derived from patient records at each hospital. HES data do not, however, provide details of AKI stage, or of pre-admission or post-discharge kidney function, and it is generally accepted that AKI is under-recorded on patients’ notes.

We therefore compare the national findings with data from East Kent Hospitals University NHS Foundation Trust (EHUFT). At East Kent, laboratory records were used to identify AKI, the condition was classified using the Acute Kidney Injury Network (AKIN) system [21], prior CKD status was ascertained and patients were followed for up to 2 years after discharge.

We use age- and gender-standardized extrapolation from the study findings to provide an indication of the possible level of under-recording of AKI in patient records and routine data-sets, of the distribution of AKI by AKIN stage, of prior CKD status and of post-discharge health status and care needs.

**MATERIALS AND METHODS**

Our analysis used HES data to measure the recorded prevalence of AKI in hospital admissions in England, the age and gender distribution of people with AKI, survival to discharge and the impact of AKI on inpatient costs. These findings were compared with data from EKHUFT, a group of three inpatient hospitals in the South of England, which serves a defined population of ~720 000 people. In both cases, the analysis was restricted to adults (aged ≥ 18). Elective day case and maternity admissions were excluded. In addition, patients on chronic RRT were excluded from EKHUFT data, but could not be discretely identified in HES.

**Data**

We examined all finished hospital admissions during 2010–11 in HES, and identified those with a recorded diagnosis of AKI, using International Classification of Diseases (ICD-10) codes N17 or N280.

The EKHUFT data covered admissions from 1 February to 31 July 2009 inclusive. Patients with AKI during admission were identified and classified by the AKIN criteria using serum creatinine (SCr) data from pathology records [21]. The pathology records used covered all SCr tests commissioned in primary, community and acute sectors from 1 February 2008 to 31 July 2010. Baseline SCr was estimated using the lowest level recorded in the 12 months prior to hospital admission, after the method of LaFrance et al. [23], and this was compared with the highest SCr recorded during hospital admission in the study period. In cases where there were no pre-hospitalization values and the follow-up SCr (lowest in the 12 months following discharge) was lower than the peak in the study admission, the follow-up value was used as the reference SCr. In these cases the assumption was made that, if SCr fell by more than 26.4 μmol/L after discharge, the admission involved an AKI. Cases where no SCr value was available for either the 12 months preceding or the 12 months following admission were recorded as ‘AKI status unknown’.

The lowest SCr recorded in the 12 months before admission was also used to estimate baseline glomerular filtration rate (eGFR). Patients with baseline eGFR <60 mL/min were identified as having prior CKD, and eGFR levels were used to classify stages 3–5 CKD [24].

For both HES and EKHUFT data, we calculated AKI prevalence for four patient age bands (18–39, 40–59, 60–79, 80+) sub-divided by gender to produce eight sub-groups. We applied the EKHUFT prevalence figure for each of the sub-groups to the admission numbers recorded in HES, to produce an England-level prevalence estimate standardized for age and gender.

**Inpatient analysis**

We estimated the impact of AKI on mortality and length of stay in both datasets, using regression analyses. The impact on days in critical care was examined in EKHUFT only. The impact of AKI on mortality (odds ratio) was estimated using multivariate logistic regression. The impact on length of hospital stay and on days in critical care were estimated using multilevel negative binomial regression. Two-level models were used with individual admissions nested within patients. Covariates used in the HES analysis were AKI diagnosis, patient age, gender, index of multiple deprivation score, admission method (elective or non-elective) and specialty type (surgical or non-surgical), Covariates used in the EKHUFT regressions were age, gender, index of multiple deprivation score, admission method (elective or non-elective), admission source (home or not), admission day (weekend or week day), CKD diagnosis and stage, number of hospital admissions in the previous 12 months, number of outpatient appointments in the previous 12 months, comorbidities and primary diagnosis. A complete list of covariates is provided in the Supplementary Appendix. Analyses were carried out in Stata versions 8 and 12.1.

We report results as means with standard deviations or as ratios with 95% confidence intervals. Further detail on prevalence, mortality, CKD status and AKI status at hospital admission are provided in the Supplementary Appendix.

**Inpatient costs**

We estimated acute costs related to AKI for general inpatient care and critical care. For general inpatient care, separate cost estimates were derived from HES and EKHUFT activity data. Cost estimates for critical care were based on EKHUFT data only, as HES do not provide robust data in this area.

Most inpatient care in the English NHS is reimbursed through national tariffs, which are set at Healthcare Resource Group (HRG)-level. HRGs are groups of health-care activities that are clinically related and similar in cost. Each admission is grouped to a single HRG, using ICD-10 and OPCS Classification of Interventions and Procedures (OPCS-4) codes. In admissions with multiple diagnoses and/or procedures, the HRG relating to the most expensive health-care activity is generally selected.
For admissions grouped to AKI-specific HRGs, we attributed the entire cost of the admission to AKI, and used the tariff price to estimate unit cost [25]. Tariff prices vary around England, depending on local cost differences. A formula known as the Market Forces Factor (MFF) is used to make these local adjustments. Prices used here are estimated using the average MFF for the country.

However, most admissions with recorded AKI are grouped to non-AKI HRGs, reflecting the fact that AKI frequently occurs in patients who have multiple interventions and/or diagnoses. For admissions in which the patient had AKI, but the admission was grouped to a non-AKI HRG, the cost impact of AKI was estimated using regression analyses on length of stay. Costs were estimated for excess bed days associated with AKI, using the mean cost of a hospital bed day for AKI HRGs (LA07C-G) in NHS Reference Costs for acute hospitals (£311) as an estimate of unit cost [26].

The cost of excess critical care days associated with AKI was estimated, based on the critical care regression analysis outlined above. The average unit cost of a critical care bed day was estimated from NHS Reference Costs (£1213) [26].

Long-term impacts and costs

We constructed a Markov model to estimate long-term quality-of-life impacts and costs arising from excess CKD and RRT in patients who have had AKI, relative to a matched group without AKI. The model was run for a representative patient aged 72 at outset (estimated from age distributions in HES and EKHUFT). Parameters were estimated based on data from EKHUFT, UK Renal Registry, Office for National Statistics, NHS Blood and Transplant and earlier studies (Table 1). Supplementary regression analysis on mortality (Poisson with scaled standard errors to correct for over-dispersion) was conducted to estimate relative risk for use in the Markov model. Quality-adjusted life years (QALYs) were estimated using EQ-5D utilities derived from a recent meta-analysis [27]. Model structure is shown in Figure 1. Analysis was carried out in TreeAge Pro.

Sensitivity analysis

In sensitivity analysis, we applied the upper and lower bound 95% confidence interval estimates for AKI prevalence in each of the age and gender sub-groups at EKHUFT to HES

Table 1. Markov model parameters and sources

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Estimated value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of patients with CKD Stage 3 at hospital admission</td>
<td>AKI and comparator 34.18%</td>
<td>East Kent data–AKI group. Same prevalence is applied in model to comparator.</td>
</tr>
<tr>
<td>% of patients who die during hospital admission</td>
<td>AKI 17.44%</td>
<td>East Kent data</td>
</tr>
<tr>
<td>% of patients on RRT 90 days after discharge</td>
<td>AKI 0.26% in base case, 0.11% and 0.42% in sensitivity analysis</td>
<td>East Kent data (excluding patients with CKD Stage 4 or 5)</td>
</tr>
<tr>
<td>Annual transition probabilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal kidney function to CKD</td>
<td>AKI 2.50%</td>
<td>Bucaloiu et al. (2012) [9] Baseline risk of de novo CKD × HR with reversible AKI event</td>
</tr>
<tr>
<td>CKD to RRT</td>
<td>Comparator 1.31%</td>
<td>Bucaloiu et al. (2012) [9]</td>
</tr>
<tr>
<td>Transplant graft failure</td>
<td>AKI and comparator 7.05%</td>
<td>Renal Registry 2011 [28]</td>
</tr>
<tr>
<td>CKD to death</td>
<td>AKI and comparator RR = 1.28</td>
<td>Mortality rate in RRT by age band from Renal Registry report, 2011 [28]</td>
</tr>
<tr>
<td>RRT to death</td>
<td>AKI and comparator</td>
<td></td>
</tr>
<tr>
<td>Annual cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CKD Stages 3–4</td>
<td>£241</td>
<td>Kerr et al. (2012) [34] updated to 2010–11 prices</td>
</tr>
<tr>
<td>Dialysis</td>
<td>£27 765</td>
<td></td>
</tr>
<tr>
<td>Transplant year 1 (including pre-transplant care)</td>
<td>£34 036</td>
<td></td>
</tr>
<tr>
<td>Transplant after year 1</td>
<td>£7520</td>
<td></td>
</tr>
<tr>
<td>EQ-5D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal kidney function</td>
<td>0.78</td>
<td>UK population norm, age 65–74 from Kind et al. (1999) [35]</td>
</tr>
<tr>
<td>CKD Stages 3–4</td>
<td>0.72</td>
<td>Wyld et al. [27]</td>
</tr>
<tr>
<td>Dialysis</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>Transplant</td>
<td>0.75</td>
<td></td>
</tr>
</tbody>
</table>
admission figures. We summed the lower and upper bound estimates, respectively, and used the resulting prevalence estimates to derive cost and QALY estimates.

We also re-ran the Markov model using the 95% confidence interval bounds for the proportion of patients requiring RRT at 90 days post-discharge from the EKHUFT data.

**RESULTS**

**Prevalence**

HES data record 5881635 inpatient admissions for 3792951 patients in 2010–11. AKI was recorded in 142705 of these admissions (2.43%) and 122928 patients (3.24%) had at least one admission with recorded AKI during the year. Prevalence ranged from 0.32% in patients aged 18–39 to 5.74% in those aged ≥80 (Figure 2).

During the 6-month study period at EKHUFT, there were 36015 admissions (27436 patients). Laboratory data indicate that AKI was present in 5521 admissions and that 4462 patients had at least one admission with AKI, a prevalence of 15.33% of admissions and 16.26% of patients. The EKHUFT inpatient population is older than that in HES (Figure 3). The age- and gender-standardized prevalence for England is estimated at 14.15% of admissions and 14.65% of patients.

At EKHUFT, 38.10% of patients who had AKI during the study period had pre-existing CKD stage 3–5. In 73.37% of admissions with AKI, the patient had AKI when admitted to hospital. Further detail is provided in the Supplementary Appendix.

**Mortality**

In 40109 (28.11%) admissions with recorded AKI in HES, the patient died before discharge. Mortality rates increased with age. The odds ratio for death in hospital for patients with AKI relative to those without AKI was 10.52 (95% confidence interval 9.93–11.16). The relative risk of death in hospital for patients with AKI was 4.69 (4.59–4.80) (Table 2).

In 13.93% of admissions with AKI at EKHUFT, the patient died before discharge. Of all inpatient deaths, 55.77% occurred in patients with AKI. The odds ratio and relative risk for in-hospital mortality at EKHUFT increased by AKIN stage (Table 3).
Based on the HES regression analysis, the prevalence of CKD, by stage, in inpatients with AKI were estimated that, in 2010–11, there were 977 116 excess bed days associated with AKI in 119 560 admissions grouped to HRGs other than LA07. The cost of these excess bed days is estimated at £304 million.

If the prevalence of AKI identified in laboratory data at East Kent is representative, the number of annual admissions with AKI in England is estimated at 832 235. Based on the EKHUFT regression analysis, the number of excess bed days associated with AKI in admissions grouped to HRGs other than LA07 in England is estimated at 2 565 514. Of these, 163 423 days are estimated to have been in critical care units.

Total inpatient expenditure associated with AKI admissions recorded in HES (excluding critical care use) is estimated at £380 million. Extrapolations from EKHUFT produce an estimate of £1.02 billion for inpatient expenditure related to AKI in England (Table 5).

The Markov model estimates the lifetime cost of post-discharge care for people who have had AKI as inpatients in 2010–11 at £179 million. These costs arise through higher incidence of CKD and RRT, relative to a matched population without AKI. The lifetime QALY loss is estimated at 1.4 per inpatient with AKI.

**Sensitivity analysis**

Using the lower bounds of the 95% confidence interval for each sub-group at EKHUFT, and standardizing for the age and gender of the HES population, we estimate the number of admissions with AKI in England at 740 964 (494 288 patients) in 2010–11. Using the upper bounds, we estimate

<table>
<thead>
<tr>
<th>HRG</th>
<th>Elective Activity</th>
<th>Elective Cost</th>
<th>Non-elective Activity</th>
<th>Non-elective Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA07A</td>
<td>Acute renal failure with major CCa</td>
<td>165</td>
<td>£636 524</td>
<td>10 216</td>
</tr>
<tr>
<td>LA07B</td>
<td>Acute renal failure with intermediate CCa</td>
<td>228</td>
<td>£359 100</td>
<td>11 581</td>
</tr>
<tr>
<td>LA07C</td>
<td>Acute renal failure without CCa</td>
<td>45</td>
<td>£33 752</td>
<td>910</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>438</td>
<td>£1 029 376</td>
<td>22 707</td>
</tr>
</tbody>
</table>

Notes:
1. LA07 = Acute Renal Failure with Acute Kidney Injury.
2. CCa = Complications or Comorbidities.
3. EKHUFT = East Kent University Hospital.
4. AKI = Acute Kidney Injury.
5. HRG = Healthcare Resource Group.
6. QALY = Quality Adjusted Life Year.
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suggest that AKI was associated with the AKI population. The comparison with HES data suggests that analysis 1, we estimated costs based on these prevalence estimates presented here have been standardized for age and lower con- dence intervals for post-discharge RRT in datasets and analyses. Patients on RRT were excluded from the East Kent dataset but not from HES. The East Kent regression analyses used a wider range of covariates than those available in HES.

There is uncertainty regarding the incidence of long-term RRT after AKI. The sample size for 90-day post-discharge RRT at EKHUFT was small, and the confidence intervals around the point estimate are correspondingly large. Further studies are needed to examine the impact of AKI on long-term RRT need.

This study focuses only on AKI in adult hospital inpatients. Further research is needed on the incidence and impact of AKI in primary and community care settings.

The recent NCEPOD report in the UK found that 20% of fatal post-admission AKI cases were both predictable and avoidable. Many of the failings identified in that report related to basic medical care, such as checking of electrolytes, performance of physiological observations and adequate senior review. However, at EKHUFT, AKI was present at the point of admission in nearly three quarters of admissions in which AKI occurred. It is likely therefore that efforts to prevent AKI will need to focus on primary and community care as well as on inpatient care.

If 20% of AKI cases were prevented, the figures presented in this report suggest that the gross savings to the NHS could be in the region of £200 million a year, equivalent to 0.2% of the NHS budget in England. It is hoped that the estimates presented here will provide a foundation for future economic evaluation of prevention and early management interventions for AKI, and of strategies for the prevention of complications in AKI survivors.

**DISCUSSION**

The data presented here provide the most comprehensive estimate to date of AKI prevalence in inpatients in England. The figure based on laboratory data and AKIN classification is considerably higher than earlier estimates based on sub-sets of the AKI population. The comparison with HES data suggests that there may be substantial under-recording and possibly under- recognition of AKI in English hospitals.

Our study finds that AKI is associated with high mortality; the relative-risk estimates from the HES regression analysis suggest that AKI was associated with ~15,000 excess deaths among inpatients in England in 2010–11, while extrapolations from EKHUFT data suggest the annual number of excess deaths associated with AKI in England may be above 40,000. We also find that AKI is associated with large QALY losses.

**SUPPLEMENTARY DATA**

Supplementary data are available online at http://ndt.oxfordjournals.org.
CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest. The contents of this paper have not been published previously in whole or part, except in abstract format.

REFERENCES