A real-time electronic alert to improve detection of acute kidney injury in a large teaching hospital

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ABSTRACT

Background. Acute kidney injury (AKI) is a common and serious problem in hospitalized patients. Early detection is critical for optimal management but in practice is currently inadequate. To improve outcomes in AKI, development of early detection tools is essential.

Methods. We developed an automated real-time electronic alert system employing algorithms which combined internationally recognized criteria for AKI [Risk, Injury, Failure, Loss, End-stage kidney disease (RIFLE) and Acute Kidney Injury Network (AKIN)]. All adult patients admitted to Nottingham University Hospitals were included. Where a patient’s serum creatinine increased sufficiently to define AKI, an electronic alert was issued, with referral to an intranet-based AKI guideline. Incidence of AKI Stages 1–3, in-hospital mortality, length of stay and distribution between specialties is reported.

Results. Between May 2011 and April 2013, 59,921 alerts resulted from 22,754 admission episodes, associated with 15,550 different patients. Overall incidence of AKI for inpatients was 10.7%. Highest AKI stage reached was: Stage 1 in 7.2%, Stage 2 in 2.2% and Stage 3 in 1.3%. In-hospital mortality for all AKI stages was 18.5% and increased with AKI stage (12.5, 28.4, 35.7% for Stages 1, 2 and 3 AKI, respectively). Median length of stay was 9 days for all AKI.

Conclusions. This is the first fully automated real time AKI e-alert system, using AKIN and RIFLE criteria, to be introduced to a large National Health Service hospital. It has provided one of the biggest single-centre AKI datasets in the UK revealing mortality rates which increase with AKI stage. It is likely to have improved detection and management of AKI. The methodology is transferable to other acute hospitals.

Keywords: AKIN, acute kidney injury, early detection, electronic alert, RIFLE

INTRODUCTION

Acute kidney injury (AKI) is common, serious and expensive. It affects up to 18% of hospitalized patients [1] and is associated with significant mortality, morbidity and increased length of hospital stay. Patients who develop AKI are more likely to require admission to intensive care units (ICU) and to develop chronic kidney disease (CKD) and other long-term health problems [2–6]. AKI per se is estimated to cost the United Kingdom National Health Service (NHS) up to £620 million per year [7].

The 2009 report by the National Confidential Enquiry into Patient Outcome and Death (NCEPOD) highlighted inadequacies in management of AKI in the UK [8]. Fewer than 50% of cases studied were considered to have been managed well and there were delays in detection of post-admission AKI in 43% of cases. Recommendations of the report included mandatory serum creatinine (SCR) check and risk assessment for AKI at presentation for all emergency admissions.

To improve detection rates at our large NHS hospital, we developed a fully automated, real-time electronic alert system (e-alert) which identifies and stages all cases of AKI occurring in patients over 16 years. The aim was to improve clinical outcomes of AKI by early detection combined with advice on appropriate early management and timely referral to the renal
service. The system was also designed to collect data on AKI incidence and some outcome measures, providing opportunity to investigate the effect of introduction of the system.

Nottingham University Hospitals NHS Trust (NUH) is one of the largest NHS trusts in the UK. It provides services for 2.5 million residents and specialist services to 3–4 million from neighbouring counties per year, with 1700 inpatient beds on two campuses situated 3 miles apart. There are ~250 000 admission episodes each year and ~170 000/year excluding patients under 16 years and those not admitted overnight. The hospital provides all main specialties including cardiac surgery, primary angioplasty, neurosurgery and is a major regional trauma centre. Many of the ‘acute’ specialties, including the emergency department, acute medicine, acute surgery and the trauma centre are based at one campus (Queen’s Medical Centre), whereas the renal unit is based at the other (City Hospital Campus). There are adult ICUs at both campuses. This separation of renal services from several important acute services provided additional incentive for implementing an e-alert. Studies of incidence and outcomes of AKI have, until recent years, produced inconsistent results, mainly because of inconsistent definitions of AKI [9, 10]. The establishment of Risk, Injury, Failure, Loss, End-stage kidney disease (RIFLE) [11], followed by the Acute Kidney Injury Network (AKIN) [12] and more recently Kidney Disease: Improving Global Outcomes (KDIGO) criteria [13] has provided some consensus. Studies using these classifications have confirmed that AKI is associated with increased mortality and suggested that outcome worsens with increasing AKI stage [1–3, 14–16]. Debate remains about some details of AKI definition. AKIN classification specified a time limit over which specified SCr rises must occur to define AKI (48 h) and added an extra subgroup of Stage 1 AKI based on an absolute rise in SCr (0.3 mg/dL). AKIN and RIFLE systems therefore detect slightly different, but mostly overlapping, populations of Stage 1 AKI.

The Nottingham AKI e-alert was developed after publication of RIFLE and AKIN classification systems but before KDIGO. We chose to assess all inpatient SCr results using a combination of RIFLE and AKIN criteria. For example, a Stage 1 alert would be issued with either a 50% increase in SCr within a 7-day period (RIFLE) or a rise of 0.3 mg/dL (26 µmol/L) within 48 h (see Supplementary Figure S1 summary of how e-alert functions and Supplementary Figure S2 for full description of algorithms). Where application of RIFLE and AKIN criteria would result in discrepancy of AKI stage, the higher is reported. For assessment of the first SCr of admission and any subsequent SCr in the first 48 h of admission, an additional comparison is made against the lowest SCr on record from 7 to 365 days prior to admission. Where no SCr is available an additional comparison is made against the lowest SCr on record of AKI stage, the higher is reported. For assessment of the application of RIFLE and AKIN criteria would result in discrepancy supplementary Figure S2 for full description of algorithms). Where supplementary Figure S1 summary of how e-alert functions and Supplementary (RIFLE) or a rise of 0.3 mg/dL within 48 h (see Supplementary (RIFLE) or a rise of 0.3 mg/dL within 48 h (see Supplementary Figure S1 summary of how e-alert functions and Supplementary Figure S2 for full description of algorithms).

Electronic alert for early detection of AKI 1889

RESULTS

The e-alert went live in April 2011, having been tested in pilot form over the previous year. We analysed data from the first 2 years after full implementation. During this time 338 956 completed patient admission episodes occurred, including maternity services: day cases 125 960 (37.2% of all episodes), elective admissions 33 383 (9.8%) and emergency admissions 179 613 (53.0%). The number of completed hospital admissions relevant to our incidence calculation was 212 996. The

MATERIALS AND METHODS

There are clinical pathology laboratories at both campuses of NUH. The Jaffe method is used for SCr measurement and assay specific adjustments are carried out in line with the National External Quality Assessment Scheme (NEQUAS UK). Cross campus agreement is excellent at 0.83 and 0.91% for delta median SCr 93 and 543 µmol/L, respectively.

NUH uses the laboratory management information system Winpath (CliniSys Group, Surrey, UK). SCr and other laboratory results are transferred to the hospital information system, ‘NotIS’ (Nottingham Information System), a system developed in-house several years ago which acts as a portal for clinicians to access laboratory and other clinical results as well as to request investigations. NotIS has interfaces with other hospital IT systems including the patient administration system (PAS), which contains further clinical data including ethnicity, codes of outpatient clinics attended and hospital admissions.

We coded algorithms in NotIS because it contains an extensive archive of SCr results allowing us to search for baseline SCr as far back as 1 year prior to admission. This contributed to improved sensitivity of AKI detection, a design priority. Furthermore, coding in NotIS facilitated identification of ethnicity, required for MDRD equation calculations and allowed exclusion of patients with known end stage renal disease through its interface with PAS, which records attendances at dialysis clinics. Chronic dialysis and age <16 years were the only exclusion criteria for the alert system. Patients with renal transplant were included. The algorithms run fully automatically at all stages. Logic for the algorithms used in this study is shown as Supplementary Figure S2.

The alert is presented to the clinician real time as a statement accompanying the qualifying SCr result. The statement includes the stage of the alert and refers the clinician to hospital AKI guidelines on the hospital intranet. Responsibility for the alert resides with the clinician.

Statistical analysis

Patient characteristics are those at first admission. Data were analysed in Microsoft Excel (version 2010) and IBM statistical package for the social sciences (SPSS) version 19 for Windows (SPSS (UK) Ltd, Woking, Surrey, UK). Data are presented as mean (95% confidence interval) and medians (interquartile range, IQR). Numbers and percentages were used to summarize categorical data and χ² test to compare proportions. Variables not normally distributed were log-transformed prior to analysis. Group means were compared using one-way analysis of variance (ANOVA). ANOVA post hoc testing was carried out using the Bonferroni correction. A P-value <0.05 (two-sided) was considered significant.
number of e-alerts issued during this time was 59,921, which related to 22,754 completed patient episodes (i.e. one patient admission could result in several alerts, so for this analysis, only one alert per patient episode is considered, the highest AKI stage reached for the first admission). Overall incidence of AKI for inpatients (defined as an admission including overnight stay) was 10.7%. Of these, the highest AKI stage reached was: Stage 1 in 7.2%, Stage 2 in 2.2% and Stage 3 in 1.3%.

The 22,754 admission episodes generating an e-alert related to 15,550 different patients. The proportion of admission episodes generating an AKI alert with highest Stages 1, 2 and 3, respectively was 15,328 (67.4%), 4,614 (20.3%) and 2,812 (12.3%). Percentages of alerts by AKI stage were similar when analysed per patient rather than per admission episode (Table 1). The number of patients with multiple admissions involving AKI was 3,862 (24.8% of patients who triggered an alert). Of these patients with multiple admissions 2,375 (60.5%) were admitted twice, and 1,253 (28.3%) 3 times generating an AKI alert with highest Stages 1, 2 and 3, respectively was 15,328 (67.4%), 4,614 (20.3%) and 2,812 (12.3%). Percentages of alerts by AKI stage were similar when analysed per patient rather than per admission episode (Table 1). The number of patients with multiple admissions involving AKI was 3,862 (24.8% of patients who triggered an alert). Of these patients with multiple admissions 2,375 (60.5%) were admitted twice, and 1,253 (28.3%) 3 times generating an AKI alert with highest Stages 1, 2 and 3, respectively was 15,328 (67.4%), 4,614 (20.3%) and 2,812 (12.3%). Percentages of alerts by AKI stage were similar when analysed per patient rather than per admission episode (Table 1).

Patient characteristics in Table 1 are based on per patient analyses rather than per admission episode, i.e. only one admission per patient is considered. For patients with multiple ‘AKI admissions’, we calculated mortality separately for first and last completed admission episode, in case there was significant difference between these.

Median age of AKI patients was 74 years (first and third quartiles 30, 92), which was the same across all stages of AKI. There is a significant preponderance of males in the AKI Stage 3 group compared with combined groups of patients with AKI Stages 1 and 2. Ethnicity reflects the location of our hospital and was predominantly white (92.1%, with 2.5% Asian, 1.7% black, 0.4% mixed and 3.3% other). Median length of hospital stay was similar across all stages of AKI: 9, 9 and 10 days for Stages 1–3, respectively (IQR first and third quartiles 5–17, 5–18 and 5–19 days, respectively). The proportion that required a critical care bed increased significantly with each increment in AKI stage: 5.5, 10.2 and 12.4% respectively. Overall in-hospital mortality for all stages of AKI was 18.5% (2,873 patients) compared with general in-hospital mortality for non-AKI patients of 2.2% (unpublished data from local AKI database). In-hospital mortality for Stages 2 and 3 AKI was significantly higher than for Stage 1, at 21.0 and 25.5% (P < 0.001, 881 and 674 patients, respectively) compared with 9.0% (1,318 patients) in Stage 1. Because a significant number of patients had multiple admissions we additionally present data on mortality using last admission (Table 1). Mortality is lower if analysis is based on first ‘AKI admission’, not surprisingly, as patients obviously do not die on any admission but their last. These data illustrate the importance of specifying precisely the criteria on which important outcome measures are based.

**‘Community acquired’ and ‘hospital acquired’ AKI**

We defined community acquired AKI as an alert triggered within 48 h of admission using comparison against pre-admission baseline SCr. In the absence of a baseline, we calculated a theoretical SCr (see Materials and Methods). All alerts relating to day case and elective admissions were assumed to be hospital acquired irrespective of timing. Using this definition, community acquired AKI admissions were: 49.8% Stage 1, 70.7% Stage 2 and 84.4% Stage 3. It is widely accepted that using theoretical SCr (calculated assuming normal GFR of 75 mL/min) overestimates incidence of community acquired AKI. Percentage of patients with unknown baseline increased with stage of AKI alert: 22.4% of Stage 1, 29.0% of Stage 2 and 38.3% of Stage 3. Excluding patients without known baseline SCr considerably alters the proportion of community versus hospital acquired AKI, particularly in Stages 2 and 3 (Table 2).

**Table 1. Patient characteristics (per patient analysis). In-hospital mortality is shown separately for first and last hospital admission**

<table>
<thead>
<tr>
<th>AKI stage</th>
<th>Number of patients</th>
<th>AKI stage (%)</th>
<th>Gender ratio M: F (%)</th>
<th>Age (years) median (first and third quartiles)</th>
<th>First admission LOS (days) median (first and third quartiles)</th>
<th>In hospital mortality number (%)</th>
<th>In hospital mortality last AKI admission number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10,557</td>
<td>67.9</td>
<td>46.54</td>
<td>74 (28,92)</td>
<td>9 (5,17)</td>
<td>976 (9.0)</td>
<td>1318 (12.5)</td>
</tr>
<tr>
<td>2</td>
<td>3,105</td>
<td>20.0</td>
<td>48.52</td>
<td>76 (36,92)</td>
<td>9 (5,18)</td>
<td>623 (21.1)</td>
<td>881 (28.4)</td>
</tr>
<tr>
<td>3</td>
<td>1,888</td>
<td>12.1</td>
<td>57.43</td>
<td>74 (38,92)</td>
<td>10 (5,19)</td>
<td>454 (25.5)</td>
<td>674 (35.7)</td>
</tr>
<tr>
<td>1–3</td>
<td>15,550</td>
<td>100</td>
<td>48.52</td>
<td>74 (30,92)</td>
<td>9 (5,17)</td>
<td>2,053 (13.2)</td>
<td>2,873 (18.5)</td>
</tr>
</tbody>
</table>

LOS, length of stay.
Progression of AKI during hospital stay

Analysing first alert for all patients \((n = 15\,550)\), 12\,122 (77.9\%) are reported as Stage 1, 2285 (14.7\%) as Stage 2 and 1143 (7.4\%) as Stage 3. For first alert of Stage 1 AKI, 989 (8.2\%) progressed to maximum of Stage 2 AKI and 314 (2.6\%) progressed to maximum of Stage 3 during the admission. An additional 321 (14.0\%) of the group with first alert of Stage 2 progressed to Stage 3 during admission.

Distribution of AKI alerts by service specialty

The speciality distribution of patients with AKI stratified by stage is shown in Figure 2A and B. Figure 3 shows the proportion of patients as a percentage of all AKI by service speciality.

**DISCUSSION**

We have developed a fully automated real-time electronic alert system to detect AKI in a large NHS hospital. Our primary goal was to develop a clinical tool to improve timing and accuracy of AKI detection, in order to facilitate early intervention. We collected incidence and outcome data for 2 years after introduction of the e-alert system. These data demonstrate that, in our population, 10.7\% of hospital admissions involved at least one AKI episode. Mortality increased with stage of AKI but length of hospital stay did not seem to vary significantly between AKI stages.

This is the first report of a fully automated AKI e-alert system using internationally recognized (both RIFLE and AKIN) criteria. We decided that a high degree of sensitivity was desirable for our alert system, given the size of our hospital and the fact that many of the acute specialties did not, at the time, have direct access to a renal consultant service. We preferred a low threshold for alerting AKI, giving the clinician the choice of whether to follow-up the alert, rather than risk an episode being missed. We followed internationally accepted criteria as far as possible, to allow valid comparison with other institutions. The Nottingham e-alert system was developed after publication of RIFLE and AKIN classification systems but before KDIGO criteria. Following analysis of pilot data, we decided to combine RIFLE and AKIN criteria in order to increase sensitivity. The additional AKIN Stage 1 criterion of SCr rise of 0.3 mg/dL within 48 h increased total number of Stage 1 alerts compared with use of RIFLE criteria alone. However, the 48-h window specified by AKIN led to the possibility of missing potentially important but insidious SCr rises. We therefore combined the 7-day timeframe of RIFLE with the additional Stage 1 criterion of AKIN. In practice, this produced an AKI definition similar to the subsequently published KDIGO criteria.

![Figure 2](image1.png)

**FIGURE 2:** (A) The number of patients that triggered an AKI episode by service speciality and (B) The proportion of patients by AKI stage and service speciality.

![Figure 3](image2.png)

**FIGURE 3:** All AKI by service speciality presented as a proportion of total patients. Not all specialities are shown those missing had <2%.
Design of the e-alert had to address definition of baseline SCr, against which the first SCr of a hospital admission is compared. If baseline were restricted to SCr obtained within the previous 7 days, there would be high probability of no qualifying result being available. Even if a SCr were available, it might be influenced by the prodrome of the presenting illness. There are various arguments about what constitutes suitable baseline SCr. Exclusion of results from 7 days prior to admission addresses the possibility of those results being spuriously high if acute illness is developing. Different time frames have been suggested, including 3, 6 or 12 months prior to admission [18, 19]. Within the chosen timeframe, the preferred baseline SCr could be the lowest, the average or the most recent. Our choice of lowest SCr reflected our preference for high sensitivity.

Where no qualifying baseline SCr exists, it would often be inappropriate to exclude patients from alerting, as they might have very high SCr on admission. Our algorithms therefore incorporated, where appropriate, calculation of ‘theoretical’ baseline SCr by assuming estimated GFR of 75 mL/min per 1.73 m², using the MDRD equation [20].

An advantage of our system is its fully automated operation. This was essential for our large institution with so many acute admissions. Automation not only confers negligible running costs, but it removes human error and inconsistency from the decision process. As the e-alert operates purely with mathematical algorithms, false-negative rate (using either RIFLE or AKIN criteria) is zero, i.e. any patient with qualifying SCr rise will be identified. This has been verified by examining randomly selected cohorts of inpatients.

The Nottingham AKI e-alert does have some limitations in its current form. It issues a ‘passive’ alert, where an advisory message accompanies the qualifying SCr result in real time. The message includes AKI stage and referral to the hospital’s guideline for AKI management on the intranet. With the high frequency of alerts, at the time of development, an active system requiring manual input was considered impractical. Responsibility to act upon the alert is currently left with the end-user. It has been suggested that active alerts, involving a telephone call or use of an AKI outreach team, might be more effective [21–24]. Studies are underway, at our institution and elsewhere, to investigate the effectiveness of specialist AKI outreach teams responding to e-alerts [22].

The use of assumed, or calculated, baseline SCr is controversial. In our system, calculated baseline is used pragmatically, only when no actual SCr is available. This is relevant only to the ‘community acquired’ AKI episodes. Given that CKD is quite common in the general population [25–28], assuming eGFR of 75 mL/min will lead to some false-positive alerts, as a falsely low baseline SCr will have been assumed. Our data demonstrate that this caveat is particularly relevant in Stages 2 and 3 AKI, This is more a limitation of current definitions of AKI (and CKD) than of the e-alert. If no baseline SCr is available, it is safer to assume that an elevated SCr on admission represents AKI until proven otherwise.

Similarly, our choice of baseline SCr as the lowest in the 7–365 days prior to admission is debatable. Average SCr over this time could have been chosen, which would be expected to reduce the reported incidence of community acquired AKI slightly. The time range for establishing baseline SCr might also be chosen differently, e.g. 3 or 6 months rather than 12. Our choice maximized sensitivity. An alert could be triggered by a spuriously low SCr during the qualifying period, but this should be apparent to the clinician.

Other hospital-wide electronic reporting systems for AKI have been described [22, 23] but they have either not used internationally recognized staging systems or have not been fully automated. One has required manual verification of the AKI stage, thus introducing potential for human error and inconsistency, as well as being impractical in a large acute hospital requiring 24-h real-time availability. Colpaert et al reported a real time AKI e-alert which monitored changes in RIFLE stage, but was restricted to ICU [29]. The AKI e-alert dataset presented here includes all specialties and is ~20 times greater than any previously published.

We confirm the high incidence of AKI in a typical large acute hospital in the UK and the associated high mortality rate, which increases with AKI stage. More importantly, this study demonstrates an effective means of detecting and staging AKI as soon as it occurs. Important UK government sponsored studies such as NCEPOD have highlighted that timely detection of AKI is a serious problem. This e-alert provides a pragmatic solution. The methodology is transferrable, with appropriate technology, and algorithms can be adjusted where different levels of sensitivity are required.

We anticipate that earlier detection of AKI, with appropriate prompt intervention, will lead to improvement in outcomes such as progression of AKI stage, in-hospital mortality and length of hospital stay.

SUPPLEMENTARY DATA

Supplementary data are available online at http://ndt.oxfordjournals.org.

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CONFLICT OF INTEREST STATEMENT

The results presented in this paper have not been published previously in whole or in part, except in abstract format. A proportion of the data presented in this manuscript were presented in abstract form at Renal Week of the American Society of Nephrology, November 2011. None of the authors has any conflicts of interest to declare.

(See related article by Handler, Kane-Gill and Kellum. Optimal and early detection of acute kidney injury requires effective clinical decision support systems. Nephrol Dial Transplant 2014; 29: 1802–1803.)
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