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RESEARCH

The burden of hyperkalaemia on hospital healthcare resources

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Abstract

Hyperkalaemia is associated with prolonged hospital admission and worse mortality. Hyperkalaemia may also necessitate clinical consults, therapies for hyperkalaemia and high-dependency bed utilisation. We evaluated the 'hidden' human and organisational resource utilisation for hyperkalaemia in hospitalised patients. This was a single-centre, observational cohort study (Jan 2017–Dec 2020) at a tertiary-care hospital. The CogStack system (data processing and analytics platform) was used to search unstructured and structured data from individual patient records. Association between potassium and death was modelled using cubic spline regression, adjusted for age, sex, and comorbidities. Cox proportional hazards estimated the hazard of death compared with normokalaemia (3.5–5.0 mmol/l). 129,172 patients had potassium measurements in the emergency department. Incidence of hyperkalaemia was 85.7 per 1000. There were 49,011 emergency admissions. Potassium > 6.5 mmol/L had 3.9-fold worse in-hospital mortality than normokalaemia. Chronic kidney disease was present in 21% with potassium 5–5.5 mmol/L and 54% with potassium > 6.5 mmol/L. For diabetes, it was 20% and 32%, respectively. Of those with potassium > 6.5 mmol/L, 29% had nephrology review, and 13% critical care review; in this group 22% transferred to renal wards and 8% to the critical care unit. Dialysis was used in 39% of those with peak potassium > 6.5 mmol/L. Admission hyperkalaemia and hypokalaemia were independently associated with reduced likelihood of hospital discharge. Hyperkalaemia is associated with greater in-hospital mortality and reduced likelihood of hospital discharge. It necessitated significant utilisation of nephrology and critical care consultations and greater likelihood of patient transfer to renal and critical care.

Keywords Hyperkalaemia · Resource · Inpatient

Abbreviations

A&E	Accident and emergency department
AKI	Acute kidney injury
CKD	Chronic kidney disease
ECG	Electrocardiogram
EPR	Electronic patient record
HDU	High dependency unit
ICU	Intensive care unit
KCH	King's College Hospital
KDIGO	Kidney Disease: Improving Global Outcomes
KERRI	King's Electronic Patient Record Interface
MedCAT	Medical Concept Annotation Tool
UK	United Kingdom

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Background

The prevalence of hyperkalaemia in the general population is less than 2%, although this will vary by definitions employed and study population [1, 2]. However, in patients with chronic kidney disease (CKD), diabetes, and in patients taking medications that are known to increase potassium levels, the prevalence of hyperkalaemia may be as high as 40–50% [3–7]. Overall, the incidence in hospitalised patients is higher than the general population and may be up to 10% [1]. Hyperkalaemia is a potentially serious condition that can result in life-threatening cardiac arrhythmias and is associated with an increased mortality risk. The presence

of hyperkalaemia therefore requires careful monitoring and often therapeutic intervention. Options for treatment include oral cation exchange resins such as calcium resonium, insulin-glucose infusion, beta-agonists and sodium bicarbonate, as well as calcium gluconate for stabilising myocyte cell membrane potential [8]. A more recent addition to the therapeutic armamentarium are the intestinal potassium binders patiromer (Valtessa™) and sodium zirconium cyclosilicate (Lokelma™).[9, 10] If medical interventions fail, renal replacement therapy may be required. However, there are few data for frequency of use of these therapies and for the requirement for multiple dosing in treating acute hyperkalaemia [1, 8]. Timely specialist referral and escalation of care are also key aspects of management. Hyperkalaemia in the primary care setting has associated with increased healthcare costs and resource utilisation [11]. However, how much burden hyperkalaemia places on resource utilisation within hospital care is poorly explored [12]. Evaluation of resource utilisation allows for better understanding of healthcare needs, prioritisation of resource allocation and identification of parameters for cost-effectiveness studies. We have therefore examined the total healthcare burden of resource utilisation for hyperkalaemia at a single centre, tertiary hospital, in the United Kingdom (UK).

Methods

This was a retrospective cohort study, using data gathered from the electronic patient records (EPR) and electronic prescribing and medicines administration (EPMA) systems of King's College Hospital (KCH), London, UK. This is a large, urban, tertiary-care hospital with 950 beds and four (adult) critical care units, at the time of study. The admissions come, predominantly, from a South London catchment population of approximately 1.2 million. We included all hospital admissions to KCH from 1st January 2017 to 31st December 2020. The study period is based on the availability of complete data across the hospital system. We used data captured through routine care in a single EHR instance (Sunrise Clinical Manager, Allscripts). We used the CogStack ecosystem to access structured fields in the EHR. CogStack is an information retrieval, extraction, and natural language processing platform. It can search any clinical data source (unstructured and structured), with natural language processing (NLP) applications developed to automate information extraction of medical concepts.

Inclusion criteria were hospitalised patients at King's College Hospital between 1st January 2017 and 31st December 2020 admitted via the emergency department. Patients < 18 years of age, or admitted via other routes, were excluded.

Definitions

Index date and time were defined as the date (time) of first hyperkalaemic potassium measurement (within 24 h of hospitalisation or during hospitalisation). A hospital admission was considered length of stay > 24 h. Admissions on the same day as discharge or transfers between departments were considered as a single hospitalisation. Hyperkalaemia was defined as > 5.0 mmol/L. Pharmacological treatment for hyperkalaemia refers to the following pre-specified therapies: insulin-dextrose, calcium resonium, calcium gluconate, Valtessa™ or Lokelma™, salbutamol nebulisers, loop or thiazide diuretics. It does not refer to any treatments given for the underlying aetiology. CKD severity was based on the estimated glomerular filtration rate. Acute kidney injury (AKI) was determined from text using the Medical Concept Annotation Tool (MedCAT), a supervised machine learning algorithm which facilitates the extraction of medical concepts from unstructured text) [13]. AKI alerts, in free text, are automatically generated with the biochemical data, using Kidney Disease: Improving Global Outcomes (KDIGO) criteria [14]. Patients receiving dialysis could be identified from keyword searches (Supplementary Table 1).

Renal consults were identified and reported by two means, (1) entry in the clinical notes by a renal clinician [identified by key word search terms; Supplementary Table 1]), and (2) Patients being on the renal specialist ward. KCH utilises critical care outreach teams. The outreach team offers intensive care skills to patients with, or at risk of, critical illness receiving care in locations outside the intensive care unit [15]. Critical care outreach review could be made by a doctor or nurse and could be 'virtual review' or bedside review.

Laboratory data

In addition to serum samples, sent to the laboratory, potassium values may be obtained and/or actioned based-upon venous blood gas samples. Blood gas data were also accessed through CogStack system. These were analysed and found to be within clinically meaningful range of the "true" laboratory result > 99% of the time, and the overwhelming majority had a laboratory sample taken simultaneously [16]. Two further point-of-care analysers were not connected to the EPR and therefore not accessible via CogStack.

Statistical analysis

Descriptive statistics of the hospitalised cohort were made using mean and 95% confidence interval; median and interquartile range for continuous data, and counts and proportions (%) for categorical data. Independent sample tests of

categorical variables against outcomes were tested with chi-square tests of significance for categorical variables. Continuous variables were tested by the Kruskal–Wallis test.

The association between index (hyperkalaemic) serum potassium and death was modelled using cubic spline regression with boundary knots placed at 2.5 and 8 mmol/l, adjusting for covariates of age, sex, and high-risk comorbidities (diabetes, cardiac failure, chronic kidney disease). The Cox proportional hazard model was applied to estimate the hazard ratio of death in patients with hyperkalaemia and hypokalaemia compared with patients with normokalaemia (3.5–5.0 mmol/l). Data were right-censored by readmission. Univariate and multivariate analyses with adjustment for age, sex, and high-risk comorbidities were performed. Although a serum potassium reading of ≥ 5.1 mmol/l defined a hyperkalaemia episode, we have also reported the incidence according to the severity of hyperkalaemia episode, as serum potassium ≥ 5.5 and ≥ 6.0 mmol/l. Analyses were performed using R statistical software, version 3.6.1.

Ethical approval

The King's College Hospital Research and Innovation Department, after review of the project, considered this as a service evaluation, rather than research. We confirmed this opinion using the HRA 'Is this research?' decision tool (http://www.hra-decisiontools.org.uk/research/). Local approval for use of CogStack EPR searched was sought from the King's Electronic Patient Record Interface (KERRI) committee (project ID 20210405A), and approval was received on 7th May 2021.

Results

In total, 129,172 blood tests that included a potassium measure were taken over the study period (males 60,953; females 68,201). Of these, 49,011 were from patients who were admitted to a ward. The mean age was 49.6 years [standard deviation (SD) 23.6]. The median number of admissions per patient, over the study period, was one (IQR 1-3) and the median length of admission was 0.4 days (IQR 0.2-2.7). A total of 8355 patients (6.5%) in this study died during the follow-up period, of which 2322 deaths were within King's College Hospital. Of all patients who had blood tests within the emergency department, the prevalence of hyperkalaemia was 85.7 per 1000. Of those patients who were admitted, the prevalence of hyperkalaemia was 167.9 per 1000 patients.

We determined, per hyperkalaemic strata, the burden of comorbidities associated with hyperkalaemia (Table 1). This showed escalating proportions of CKD and heart failure in higher hyperkalaemic strata. The population with hyperkalaemia was split into strata of escalating potassium (Table 2), and the proportion of each strata receiving medication, considered as contributing agents, are displayed.

As potassium threshold moved from 5.5 to 6, 6.5 mmol/L and greater, so the proportion with impaired renal function increased (Supplementary Table 2). For each increasing hyperkalaemia threshold, a greater proportion of those with impaired renal function had AKI. For instance, in those with creatinine > 150 µmol/L and potassium 5.0–5.49 mmol/L, the proportion with AKI was 28%, whereas in those with creatinine > 150 µmol/L and potassium > 6.5 mmol/L, the proportion with AKI was 45%.

In-hospital management and outcomes of hyperkalaemia

The type of ward in which hyperkalaemia was encountered is shown in Table 3. As expected, the renal ward was the most common location, followed by the intensive care unit (ICU). Of note, 'accident and emergency' represents all patients in A&E. There was very little difference in mean potassium between the ward areas (Table 3). We examined the 'hidden' burden of medical resource used within the hospital system. In particular, the proportions (per hyperkalaemic strata) that had a renal review or a critical care outreach review (Table 4). Nearly one-quarter of patients with a potassium > 6.5 mmol/L were transferred to a renal ward, compared to 2% of those with potassium 5.0—5.5 mmol/L.

Table 1 Description of the proportion of comorbidities per strata of hyperkalaemia

Proportion of patients within each strata who have comorbidity (95% CI)						
Hyperkalaemia (mmol/L)	*n*	ESRF	ESRF on dialysis	Diabetes	CKD	Heart failure
(5.0–5.5]	7148	5 (4, 5)	3 (3, 3)	20 (19, 21)	21 (20, 22)	29 (28, 30)
(5.5–6.0]	2313	12 (11, 14)	9 (8, 10)	30 (28, 32)	35 (34, 37)	40 (38, 42)
(6.0–6.5]	876	21 (19, 24)	17 (15, 20)	34 (31, 37)	49 (46, 52)	47 (44, 50)
(6.5–Inf]	733	32 (28, 35)	24 (21, 28)	32 (29, 36)	54 (50, 57)	48 (45, 52)

For the degree of hyperkalaemia, square brackets signify the number is included. Numbers in parentheses are 95% CI for the mean

CKD, chronic kidney disease; ESRF, end stage renal failure

Table 2 The proportion of each strata prescribed medications known to promote hyperkalaemia

Hyperkalaemia (mmol/L)	*N*	Proportion (%) of strata prescribed medication on admission mean (95% CI)									
		ACEi	ARB	Beta-blocker	Calcineurin inhibitor	MRA	NSAID	Azole antifungal	Trimethoprim	Pentamidine	Amiloride
(5.0–5.5]	3508	29 (27, 30)	13 (12, 14)	35 (34, 37)	2 (2, 3)	7 (6, 8)	8 (7, 9)	2 (1, 2)	2 (1, 2)	0 (0, 0)	0 (0, 0)
(5.5–6.0]	1414	32 (29, 34)	12 (11, 14)	41 (38, 44)	3 (2, 4)	7 (6, 9)	5 (4, 7)	1 (1, 2)	2 (1, 3)	0 (0, 0)	0 (0, 0)
(6.0–6.5]	581	31 (28, 35)	12 (9, 15)	41 (37, 46)	3 (2, 5)	7 (5, 9)	4 (2, 6)	2 (1, 3)	2 (1, 4)	0 (0, 1)	0 (0, 1)
(6.5–Inf]	493	26 (22, 30)	16 (13, 19)	42 (37, 46)	4 (3, 7)	6 (4, 8)	4 (3, 7)	3 (1, 5)	2 (1, 4)	0 (0, 1)	0 (0, 2)

For the degree of hyperkalaemia, square brackets signify the number is included. Numbers in parentheses are 95% CI for the mean. Azole antifungals included ketoconazole, fluconazole, and itraconazole. MRA included spironolactone, eplerenone

ACEi, angiotensin converting enzyme inhibitor; ARB, angiotensin receptor blocker; MRA, mineralocorticoid receptor blocker (eplerenone or spironolactone); NSAID, non-steroidal anti-inflammatory drug

The corresponding figures for those transferred to HDU or ICU were 8 and 5% (Table 5).

Relatively few individuals received treatment for hyperkalaemia in the 5.0–5.5 mmol/L range (Table 6), but with increasing proportions—particularly with potassium > 6.0 mmol/L. In those with potassium > 6.5 mmol/L, Insulin-dextrose was the most common treatment (56%) with nearly one-half of these individuals ($n = 196$; 48% of those receiving insulin-dextrose) requiring more than one dose. Calcium resonium was used in 11%. Nearly one-third were being prescribed a diuretic, but this was not temporally related to the finding of hyperkalaemia. Of note, nearly half of all patients with hyperkalaemia over 6.5 mmol/L had heart failure. Sodium bicarbonate capsules were commenced in nearly one-quarter of patients with potassium > 6.5 mmol/L, whereas the institution of diuretic therapy was small, overall.

Of those with potassium > 6.5 mmol/L, nearly two-thirds achieved normalisation of potassium prior to hospital discharge (Table 7), whereas that figure was approximately 40–50% for lower strata of hyperkalaemia.

In total, 2322 patients died in hospital and a further 6,033 died after discharge from A&E or an in-patient ward. Those in higher potassium strata had longer admissions (Fig. 1). Admission hyperkalaemia and hypokalaemia were independently associated with reduced likelihood of hospital discharge (Supplementary Tables 3, 4). Patients with a last measured plasma potassium of 3.5–4.0 mmol/L had the greatest likelihood of being discharged (Supplementary Fig. 1). Hyperkalaemia was also associated with greater in-hospital mortality (Fig. 2). We found no survival advantage in those treated with dextrose-insulin (Supplementary Fig. 2) compared to no therapy.

Discussion

Our data have confirmed the high incidence of hyperkalaemia in-hospital and the higher mortality associated with hyperkalaemia. In a comprehensive assessment, we show the 'hidden' burden of healthcare resource taken up in the management of patients with hyperkalaemia, including the proportions requiring specialist consultations, the medications used and the efficacy of treatment for hyperkalaemia. Furthermore, we have shown the high proportions requiring HDU transfer and support.

An elevated potassium has been reported in up to 10% of hospitalised patients [3, 17–19], with 10% of those patients (i.e. up to 1% of hospitalised patients) having serum potassium greater than or equal to 6 mmol/L [20]. Our data are broadly in agreement with that—the prevalence of hyperkalaemia was 85.7 per 1000 (8.6%) but this was data from all measures of patients attending A&E—which would capture the majority of patients who didn't

Table 3 The ward location at time of notification of hyperkalaemia

Clinical area	Mean potassium (mmol/L)	Total number of tests for potassium	Percentage with hyperkalaemia
Renal	4.7 (4.7, 4.7)	7026	32 (30, 33)
ICU	4.5 (4.5, 4.5)	10,271	17 (16, 18)
Cardiac, cardiothoracic, vascular	4.4 (4.4, 4.5)	14,682	14 (13, 14)
Liver and HPB	4.3 (4.3, 4.3)	9322	11 (11, 12)
Elderly care	4.3 (4.3, 4.3)	32,045	11 (10, 11)
Acute medicine	4.3 (4.3, 4.3)	72,514	10 (10, 10)
Liver intensive care unit	4.4 (4.4, 4.5)	716	10 (8, 13)
Medical assessment centre (in A&E)	4.3 (4.2, 4.3)	711	10 (8, 12)
Frailty assessment unit	4.3 (4.3, 4.4)	1080	8 (7, 10)
Surgical	4.3 (4.3, 4.3)	38,430	8 (8, 8)
Haematology	4.2 (4.2, 4.2)	8228	8 (7, 8)
Stroke	4.2 (4.2, 4.3)	8501	8 (7, 8)
Obstetrics and gynaecology; postnatal	4.2 (4.2, 4.2)	11,990	5 (4, 5)
Neurology and neurosurgery	4.2 (4.2, 4.2)	20,411	4 (4, 5)
Clinical decision unit (based within A&E)	4.2 (4.2, 4.3)	8591	4 (4, 5)
Accident and emergency	4.2 (4.2, 4.2)	71,716	3 (3, 3)

Numbers in parentheses are 95% CI for the mean

Table 4 Consultations for hyperkalaemia

Hyperkalaemia	*n*	'Renal' appearing in notes (%)	'Renal reg' in notes or blood test on renal ward (%)	'Renal reg' in notes but no blood sampling from renal ward (%)	Critical care outreach (%)
(5.0–5.5]	7148	2 (2, 3)	4 (3, 4)	2 (2, 2)	10 (9, 11)
(5.5–6.0]	2313	6 (5, 7)	10 (9, 12)	4 (4, 5)	12 (11, 13)
(6.0–6.5]	876	9 (7, 11)	19 (16, 22)	7 (5, 9)	15 (12, 17)
(6.5–Inf]	733	12 (10, 15)	29 (26, 33)	8 (6, 10)	13 (11, 16)

For the degree of hyperkalaemia, square brackets signify the number is inclusive. Numbers in parentheses are 95% CI for the mean

Table 5 Per cent transferred to renal/HDU/ICU from within the hospital

Maximum in-patient potassium (mmol/L)	*n*	HDU and ICU	Renal transfer
(5.0–5.5]	7148	5 (4, 5)	2 (1, 2)
(5.5–6.0]	2313	5 (5, 6)	6 (5, 7)
(6.0–6.5]	876	7 (6, 9)	12 (10, 15)
(6.5–Inf]	733	8 (6, 10)	22 (19, 25)

For the degree of hyperkalaemia, square brackets signify the number is inclusive. Numbers in parentheses are 95% CI for the mean

HDU, high-dependency unit; ICU, intensive care unit

require admission. A recent report of the prevalence of hyperkalaemia in a Swiss A&E unit was 8.8% when hyperkalaemia defined as > 4.7 mmol/L [21]. Data from A&E departments in USA have the prevalence of hyperkalaemia (defined as > 5.0 mmol/L) as 3.6% [22, 23]. Patients with CKD are known to be particularly at risk of hyperkalaemia, with its incidence rising from 2 to 42% as glomerular filtration rate drops from 60 to 20 mL/min [24]. In CKD with an estimated glomerular filtration rate < 30 ml/min, the prevalence of hyperkalaemia was 1.8% in a large USA cohort [25] and 4–5% in an Italian cohort [24]. We found a continuous positive relationship between the proportion of hospitalised patients with CKD and the maximum in-hospital potassium (for instance, 21% of those with potassium 5.0–5.4 mmol/L and 54% of those with potassium > 6.5 mmol/L).

To our knowledge, there is no study of the prevalence of hyperkalaemia in unselected patients presenting with acute kidney injury (AKI). However, an ICU prevalence of 3.4% with no AKI has been reported in ICU, rising to 8.8% in AKI stage 1; 17% in AKI stage 2; and 32.2% in AKI stage 3 [26]. Our cohort is not one of all patients with AKI but rather of all those with hyperkalaemia. We show that acute kidney injury (identified from automated AKI alerts) was a driving force for hyperkalaemia (up to 6.5 mmol/L) in nearly two-thirds of those who had eGFR < 30 ml/min.

Table 6 Therapies employed for the treatment of hyperkalaemia

Maximum in-patient potassium (mmol/L)	*n*	% Treated with insulin-dextrose	Number requiring ≥ 2 doses of insulin-dextrose	% Treated with calcium resonium	% Treated with calcium gluconate	% Treated with thiazide or loop diuretic	% Treated with salbutamol	% Treated with Bicarbonate infusion	% Receiving dialysis
(5.0–5.5]	7148	1 (0, 1)	2	0 (0, 0)	2 (1, 2)	19 (18, 20)	3 (2, 3)	0 (0, 0)	7 (7, 8)
(5.5–6.0]	2313	7 (6, 8)	19	3 (2, 3)	9 (8, 10)	26 (24, 28)	4 (3, 4)	0 (0, 1)	16 (15, 18)
(6.0–6.5]	876	34 (31, 38)	103	7 (5, 9)	34 (31, 37)	30 (27, 33)	6 (4, 7)	0 (0, 1)	28 (25, 31)
(6.5–inf]	733	56 (52, 59)	196	11 (9, 14)	58 (54, 61)	29 (26, 33)	11 (9, 13)	1 (0, 02)	39 (36, 43)

For the degree of hyperkalaemia, square brackets signify the number is inclusive. Numbers in parentheses are 95% CI for the mean. Dialysis could include haemofiltration or peritoneal dialysis

Table 7 Biochemical outcomes following the observation of hyperkalaemia during admission

Hyperkalaemia (mmol/L)	*n*	Proportion achieving normokalaemia (%)	Time to normalisation of potassium, in hours [median (IQR)]	Last potassium concentration (mmol/L) before discharge[a]
(5.0–5.5]	4474	39 (37, 40)	43 (18, 49)	5 (5, 5)
(5.5–6.0]	1238	48 (45, 51)	50 (13, 55)	5.2 (5.1, 5.2)
(6.0–6.5]	403	55 (50, 60)	43 (13, 50)	5.2 (5.2, 5.3)
(6.5–Inf]	349	62 (57, 68)	45 (10, 54)	5.5 (5.3, 5.7)

For the degree of hyperkalaemia, square brackets signify inclusive of the number. Normokalaemia ≤ 5.0 mmol/L

[a]Mean (95% CI)

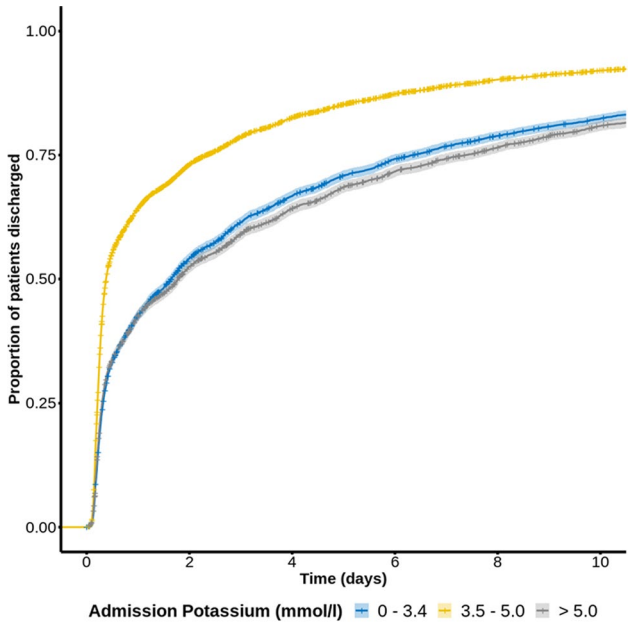

Fig. 1 Length of hospital admission, per potassium strata

Hyperkalaemia in-hospital is associated with greater mortality [23, 27]. Others have shown that patients with a potassium of 5.1–5.5 have twice the risk of dying in hospital than those with levels between 3.5 and 5.0 [23]. Our data show 14-day mortality in the > 6 mmol/L group being near double that of the 5–6 mmol/L. and that hyperkalaemia remained an independent predictor after adjustment for confounding variables.

Hyperkalaemia has also been associated with longer hospital stay [28, 29], as well as an increased number of intensive care unit (ICU) stays [11] and emergency department visits [29]. However, to date there has been little study of the in-hospital resource allocation. European and North American nephrology and resuscitation guidelines advise the use potassium exchange resins, such as calcium resonium 15–30 g "if treatment is indicated", at potassium concentration 5.0–5.9 mmol/L [30–32]. However, we found that calcium resonium was prescribed infrequently—only 3% of individuals with potassium 5.5–6.0 mmol/L were treated with calcium resonium. This may be due to the side-effect profile and/or to the relatively slow method of reducing serum potassium, with onset of action being 2–12 h. Furthermore, there is a requirement to administer at least 3 h before, or 3 h after other oral medications [33]. Internationally, there is a wide variation in use of cation exchange resins, ranging from 42% of patients in France to less than 1% in Japan, Spain and the United Kingdom [34].

Insulin-glucose and beta-agonists are endorsed for moderate elevation (6.0–6.4 mmol/L) [30–32]. At our centre, 35% of 6.0–6.5 mmol/L and 56% of > 6.5 mmol/L received insulin-dextrose; although 7% of patients with potassium 5.5–6.0 mmol/L also received insulin-dextrose. A much lower percentage were treated with nebulised salbutamol.

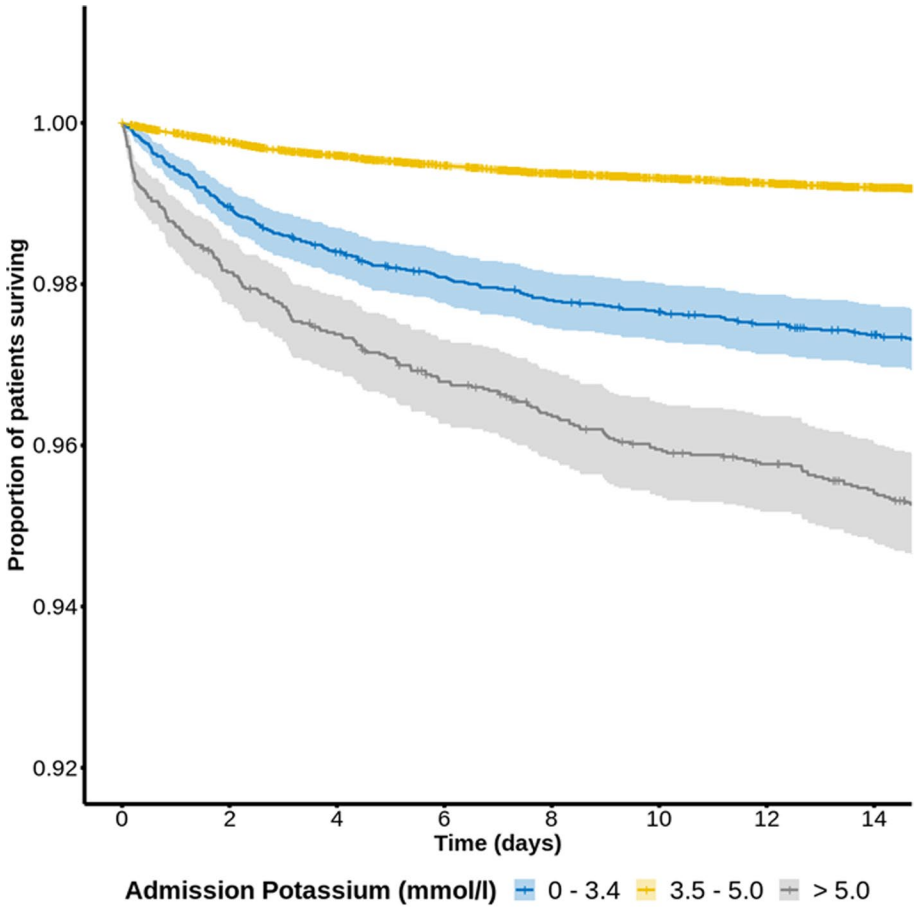

Fig. 2 In-hospital mortality

Despite limited data, there is a suggestion that salbutamol and insulin have broadly comparable effectiveness [8].

We have shown the high levels of hospital resource needed both in terms of renal and critical care consultations—up to one-third of patients had either an entry made by a renal doctor or a blood test being taken on a renal ward (suggesting renal involvement). In addition, approximately one-eighth had a critical care outreach review, although the proportions requiring critical care outreach review were mostly unchanged across potassium strata. Transfer to renal wards showed a continuous relationship to the maximum in-hospital potassium value (2% of those in potassium 5.0–5.5 mmol/L stratum and 28% in the > 6.5 mmol/L stratum). The figures for HDU/ICU transfers showed a similar trend, albeit fewer numbers overall (1% and 7%, respectively). These are the 'hidden' costs of hyperkalaemia. As an approximation, at 2019 prices, the average cost of an A&E attendance was £139 ($170 US), a general medical bed £550 ($670 US) per day and the direct costs associated with an ICU admission is ~£1700 per day ($2100 US) [35–37]. By measuring the true quantities of healthcare resources utilised, it would be possible to generate valid costing estimates. Although other groups have evaluated the community costs associated with hyperkalaemia [11, 38]; to our knowledge, this is the first attempt to determine the in-hospital burden of hyperkalaemia.

We report the proportions achieving correction of hyperkalaemia—39% of those with potassium 5.0–5.5 mmol/L and 62% of those with potassium > 6.5 mmol/L achieving documented correction of potassium. These figures may partially represent the greater propensity to treat higher potassium values. The proportions achieving normalisation are far less than a US series, in whom 86.8% achieved correction during the in-patient stay[39], perhaps due to less utilisation of temporising agents in our cohort (in the US cohort, therapies were employed in 28.9%; 46.0%; 73.0% for mild [> 5.0–5.5 mmol/L], moderate [> 5.5–6.0 mmol/L], and severe [> 6.0 mmol/L] hyperkalaemia, respectively). The time taken for correction of hyperkalaemia was nearly 48 h, this is slower than has been reported [40, 41], although we cannot discount a point-of-care test from a machine not connected to the electronic patient network being used in the interim, to confirm hyperkalaemia resolution. In a study from Saudi Arabia, the mean duration for the resolution of hyperkalaemia was 12 ± 9.4 h.[40] The difference may relate to propensity to remeasure potassium. In the Saudi study, the use of intravenous insulin (48% hospitalised patients) was little different. Sodium polystyrene sulfonate was used

in 39% and 38% patients were not specifically treated for hyperkalaemia. In a Canadian study of 1944 patients, of the 203 (23%) patients who were treated (mean potassium ~ 5.5 [CI 5.3–5.8] mmol/L), the time taken for resolution of hyperkalaemia was 13.8 ± 5.8 h.[41] The time taken to correct hyperkalaemia may, in part, explain the well-known positive association between hyperkalaemia and length of stay [39]. We found no difference in mortality between those treated/not treated with insulin-dextrose (per hyperkalaemia strata), although this may reflect a propensity to use dextrose-insulin in the sickest individuals. We were not able to access physiological variables to calculate illness severity scores in our cohort and use in regression modelling.

The likelihood of discharge from hospital was less for those with potassium greater than 5.0 mmol/L. Together, these novel data complement what is known regarding greater mortality and length of stay with hyperkalaemia.

Limitations

This is a comprehensive account of the in-patient management and outcomes of hyperkalaemia. Severe hyperkalaemia has been defined as serum potassium > 6.5 mmol/L [32]. An indicator of hyperkalaemia severity can also include the presence of ECG abnormalities [42] but at the time of study, the CogStack system could not 'read' electrocardiograms (ECGs). Serum potassium will increase as serum pH decreases because potassium shifts from the cellular to the vascular space. To what degree hyperkalaemia is a pathophysiological bystander for co-incident acidaemia is uncertain and further work is needed to establish this. It is noteworthy that a third of individuals with maximum potassium > 6.5 mmol/L had an eGFR of > 30 mls/min/m^2. Whether hyperkalaemia directly led to admissions, for example, through muscle weakness, cardiac problems, and resulting falls, is uncertain. This is especially true with comorbidity [43]—in our cohort, heart failure, diabetes and kidney failure were all over-represented in those with hyperkalaemia.

Conclusion

In this work, we have shown that the 'hidden burden' of hyperkalaemia in hospital is considerable. The outcomes of therapeutic interventions are described, as are the utilisation of renal and higher-dependency unit consultations and patient transfer. These data will help to inform the economic analysis of newer therapies to treat hyperkalaemia.

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Data availability The code used to interrogate the data is available on request from corresponding author. The datasets generated and analysed during the current study are not publicly available as the data comprise individual medical health records. Access to the clinical data can only be made on-site at King's College Hospital, via an application to the KERRI committee (Prof James Teo, King's College Hospital).

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval The King's College Hospital Research and Innovation Department, after review of the project, considered this as a service evaluation, rather than research. We confirmed this opinion using the HRA 'Is this research?' decision tool (http://www.hra-decisiontools.org.uk/research/). We used anonymous data, at scale, at source (within the hospital IT system) and therefore patient level consent was not required. Approval for this approach to use of CogStack is within London—South East Research Ethics Committee approval (18/LO/2048) 2nd January 2019. King's Electronic Patient Record Interface (KERRI) committee (Project ID 20210405A) approved the project (within the boundaries of CogStack ethical approval 18/LO/2048) on 7th May 2021.

Consent for publication Not applicable.

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