Effect of a Computerized Alert on the Management of Hypokalemia in Hospitalized Patients

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**Background:** Electrolyte abnormalities, including hypokalemia, are frequently encountered among hospitalized patients. Their management, when carefully audited, reveals major shortcomings.

**Objective:** To evaluate the effect of a computerized alert on the management of severe hypokalemia in hospitalized patients.

**Methods:** All patients who experienced severe hypokalemia (serum potassium levels <3.0 mEq/L) during their hospitalization at Hadassah Medical Center (a 1000-bed teaching institution on 2 campuses in Jerusalem, Israel) were included in the study. The study intervention was a computerized alert consisting of a flashing screen or printed warning for patients with serum potassium levels below 3.0 mEq/L, visible whenever an individual patient’s or entire ward’s results were accessed on any hospital computer. Using a previously validated computerized audit technique, we analyzed the management of hypokalemia 6 months before and 6 months after implementation of the alert intervention.

**Results:** Comparing outcomes before and after the intervention, nonmeasurement of a subsequent serum potassium level after an initial low value decreased by 36.1% ($P = .08$). Failure to correct the serum potassium level to above 3.5 mEq/L during the hospitalization decreased by 28.6% ($P = .02$). Discharge from the hospital with a subnormal serum potassium level decreased by 17.2% ($P = .06$).

**Conclusions:** A computerized alert system improved the management of hypokalemia in a tertiary care hospital. This was achieved at minimal cost and with no evidence of harm. The computerized audit based on a laboratory information system is an efficient tool for evaluating this intervention.

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**METHODS**

**SETTING**

Hadassah Medical Center is a 1000-bed tertiary teaching institution located on 2 campuses in Jerusalem, Israel. In most wards, house officers (residents and fellows) were responsible for ordering tests and drawing blood. In the intensive care units, nurses drew the blood after receiving physician orders. No explicit protocols were in place for the management of hypokalemia during the study. The hospital computerized laboratory database is a valid and efficient source of information reflecting the clinical management of hypokalemia. We hypothesized that the computer could be used as a tool for quality improvement and not merely quality assessment. In this study, we report the effect of a computerized alert on the management and correction of hypokalemia as assessed by the computerized laboratory database.

Electrolyte disorders are among the most common laboratory abnormalities in hospitalized patients. Systematic scrutiny has revealed deficiencies in the management of these disorders, including intensive care units and general hospital wards. In light of these deficiencies, several corrective strategies have been implemented, including telephone notification of critical values to the ward secretary, nurse, or physician; fax reminders regarding appropriate management; and computerized reminders. The latter have been shown to be effective in influencing physician behavior since they were first instituted 25 years ago.

Despite some controversy on the appropriate management of hypokalemia, there is a general consensus that very low levels of serum potassium (<3.0 mEq/L) are undesirable and should be corrected. It has previously been shown that
PATIENTS

The study group included all inpatients who experienced a serum potassium level below 3.0 mEq/L during their hospitalization. We excluded hospitalizations in the short-stay unit and the hospice. If a patient experienced severe hypokalemia in more than 1 hospitalization during the study, we included only the last such admission in the study.

INTERVENTION

On April 1, 2000, a system of computerized alerts for patients with severe hypokalemia (serum potassium levels <3.0 mEq/L) was instituted. Whenever a physician accessed the computer to obtain results on a particular patient or concentrated results for an entire ward, a warning concerning patients whose serum potassium levels were below 3.0 mEq/L would flash on the screen. The alert was nondirected because in many cases the physician who ordered the blood test or drew the blood was not the same person who would later check the result. When the individual patient’s result or summary of all results for the ward was printed for that day, a printed warning would appear with the words: “Attention: serum potassium <3.0 mEq/L [patient’s name and identification number].” This warning would persist until a subsequent laboratory result for that patient showed a serum potassium level above 3.0 mEq/L. The warning would reappear if a subsequent drop occurred. During the study, no other change in hospital procedures was made. A policy of telephone notification from the laboratory regarding serum potassium levels (if <3.0 or >5.5 mEq/L) was not altered.

DATA ANALYSIS

We performed a before and after comparison using the laboratory computerized database and the demographic and administrative database. For the 6 months before April 1, 2000, and 6 months after April 30, 2000 (1 month was allowed to debug the computer program), we identified all hospitalized patients who had at least 1 serum potassium level below 3.0 mEq/L. To exclude secular trends in the prevalence of hypokalemia and its management, we compared the baseline data with results of the previous study10 evaluating the computer-kalemia and its management, we compared the baseline data

RESULTS

During the study, 636 admissions were included before the intervention and 519 after the intervention. Table 1 shows the analysis of patient characteristics before and after the intervention. For comparison purposes, we have also included the characteristics of patients in the first study (1997).10 The analysis indicated that there were no systematic differences in age, sex, admission department, and initial level or timing of hypokalemia between the study intervals. Minor differences in the distribution of discharge diagnoses were noted.

Table 2 presents the outcome variables comparing hospitalizations before and after the intervention (columns 2 and 3). For all outcomes, there was improvement in the management of hypokalemia after the intervention, but the change was statistically significant only for achievement of normokalemia (correction of serum potassium levels) (P =.02).

The effect of the intervention after adjustment for baseline variables is given in the last column of Table 2. The multivariate models included age, admission department, transfer between departments during the hospitalization, hospital campus, initial level of serum potassium, and whether severe hypokalemia was present on admission or developed in the hospital. A significant effect of the intervention was observed on the correction of hypokalemia, and borderline associations were seen with remeasurement of serum potassium levels and discharge from the hospital with normokalemia (although for the 2 latter outcomes, the 95% confidence intervals are also compatible with no effect). A significant interaction was observed between the intervention and the time of onset of hypokalemia. After the intervention, there was an odds reduction of 82% in the nonmeasurement of serum potassium levels after an initial low result in patients whose level on the day of admission was below 3.0 mEq/L, as opposed to those who developed severe hypokalemia during their hospitalization (odds ratio for interaction term, 0.18; 95% confidence interval, 0.04-0.75; P <.02). There were no other significant interactions.

No significant reduction in the mean time to remeasurement of the serum potassium levels (18.4 vs 17.9 hours) or in the mean time to correction of serum potassium levels (107 vs 95 hours) was observed after the intervention. Furthermore, the mortality before (16.8%) and after (18.3%) the intervention in this hypokalemic population did not change significantly (P =.51).

A flowchart showing the outcomes of all study subjects is shown in the Figure.

COMMENT

This study demonstrates that modest improvements in the management of a severe electrolyte disturbance in hos-
hospitalized patients can be achieved using a simple computerized alert. The intervention was associated with an increase in the proportion of patients whose serum potassium levels were corrected during their hospitalization, as well as an improvement in the proportion of patients with severe hypokalemia who left the hospital with normal serum potassium values. Patients who presented to the hospital with severe hypokalemia were also more likely to have their serum potassium levels remeasured after the intervention.

Using a computerized audit method that had been previously validated and shown to reflect the actual clinical management of hypokalemia,10 we demonstrated a quantifiable improvement in the physicians’ response to this serious electrolyte disorder. Thus, an audit and reaudit cycle was completed. Although we did not use a randomized design (because of logistical concerns), the before and after comparison showed a trend to improvement in all outcome measures assessed. The baseline characteristics and outcomes in the preintervention periods were virtually identical to those in the previous study, suggesting that the improvement was not due to a secular trend or change in case mix.

Our study had some limitations. Because data collection after the intervention was for 6 months only, it is possible that our study had insufficient power to detect a significant effect of the intervention on remeasurement of serum potassium levels and hospital dis-

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Table 1. Baseline Characteristics of Patients Included in the Original Study of Hypokalemia and Before and After the Intervention

<table>
<thead>
<tr>
<th>Variable</th>
<th>First Study&lt;sup&gt;10&lt;/sup&gt; (n = 866)</th>
<th>Before (n = 636)</th>
<th>After (n = 519)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>403 (46.5)</td>
<td>286 (45.0)</td>
<td>221 (42.6)</td>
<td>.44</td>
</tr>
<tr>
<td>Female</td>
<td>463 (53.5)</td>
<td>350 (55.0)</td>
<td>298 (57.4)</td>
<td></td>
</tr>
<tr>
<td>Mean age, y</td>
<td>51.02</td>
<td>54.23</td>
<td>51.86</td>
<td>.15</td>
</tr>
<tr>
<td>Length of stay, mean/median, d</td>
<td>24.9/14.0</td>
<td>21/10.5</td>
<td>23.4/14.0</td>
<td>.10</td>
</tr>
<tr>
<td>Hospital campus</td>
<td>Ein Kerem (100%)</td>
<td>468 (73.6)</td>
<td>368 (70.9)</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td>Mount Scopus</td>
<td>168 (26.4)</td>
<td>151 (29.1)</td>
<td>.</td>
</tr>
<tr>
<td>Admission department</td>
<td>Pediatrics</td>
<td>97 (11.2)</td>
<td>63 (9.9)</td>
<td>.44</td>
</tr>
<tr>
<td></td>
<td>Intensive care</td>
<td>80 (9.2)</td>
<td>70 (11.3)</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>Surgery</td>
<td>192 (21.0)</td>
<td>117 (18.4)</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>Internal medicine</td>
<td>329 (38.9)</td>
<td>285 (44.8)</td>
<td>.53</td>
</tr>
<tr>
<td></td>
<td>Hematology/oncology/bone marrow transplantation</td>
<td>162 (18.7)</td>
<td>85 (13.4)</td>
<td>.66</td>
</tr>
<tr>
<td></td>
<td>Obstetrics/gynecology</td>
<td>16 (1.8)</td>
<td>16 (2.5)</td>
<td>.15</td>
</tr>
<tr>
<td>Transfer from admission department</td>
<td>Discharged from admission department</td>
<td>733 (84.6)</td>
<td>539 (84.7)</td>
<td>.68</td>
</tr>
<tr>
<td></td>
<td>Discharged from different department</td>
<td>133 (15.4)</td>
<td>97 (15.3)</td>
<td></td>
</tr>
<tr>
<td>Discharge diagnosis ICD-9 code</td>
<td>Diabetes mellitus</td>
<td>83 (9.6)</td>
<td>81 (12.7)</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>Ischemic heart disease</td>
<td>131 (15.1)</td>
<td>95 (14.9)</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>Leukemia</td>
<td>65 (7.5)</td>
<td>29 (4.8)</td>
<td>.35</td>
</tr>
<tr>
<td></td>
<td>Kidney disorder</td>
<td>106 (12.2)</td>
<td>86 (13.5)</td>
<td>.25</td>
</tr>
<tr>
<td>Initial serum potassium level, mEq/L</td>
<td>≤2.4</td>
<td>72 (8.3)</td>
<td>55 (8.6)</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>2.5-2.9</td>
<td>794 (91.7)</td>
<td>581 (91.4)</td>
<td>.46</td>
</tr>
<tr>
<td>Onset of severe hypokalemia</td>
<td>On date of admission</td>
<td>142 (16.4)</td>
<td>117 (18.4)</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>Developed in the hospital</td>
<td>724 (83.6)</td>
<td>519 (81.8)</td>
<td></td>
</tr>
</tbody>
</table>

*Data are given as number (percentage) unless otherwise indicated. Ellipses indicate not applicable. Some percentages do not sum to 100 because of rounding.

Table 2. Effect of Computerized Alert on Management of Hypokalemia

<table>
<thead>
<tr>
<th>Outcome</th>
<th>First Study&lt;sup&gt;10&lt;/sup&gt; (n = 866)</th>
<th>Before (n = 636)</th>
<th>After (n = 519)</th>
<th>% Reduction [P Value] (95% CI)</th>
<th>Adjusted† Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsequent test not performed</td>
<td>55 (6.4)</td>
<td>46 (7.2)</td>
<td>24 (4.6)</td>
<td>36.1 [.08] (−3 to 60)</td>
<td>0.63 (0.37 to 1.05)</td>
</tr>
<tr>
<td>Normokalemia (serum potassium level ≥3.5 mEq/L never achieved)</td>
<td>139 (16.1)</td>
<td>111 (17.5)</td>
<td>65 (12.5)</td>
<td>28.6 [.02] (5 to 46)</td>
<td>0.68 (0.43 to 0.95)</td>
</tr>
<tr>
<td>Serum potassium level at discharge &lt;3.5 mEq/L</td>
<td>260 (30.0)</td>
<td>185 (29.1)</td>
<td>125 (24.1)</td>
<td>17.2 [.06] (−2 to 36)</td>
<td>0.77 (0.59 to 1.01)</td>
</tr>
</tbody>
</table>

Abbreviation: CI, confidence interval.
*Data are given as number (percentage) unless otherwise indicated.
†Multivariate analysis comparing outcomes after the intervention with those before the intervention, controlling for hospital campus, age, transfer between wards, admission ward, initial serum potassium level, and whether severe hypokalemia was present on date of admission or developed in the hospital.
charge with normokalemia. However, if we combine the results of the baseline analysis in 1997 and data from the 6 months before the intervention (columns 1 and 2 of Table 2), a statistically significant improvement after the intervention in the rate of discharge with subnormal serum potassium values was achieved ($P = .03$).

The intervention produced a modest effect, possibly because it was nondirected. Furthermore, because the alert drew attention to extreme levels of hypokalemia ($<3.0 \text{ mEq/L}$) and a positive assessment of response was correction of hypokalemia, our analysis was, by definition, insensitive to improvements in the serum potassium levels that did not cross the threshold of 3.5 mEq/L.

The use of computerized alerts has been shown to increase the proportion of patients with electrolyte abnormalities receiving appropriate care, decrease the time spent in a life-threatening situation, and reduce the length of hospitalization. Computerized alerts regarding rising serum creatinine levels among patients receiving nephrotoxic drugs resulted in a significant decrease in the risk of renal impairment. Furthermore, computerized alerts have been used to prevent adverse drug events and to improve appropriate drug prescription. In some systems, computerized alerts are transmitted directly to the physician, and in others, another evaluator (eg, a pharmacist) receives the alert and notifies the physician. The alert in our study was widely accessible, appearing on all hospital computer terminals. Some systems include an interactive option whereby the treating physician acknowledges that he or she has seen the alert and taken care of the problem.

Not all authors agree that computerized display of laboratory results improves medical practice. Kilpatrick and Holding, in a retrospective audit of providing emergency laboratory test results via computer screen, found that in 83% of cases of hypokalemia ($<3.0 \text{ mEq/L}$) or hyperkalemia ($>6.0 \text{ mEq/L}$) the results were not seen by the physician before a final report was printed. Their conclusion was that the appearance of these results on the computer terminal without a concomitant telephone call could actually delay the transfer of information. Our intervention took place without changing the laboratory policy of telephoning extreme values to the ward and was therefore an addition to the protocol already in place. We did not verify whether these telephone calls were actually made.

It would seem fair to infer that this simple and inexpensive computerized intervention did not harm patients and probably improved the response of physicians to severe hypokalemia. No effect of the intervention on mortality rates was observed, and in light of growing concern about the potential dangers of treatment with intravenous potassium chloride, this is an important observation. McDonald noted in 1976 that many errors in medicine may be caused by clinician sensory overload or faults in information processing. Computerized reminders can assist the busy physician or nurse to notice abnormalities that may otherwise blend into the “noise” caused by multiple data items with which the clinician must cope. There is a danger that computerized reminders could add to this overload, and the fact that we introduced only one alert may have minimized this danger. Creative measures will need to be applied to sustain the effect of computerized alerts if they are used to draw attention to multiple conditions. Although we did not perform a systematic survey of physician satisfaction with the alert system, we heard comments such as “That flashing computer screen makes you pay attention.” In a survey of US medical residents, 88% responded favorably to computerized alerts on hypokalemia, although in another study, 28% expressed annoyance with alerts.

We conclude that the simple addition of a flashing computer terminal screen alerting the treating team to an extremely low serum potassium value can improve the management of hypokalemia in hospitalized patients. The intervention can be applied at a minimal one-time cost and effort (the programmer’s time) and can easily be incorporated into a hospital’s quality assurance program. The efficacy of computerized alerts can be assessed using data obtained from computerized laboratory databases. The usefulness of similar alerts should be investigated in other electrolyte abnormalities and in other settings.

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REFERENCES


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