Uludağ Üniversitesi Tıp Fakültesi Dergisi
Journal of Uludağ University Medical Faculty
51 (2) 285-290, 2025
DOI: https://doi.org/10.32708/uutfd.1701404

ORIGINAL RESEARCH

Evaluation of the Relationship Between Electrocardiographic Changes and the Calcium/Potassium Ratio in Patients with Acute and Chronic Renal Failure*

Qatada Omar Mohammad ALDABBAS[1], Özlem KÖKSAL[2], Melih YÜKSEL[3], Enad KENAN[4], Vahide Aslıhan DURAK[5], Göksel AYDOĞAN[6]

[1] Hayat Hospital, Bursa, Türkiye.
[2] Bursa Uludag University Medical Faculty Emergency Medicine Department, Bursa, Türkiye.
[3] Bursa Yuksek Ihtısas Training and Research Hospital Emergency Medicine Department, Bursa, Türkiye.
[4] Orhangazi State Hospital, Bursa, Türkiye.
[5] Bursa Uludag University Medical Faculty Emergency Medicine Department, Bursa, Türkiye.
[6] Zonguldak State Hospital, Bursa, Türkiye.

ABSTRACT

The aim of this study was to investigate the relationship between serum calcium and potassium levels, as well as the calcium/potassium ratio, and electrocardiographic (ECG) changes in patients presenting to the emergency department with both renal failure and hyperkalemia. This cross-sectional study was conducted retrospectively by reviewing the medical records of patients diagnosed with renal failure and concomitant hyperkalemia (serum potassium>5.5 mEq/L) who presented to the emergency departments of a university hospital and a training and research hospital between November 1, 2022, and October 31, 2023. 55.4% of the patients were male, with a mean age of 68.31 ± 13.56 years. ECG abnormalities were detected in 69.5% of the cases. The most frequently observed ECG abnormalities were atrial fibrillation (22.0%) and peaked T waves (20.3%). Hemodialysis was performed in 52.5% of patients, 23.2% were admitted to the intensive care unit (ICU), and 15.8% died within 30 days of hospital presentation. Patients with T wave inversion had significantly lower potassium levels (6.42 ± 0.77 vs. 6.03 ± 0.71, p=0.018). In patients with any ECG abnormality, calcium levels (8.69 ± 0.87 vs. 8.36 ± 0.85, p=0.037) and calcium/potassium ratios (1.39 ± 0.19 vs. 1.32 ± 0.20, p=0.036) were significantly lower. The calcium/potassium ratio was also significantly lower in patients with peaked T waves (1.36 ± 0.20 vs. 1.27 ± 0.20, p=0.016). Among patients who died in-hospital or within 30 days, calcium/potassium ratios were significantly lower and potassium levels were significantly higher (p<0.05). In patients presenting to the emergency department with renal failure and concomitant hyperkalemia, the presence of ECG abnormalities was associated with lower calcium levels and a reduced calcium/potassium ratio. Moreover, 30-day mortality was found to be associated with higher potassium levels and a lower calcium/potassium ratio. These findings suggest that cardiac complications should be considered in clinical practice when hyperkalemia accompanies acute or chronic renal failure.

Keywords: Calcium. Potassium. ECG. Emergency service.

Akut ve Kronik Böbrek Yetmezliği olan Hastalarda Karşılaşılan EKG Değişikliklerinin Kalsiyum/ Potasyum Oranı ile İlişkisinin Değerlendirilmesi

ÖZET

Çalışmanın amacı acil serviste böbrek yetmezliğine ek olarak hiperkalemi tespit edilen hastalarda kalsiyum, potasyum düzeyinin ve kalsiyum/potasyum oranının EKG değişiklikleri ile ilişkisini araştırmaktır. Kesitsel tipte olan bu çalışma, 1 Kasım 2022 – 31 Ekim 2023 tarihleri arasında bir üniversite hastanesi ve eğitim araştırma hastanesi acil servislerinde böbrek yetmezliği tanısına ek olarak hiperkalemi (>5,5 mEq/L) saptanan olguların dosyalarının retrospektif olarak değerlendirilmesi ile gerçekleştirilmiştir. Olguların %55,4'ü erkekti ve yaş ortalaması 68,31 ± 13,56 yıldı. Olguların %69,5'inin EKG'sinde en az bir patolojik değişiklik saptandı. En sık saptanan patolojik değişiklikler atrial fibrilasyon (%22,0) ve sivri T dalgasıydı (%20,3). Olguların %52,5'ine hemodiyaliz uygulandığı, %23,2'si YBÜ'ye yatırıldığı ve %15,8'inin hastane başvurusu sonrasındaki 30 gün içinde exitus olduğu saptandı. T dalgası inversiyonu saptananlarda potasyum düzeyi istatistiksel olarak anlamlı düzeyde daha düşüktü (6,42±0,77 vs 6,03±0,71, p=0,018). EKG'de herhangi bir patoloji saptananlarda kalsiyum (8,69±0,87 vs 8,36±0,85, p=0,037) ve kalsiyum/potasyum oranı istatistiksel olarak anlamlı düzeyde daha düşük saptandı (1,39±0,19 vs 1,32±0,2, p=0,036). Sivri T dalgası saptananlarda kalsiyum/ potasyum oranı istatistiksel olarak anlamlı düzeyde daha düşüktü (1,36±0,2 vs 1,27±0,2, p=0,016). Hastanede veya 30 gün içinde ölen olguların kalsiyum/ potasyum düzeyi istatistiksel olarak anlamlı düzeyde daha düşük, potasyum düzeyi ise daha yüksekti (p<0,05). Sonuç olarak, acil servise böbrek yetmezliği tanısına ek olarak hiperkalemi ile başvuran olgularda EKG'de patoloji saptanma durumu daha düşük kalsiyum düzeyi ve kalsiyum/potasyum oranı ile ilişkilendirilmiştir. Ayrıca ilk 30 gün içinde mortalite, potasyum düzeyinin artışı ve kalsiyum/potasyum oranının azalışı ile ilişkili bulunmuştur. Rutin pratikte akut ya da kronik böbrek yetmezliğine ek olarak hiperkalemi saptanan olgularda kliniğe kardiyak sorunların eşlik edebileceği akılda tutulmalıdır

Anahtar Kelimeler: Kalsiyum. Potasyum. EKG. Acil servis.

Date Received: 17.May.2025
Date Accepted: 24.July.2025

* Presented as an oral presentation at the "XX. Ulusal Acil Tıp Kongresi & XI. Intercontinental Emergency Medicine Congress & XI. International Critical Care and Emergency Medicine Congress" (May 2024, Antalya)

Dr. Vahide Aslıhan DURAK
Bursa Uludag University Medical Faculty Emergency Medicine Department, Bursa, Türkiye
E-mail: aslidurakis@hotmail.com

AUTHORS' ORCID INFORMATION
Qatada Omar Mohammad ALDABBAS: 0009-0000-6725-6463
Özlem KÖKSAL: 0000-0003-2271-5659
Melih YÜKSEL: 0000- 0002- 0793-3693
Enad KENAN: 0000-0003-1572-2500
Vahide Aslıhan DURAK: 0000-0003-0836-7862
Göksel AYDOĞAN: 0009-0006-2750-207X

Renal failure is a significant clinical condition that leads to disturbances in the body's water, electrolyte, and acid-base balance. Both acute kidney injury (AKI) and chronic kidney disease (CKD) can alter serum levels of electrolytes such as potassium and calcium, potentially causing serious disruptions in the cardiac conduction system.

Hyperkalemia is a common clinical problem, often resulting from impaired urinary potassium excretion due to acute or chronic kidney disease and/or disorders or medications that inhibit the renin-angiotensin-aldosterone system (RAAS)[1]. It is typically defined as serum or plasma potassium levels exceeding the upper limit of normal, generally above 5.0–5.5 mEq/L. While mild hyperkalemia is often asymptomatic, higher levels can lead to life-threatening cardiac arrhythmias, muscle weakness, or paralysis[2]. Electrocardiographic manifestations of hyperkalemia may include a widened QRS complex, peaked T waves, prolonged QT interval, and absent P waves[3].

Hypokalemia, one of the most frequently encountered electrolyte disorders in clinical practice, can increase the risk of life-threatening arrhythmias. ECG features associated with hypokalemia (typically at potassium levels <2.7 mmol/L) include dynamic changes in T wave morphology, ST-segment depression, and U waves, particularly in mid-precordial leads (V2–V4). The PR interval may be prolonged with an increase in P wave amplitüde[4].

Another electrolyte disorder, hypercalcemia, is defined as a serum calcium concentration >10.5 mg/dL, with primary hyperparathyroidism and malignancies accounting for 90% of cases. Management focuses on treating the underlying cause. ECG changes associated with hypercalcemia may include a prolonged PR interval and shortened QT interval[5].

Hypocalcemia, most commonly due to hypoalbuminemia, is often associated with cirrhosis, nephrotic syndrome, malnutrition, burns, chronic illnesses, and sepsis. The hallmark ECG feature of hypocalcemia is a prolonged QT interval, resulting from ST segment prolongation[6,7].

Recent studies suggest that the serum calcium/potassium ratio may serve as a novel biomarker influencing cardiac electrical activity. This ratio reflects the balance between two critical electrolytes and may have clinical significance. However, its relationship with ECG findings has not been thoroughly explored, especially in patients with renal failure[8,9].

This study aimed to evaluate the association between ECG changes and serum calcium and potassium levels, as well as the calcium/potassium ratio, in patients diagnosed with acute or chronic renal failure accompanied by hyperkalemia.

Material and Method

This study was conducted with the approval of the Clinical Research Ethics Committee (November 23, 2022; decision number: 2022-18/43) by retrospectively reviewing the medical records of patients diagnosed with renal failure and hyperkalemia (serum potassium>5.5 mEq/L) who presented to the emergency departments of Bursa Uludağ University Faculty of Medicine Hospital (n=137) and Bursa High Specialization Training and Research Hospital (n=44) between November 1, 2022, and October 31, 2023.

Inclusion criteria were a confirmed diagnosis of acute or chronic renal failure, serum potassium levels above 5.5 mEq/L, and complete clinical and ECG data. Recorded parameters included age, sex, vital signs (blood pressure, oxygen saturation, heart rate), diagnosis of acute or chronic renal failure, laboratory results (arterial and venous blood gases), ECG findings, need for hemodialysis, clinical outcomes, and 30-day mortality.

All ECG's were evaluated retrospectively by two emergency physicians experienced in electrocardiography, each with more than five years of clinical experience and inter-observer agreement was not formally assessed. Inter-observer reliability was assessed using Cohen's kappa coefficient, which indicated substantial agreement ($\kappa = 0.78$).

Statistical Analysis

Data were analyzed using SPSS version 26.0. Categorical variables were summarized as counts and percentages, while continuous numerical variables were reported as means, standard deviations, and medians. Normal distribution of continuous data was assessed using the Shapiro-Wilk test and was found to be non-normal. Comparisons between two groups were performed using the Mann-Whitney U test, while

comparisons among three groups were conducted using the Kruskal-Wallis test. Bonferroni correction and pairwise comparisons were applied to identify significant group differences. A p-value of <0.05 was considered statistically significant. Box-and-whisker plots were used for data visualization. To assess the ability of the calcium/potassium (Ca/K) ratio to predict 30-day mortality, a receiver operating characteristic (ROC) curve analysis was conducted. The area under the curve (AUC) was calculated to determine the discriminative performance of the Ca/K ratio. The optimal cut-off value was determined using the Youden index, and corresponding sensitivity and specificity values were reported. Roc Analysis was performed using MedCalc® Statistical Software version 23.0.8 (MedCalc Software Ltd, Ostend, Belgium; 2024). Additionally, a multivariate logistic regression analysis was performed to identify independent predictors of 30-day mortality. Variables with p<0.10 in univariate comparisons (e.g., serum potassium, serum calcium, calcium/potassium ratio, need for hemodialysis, and ICU admission) were included in the model. The results were presented as odds ratios (OR) with 95% confidence intervals (CI), and a p-value<0.05 was considered statistically significant.

Results

Among the 177 patients included in the study, 55.4% were male and 44.6% were female. Of these, 44.6% were diagnosed with chronic renal failure, 52.0% with acute renal failure, and 3.4% with acute-on-chronic renal failure.

ECG abnormalities were detected in 69.5% of cases. The most common pathological findings were atrial fibrillation (22.0%) and peaked T waves (20.3%) (Table I) Hemodialysis was performed in 52.5% of the patients, 23.2% were admitted to the intensive care unit (ICU), and 15.8% died within 30 days of hospital admission.

Compared to patients without T wave inversion, those with this finding had significantly lower potassium levels (p=0.018).

Compared to discharged patients and those admitted for treatment, patients who died had significantly higher potassium levels (p=0.001). On day 30 following hospital admission, potassium levels were significantly higher in deceased patients compared to survivors (6.31 ± 0.71 vs. 6.85 ± 0.94, p = 0.006).

The calcium/potassium ratio was significantly lower in patients with peaked T waves compared to those without (1.36 ± 0.20 vs. 1.27 ± 0.20, p = 0.016). No statistically significant association was found between other ECG abnormalities and the calcium/potassium ratio (p > 0.05) (Table II)

Table I. Distribution of Electrocardiographic (ECG) Findings

Variables	Number (n)	Percent (%)
Pathological findings in ECG		
None	54	30.5
ECG findings present	123	69.5
Atrial fibrillation	39	22.0
Peaked T wave	36	20.3
Bundle branch block	18	10.2
T wave inversion	12	6.8
QRS prolongation	9	5.1
Prolonged PR interval	6	3.4
Loss of P wave	4	2.3
Asystole	4	2.3
Progressive QRSwidening	1	0.6
ST segment elevation	1	0.6
Ventricular tachycardia	1	0.6
Ventricular fibrillation	1	0.6

Table II. Calcium/Potassium Ratio Based on Specific ECG Changes

Variables	Calcium/Potassium Ratio (Mean±SD. Median)	*p*
Any ECG pathology		
None	1.39 ± 0.19 (1.39)	**0.036**
Present	1.32 ± 0.2 (1.33)	
Peaked T wave		
None	1.36 ± 0.2 (1.38)	**0.016**
Present	1.27 ± 0.2 (1.27)	
Bundle branch block		
None	1.34 ± 0.2 (1.37)	0.778
Present	1.33 ± 0.21 (1.3)	
Prolonged PR interval		
None	1.34 ± 0.2 (1.35)	0.670
Present	1.37 ± 0.21 (1.39)	
Loss of P wave		
None	1.34 ± 0.2 (1.36)	0.343
Present	1.25 ± 0.18 (1.26)	
QRS prolongation		
None	1.35 ± 0.2 (1.36)	0.167
Present	1.23 ± 0.23 (1.19)	
VF/VT/Asystole		
None	1.34 ± 0.2 (1.36)	0.370
Present	1.27 ± 0.18 (1.28)	
T wave inversion		
None	1.34 ± 0.2 (1.35)	0.276
Present	1.39 ± 0.21 (1.41)	
Atrial fibrillation		
None	1.34 ± 0.21 (1.36)	0.733
Present	1.33 ± 0.17 (1.34)	

VF: Ventricular fibrillation. VT: Ventricular tachycardia

Compared to discharged and hospitalized patients, those who died had significantly lower calcium/potassium ratios ($p<0.001$). Similarly, on day 30, deceased patients had significantly lower calcium/potassium ratios compared to survivors (1.36 ± 0.19 vs. 1.23 ± 0.21, p = 0.002) (Table III).

Table III. Calcium/Potassium Ratio by Type of Renal Failure and Clinical Outcomes

Variables	Calcium/Potassium Ratio (Mean±SD. Median)	p
Type of renal failure		
Chronic	1.33 ± 0.18 (1.34)	0.171
Acute	1.34 ± 0.21 (1.38)	
Acute on chronic renal failure	1.52 ± 0.23 (1.43)	
Clinical outcome		
Treatment rejection	1.33 ± 0.18 (1.27)	**<0.001**
Discharged	1.42 ± 0.19 (1.39)[a]	
Clinical admission (hospitalized)	1.37 ± 0.19 (1.39)[a]	
ICU admission	1.28 ± 0.2 (1.31)	
Eksitus	1.18 ± 0.17 (1.16)[b]	
30 day mortality		
None	1.36 ± 0.19 (1.38)	**0.002**
Present	1.23 ± 0.21 (1.2)	

ICU: Intensive care unit

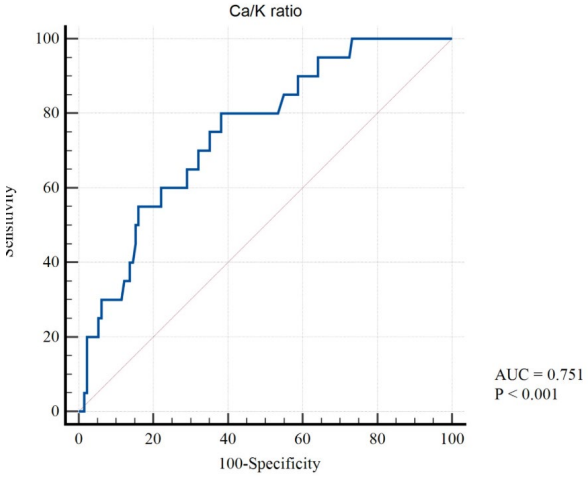
Multivariate logistic regression analysis revealed that a lower calcium/potassium ratio (OR: 0.37, 95% CI: 0.15–0.91, p=0.031) and higher serum potassium levels (OR: 2.28, 95% CI: 1.14–4.53, p=0.021) were independently associated with 30-day mortality (Table IV). Other variables (e.g., serum calcium, ICU admission, hemodialysis) did not remain statistically significant in the final model.

Table IV. Multivariate logistic regression analysis results

Variable	OR	95% CI	p
Calcium/Potassium ratio	0.37	0.15-0.91	0.031
Serum Potassium (mEq/L)	2.28	1.14-4.53	0.021
Serum Calcium (mg/dL)	0.89	0.53-1.48	0.653
Hemodialysis	1.16	0.45-2.95	0.756
ICU Admission	1.78	0.67-4.72	0.246

ICU: Intensive care unit

To evaluate the predictive value of the calcium/potassium (Ca/K) ratio for 30-day mortality, a receiver operating characteristic (ROC) curve analysis was performed. The area under the curve (AUC) was calculated as 0.751, indicating modest discriminative ability. The optimal cut-off value for the Ca/K ratio was determined to be 1.317, with a sensitivity of 80.0% and specificity of 61.83% (Figure 1).



(AUC: Area Under the Curve)

Figure 1.
ROC curve showing the predictive performance of the calcium/potassium (Ca/K) ratio for 30-day mortality in patients with renal failure and hyperkalemia. The AUC was 0.751

Discussion and Conclusion

To our knowledge, this is one of the few studies to explore the calcium/potassium ratio as a potential predictor of cardiac complications and short-term mortality in hyperkalemic renal failure patients. The observed associations may be explained by the synergistic impact of calcium and potassium on cardiac myocyte membrane stability and depolarization thresholds.

In our cohort, 52.5% of patients underwent hemodialysis, 23.2% were admitted to the ICU, and 15.8% died within 30 days. In a similar study by Davis et al[10]., involving 6,222 hyperkalemic patients, 24.3% underwent hemodialysis, 27.2% were admitted to the ICU, and the emergency department mortality rate was 15.4%. Peacock et al.[11] reported that 20.1% of 41 patients underwent hemodialysis, 79% were hospitalized, 19% required ICU care, and the 15-day mortality rate was 1.5% . These findings align in part with the literature, though differences in sample size and study settings may account for variations.

In our study, ECG abnormalities were detected in 69.5% of patients, with atrial fibrillation (22%) and peaked T waves (20%) being the most common. Potassium levels were significantly lower in patients with T wave inversions. In a study by Mulia et al[12]. involving 191 patients, ECG abnormalities were found

in 92.1%, with the most frequent being prolonged QTc interval (36.6%), fragmented QRS complex (29.8%), poor R wave progression (24.6%), peaked T waves (22.0%), and left ventricular hypertrophy (16.7%). Rafee et al. reported similar findings in their study of 67 hyperkalemic patients[13].

Studies by Thongprayoon et al. and Singer et al. also demonstrated associations between potassium levels and hospitalization or mortality[14,15]. Goyal et al. found that in patients with acute myocardial infarction, maintaining potassium levels between 3.5–4.5 mEq/L was associated with lower mortality[16].

In our study, patients with ECG abnormalities had significantly lower calcium levels compared to those without. Hou et al. showed that maintaining serum calcium levels between 8.2–10.4 mg/dL reduced the incidence of cardiac arrest in stroke patients[17]. Yarmohammadi et al. reported that low serum calcium levels were independently associated with increased risk of sudden cardiac arrest in the general population[18].

Furthermore, in our study, patients with ECG abnormalities—particularly those with peaked T waves—had significantly lower calcium/potassium ratios. Diercks and Webster also highlighted that ECG changes in hyperkalemia are strongly associated with electrolyte imbalances, and may inversely correlate with calcium levels[3,19].

Our multivariate analysis showed that both lower calcium/potassium ratio and higher serum potassium were independently associated with increased 30-day mortality, supporting their potential role as clinical markers. The ROC analysis showed that the Ca/K ratio had a modest discriminatory ability for predicting 30-day mortality (AUC = 0.751), suggesting its potential utility when combined with other clinical and laboratory parameters.

In this study, ECG abnormalities were observed in approximately 70% of patients presenting to the emergency department with renal failure and hyperkalemia. Half of these patients underwent hemodialysis, and the 30-day mortality rate was notably high (15.8%). ECG abnormalities were significantly associated with lower serum calcium levels and calcium/potassium ratios. Additionally, increased potassium levels and reduced calcium/potassium ratios were significantly linked to 30-day mortality. These findings suggest that clinicians should consider the potential for cardiac complications in patients with renal failure and hyperkalemia. Prompt recognition, comprehensive evaluation, and timely intervention may reduce morbidity and mortality. Further prospective, multicenter studies are warranted to better understand the cardiac implications of potassium and calcium imbalances in this patient population.

Limitations

The cross-sectional design of this study limits causal inferences. The absence of a normokalemic control group prevents assessment of the specificity and predictive value of ECG findings in hyperkalemia. The relatively small sample size, limited to emergency department admissions, and evaluation by a small number of ECG interpreters further restrict generalizability. Serum calcium values were not corrected for albumin levels. Given the prevalence of hypoalbuminemia in patients with renal failure, uncorrected calcium measurements may not fully reflect true ionized calcium status. This may have impacted the interpretation of the calcium/potassium ratio. Additionally, the retrospective nature of the study did not allow comparison of current ECGs with pre-illness ECGs, raising the possibility that some findings may have preceded hyperkalemia. Future prospective, multicenter studies are needed to validate these findings and assess ECG changes in hyperkalemic versus normokalemic patients while accounting for other clinical and biochemical variables.

Researcher Contribution Statement:
Idea and design: O.K, M.Y.,V.A.D, Q.M.A.; Data collection and processing: Q.M.A, E.K.,Analysis and interpretation of data: E.K, M.Y., Q.M.A.; Writing of significant parts of the article: V.A.D, O.K, G.A, M.Y., Q.M.A.
Conflict of Interest Statement:
The authors of the article have no conflict of interest declarations.
Ethics Committee Approval Information:
Approving Committee: Uludağ Üniversitesi Tıp Fakültesi Klinik Araştırmalar Etik Kurulu
Approval Date: 23.11.2022
Decision No: 2022-18/43

References

1. Clase CM, Carrero JJ, Ellison DH, et al. Potassium homeostasis and management of dyskalemia in kidney diseases: conclusions from a Kidney Disease: Improving Global Outcomes (KDIGO) Controversies Conference. Kidney Int. 2020;97(1):42-61.
2. Lindner G, Burdmann EA, Clase CM, et al. Acute hyperkalemia in the emergency department: a summary from a Kidney Disease: Improving Global Outcomes conference. Eur J Emerg Med. 2020;27(5):329-337.
3. Diercks DB, Shumaik GM, Harrigan RA, et al. Electrocardiographic manifestations: electrolyte abnormalities. J Emerg Med. 2004;27(2):153-160.
4. Wang X, Han D, Li G. Electrocardiographic manifestations in severe hypokalemia. J Int Med Res. 2020;48(1):300060518811058.
5. Merali Z, Srivaratharajah K, Panju M, et al. Hypercalcemia. In: McMaster Textbook of Internal Medicine. Kraków, Poland: Medycyna Praktyczna. Accessed August 2, 2024. https://empendium.com/mcmtextbook/chapter/B31.II.19.1.6.2. Accessed August 2, 2024

6. Slovis C, Jenkins R. ABC of clinical electrocardiography: conditions not primarily affecting the heart. BMJ. 2002;324(7349):1320-1323.
7. Panju M, Srivaratharajah K, Merali Z, et al. Hypocalcemia. In: McMaster Textbook of Internal Medicine. Kraków, Poland: Medycyna Praktyczna. Accessed August 2, 2024. https://empendium.com/mcmtextbook/chapter/B31.II.19.1.6.1. Accessed August 2, 2024
8. Noordam R, Young WJ, Salman R, et al. Effects of calcium, magnesium, and potassium concentrations on ventricular repolarization in unselected individuals. J Am Coll Cardiol. 2019;73(24):3118-3131.
9. Bukhari HA, Sánchez C, Ruiz JE, et al. Monitoring of serum potassium and calcium levels in end-stage renal disease patients by ECG depolarization morphology analysis. Sensors (Basel). 2022;22(8):2951.
10. Davis J, Israni R, Betts KA, et al. Real-world management of hyperkalemia in the emergency department: an electronic medical record analysis. Adv Ther. 2022;39(2):1033-1044.
11. Peacock WF, Rafique Z, Clark CL, et al. Real world evidence for treatment of hyperkalemia in the emergency department (REVEAL-ED): a multicenter, prospective, observational study. J Emerg Med. 2018;55(6):741-750.
12. Mulia EPB, Nugraha RA, A'yun MQ, et al. Electrocardiographic abnormalities among late-stage non-dialysis chronic kidney disease patients. J Basic Clin Physiol Pharmacol. 2020;32(3):155-162.
13. Rafee LA, Alawneh KZ, Ababneh MJ, et al. Clinical and electrocardiogram presentations of patients with high serum potassium concentrations within emergency settings: a prospective study. Int J Emerg Med. 2022;15(1):23.
14. Thongprayoon C, Cheungpasitporn W, Thirunavukkarasu S, et al. Serum potassium levels at hospital discharge and one-year mortality among hospitalized patients. Medicina (Kaunas). 2020;56(5):236.
15. Singer AJ, Thode HC Jr, Peacock WF. A retrospective study of emergency department potassium disturbances: severity, treatment, and outcomes. Clin Exp Emerg Med. 2017;4(2):73-79.
16. Goyal A, Spertus JA, Gosch K, et al. Serum potassium levels and mortality in acute myocardial infarction. JAMA. 2012;307(2):157-164.
17. Hou J, Huang Z, Zeng W, et al. Serum calcium is associated with sudden cardiac arrest in stroke patients from ICU: a multicenter retrospective study based on the eICU collaborative research database. Sci Rep. 2024;14(1):1700.
18. Yarmohammadi H, Uy-Evanado A, Reinier K, et al. Serum calcium and risk of sudden cardiac arrest in the general population. Mayo Clin Proc. 2017;92(10):1479-1485.
19. Webster A, Brady W, Morris F. Recognising signs of danger: ECG changes resulting from an abnormal serum potassium concentration. Emerg Med J. 2002;19(1):74-77.