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Nephrology-Focused ECG Interpretation: A Prospective Study in Internal Medicine Residency

Nefroloji Odaklı EKG Yorumlama: İç Hastalıkları Asistanlığında Prospektif Bir Çalışma

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Abstract

Aim: Electrocardiography (ECG) interpretation plays a crucial role in the management of nephrology patients, who are particularly vulnerable to electrolyte imbalances and arrhythmias. Despite its clinical significance, ECG interpretation accuracy remains suboptimal among non-cardiology physicians. This study aimed to evaluate the impact of a structured ECG training program on internal medicine residents' interpretation skills, with a focus on ECG patterns commonly observed in nephrology.

Method: A prospective study involving 110 internal medicine residents. Baseline ECG interpretation skills were evaluated using a 24-question multiple-choice test covering nephrology-relevant ECG abnormalities, including hyperkalemia and arrhythmias. A structured four-week ECG training program, led by cardiology faculty, was implemented. Residents attended weekly sessions reviewing 25 ECGs each, analyzing a total of 100 ECGs during the program. Post-training assessment was conducted using the same test under identical conditions.

Results: The mean baseline ECG interpretation score was 76.9/100 (range: 40–100), which significantly improved to 86/100 (range: 60–100) following the training program ($p < 0.0001$). Residents who had completed a cardiology rotation performed significantly better at both baseline and post-training

assessments ($p < 0.05$). A positive correlation was observed between residency duration and ECG interpretation performance ($p < 0.05$).

Conclusion: A structured ECG training program markedly improved interpretation accuracy among internal medicine residents, especially for nephrology-relevant patterns. Residents with prior cardiology rotations performed better, emphasizing the value of targeted specialty training. Emergency medicine experience showed no effect, underscoring the need for structured education. Standardized ECG training may enhance resident competency and potentially contribute to improved clinical decision-making in nephrology practice.

Özet

Amaç: Elektrokardiyografi (EKG) yorumlama, elektrolit dengesizlikleri ve aritmilere yatkınlık nedeniyle nefroloji hastalarının yönetiminde kritik bir öneme sahiptir. Ancak klinik önemine rağmen, kardiyoloji dışı hekimlerde EKG yorumlama doğruluğunun yetersiz olduğu bilinmektedir. Bu çalışmanın amacı, yapılandırılmış bir EKG eğitim programının iç hastalıkları asistanlarının EKG yorumlama becerileri üzerindeki etkisini, nefrolojide sık karşılaşılan EKG paternlerine odaklanarak değerlendirmektir.

Yöntem: Bu prospektif çalışmaya 110 iç hastalıkları asistanı dahil edildi. Başlangıç EKG yorumlama becerileri, hiperkalemi ve aritmiler dahil olmak üzere nefroloji ile ilişkili EKG anormalliklerini kapsayan 24 soruluk çoktan seçmeli bir test ile değerlendirildi. Kardiyoloji öğretim üyeleri tarafından yürütülen yapılandırılmış dört haftalık bir EKG eğitim programı uygulandı. Asistanlar haftada bir oturum olmak üzere her oturumda 25 EKG değerlendirdi ve program süresince toplam 100 EKG analiz edildi. Eğitim sonrası değerlendirme, aynı test kullanılarak ve aynı koşullar altında gerçekleştirildi.

Bulgular: Başlangıçta ortalama EKG yorumlama puanı 76,9/100 (aralık: 40–100) iken, eğitim programı sonrasında bu değer anlamlı olarak 86/100'e (aralık: 60–100) yükseldi ($p < 0.0001$). Kardiyoloji rotasyonunu tamamlamış olan asistanlar hem başlangıç hem de eğitim sonrası değerlendirmelerde anlamlı derecede daha yüksek performans gösterdi ($p < 0.05$). Asistanlık süresi ile EKG yorumlama performansı arasında pozitif bir korelasyon saptandı ($p < 0.05$).

Sonuç: Yapılandırılmış bir EKG eğitim programı, iç hastalıkları asistanlarında özellikle nefroloji ile ilişkili EKG paternlerinin yorumlanmasında doğruluğu belirgin şekilde artırmıştır. Önceden kardiyoloji rotasyonu yapmış olan asistanların daha yüksek performans göstermesi, hedeflenmiş uzmanlık eğitiminin önemini vurgulamaktadır. Acil tıp deneyiminin anlamlı bir katkı sağlamamış olması, yapılandırılmış eğitimin gerekliliğini ortaya koymaktadır. Standartlaştırılmış EKG eğitimi, asistanların yetkinliğini artırabilir ve nefroloji pratiğinde klinik karar verme süreçlerinin iyileştirilmesine katkı sağlayabilir.

1. Introduction

Electrocardiography (ECG) is a cornerstone diagnostic tool in clinical practice, valued for its simplicity, non-invasiveness, and cost-effectiveness (1). It is the most commonly used test in the diagnosis of cardiac diseases and requires integrating cardiac pathophysiology, anatomy, and electrophysiology to identify diagnostic patterns (2). Despite its widespread use and numerous studies on ECG interpretation training (3), limited evidence exists on the most effective methods to enhance these skills through education, particularly for nephrology-relevant ECGs (4).

In nephrology, ECG findings are critical for diagnosing and managing electrolyte imbalances, arrhythmias, and acute coronary syndromes—conditions frequently encountered in patients with chronic kidney disease or those undergoing dialysis. Internal medicine residents, often serving as first-line clinicians, must promptly recognize abnormalities such as hyperkalemia-induced sine waves or hypokalemia-related QT prolongation and initiate appropriate management. However, critical errors in ECG interpretation remain prevalent, with up to one-third of all interpretations containing significant inaccuracies (5).

While internal medicine residents are not expected to attain cardiology-level expertise in ECG interpretation, they must be proficient in identifying life-threatening arrhythmias, electrolyte disturbances, and acute coronary syndromes. Recognizing this, the Accreditation Council for Graduate Medical Education emphasizes the

need for structured ECG training programs (6). Studies highlight that targeted training significantly improves ECG interpretation accuracy, particularly for non-cardiology physicians managing high-risk populations (7), (8).

This study evaluates the baseline ECG interpretation skills of internal medicine residents, focusing on nephrology-relevant ECG patterns, and examines their improvement following a structured training program led by cardiology faculty. However, most previous studies on ECG education have focused on medical students or general ECG interpretation rather than specialty-specific clinical contexts (9). Evidence regarding structured ECG training programs addressing ECG abnormalities commonly encountered in nephrology practice among internal medicine residents remains limited. By addressing this educational gap, the findings aim to enhance ECG interpretation proficiency and improve the management of nephrology patients through targeted educational interventions. This educational intervention was conceptually informed by principles of case-based learning and deliberate practice, which emphasize repeated exposure to clinically relevant cases and structured feedback to enhance diagnostic reasoning and pattern recognition skills. These approaches are widely recognized as effective strategies for improving complex clinical interpretation abilities such as ECG analysis (10).

2. Material and Method

Participants

A total of 110 internal medicine residents actively participating in the residency program were enrolled in the study. Demographic and professional data, including gender, postgraduate year, prior emergency medicine experience, cardiology rotation status, and interest in cardiology, were collected.

ECG Selection Process

Clinically relevant ECGs were selected using a structured Delphi method to ensure educational value and practical relevance. The panel comprised two cardiologists and one nephrologist. The cardiologists provided expertise in ECG interpretation, while the nephrologist ensured inclusion of patterns particularly relevant to nephrology practice.

The Delphi process consisted of two rounds. In the first round, panel members independently proposed ECG patterns considered clinically significant for internal medicine residents. In the second round, the proposed ECGs were redistributed and reassessed. Consensus was defined a priori as ≥80% agreement among panel members. When disagreement persisted, structured discussion was conducted until consensus was achieved. Each selected ECG was reviewed independently by two cardiologists (B.S. and O.S.). In cases of disagreement, the opinion of a third cardiologist was sought.

A total of 24 ECGs were ultimately selected. This number was chosen to ensure balanced representation of critical diagnostic patterns while maintaining feasibility for assessment within a 30-minute timeframe. The list of ECGs is provided in Supplementary Table 1.

Inclusion Criteria:

Common ECG findings: Normal sinus rhythm, sinus tachycardia, sinus bradycardia.

Electrolyte imbalances: Hyperkalemia (e.g., peaked T waves, sine wave morphology), hypokalemia (e.g., U waves, QT prolongation).

Acute coronary syndromes: STEMI (e.g., ST elevations), NSTEMI (e.g., ST depressions, T wave inversions).

Arrhythmias: Atrial fibrillation, ventricular tachycardia, supraventricular tachycardia, third-degree atrioventricular (AV) block, pacemaker rhythm.

Table 1. Characteristics of Participants in the Study

Characteristic (N = 110)	Number (%)
Postgraduate Year	
1	48 (43)
2	23 (21)
3	24 (22)
4	15 (14)
Gender	
Female	59 (53)
Male	51 (47)
Work Experience as a General Practitioner	
Yes	80 (73)
No	30 (27)
Cardiology Rotation Status	
Yes	40 (36)
No	70 (64)
Baseline ECG Score	
40-50	5 (4.6)
51-60	7 (6.3)
61-70	18 (16.4)
71-80	25 (22.7)
81-90	47 (42.7)
91-100	8 (7.3)

ECG: Electrocardiogram

Exclusion Criteria:
Rare and complex ECG patterns (e.g., Brugada syndrome, epsilon wave)

Training and Assessment Process
Baseline Assessment
Residents reviewed 24 ECGs and provided the correct diagnosis for each pattern. The exam format was multiple-choice, with one correct answer per ECG. Scores were calculated out of 100 based on the number of correct responses. The assessment was completed in 30 minutes without access to external resources.

Training Program
The educational sessions were conducted in a structured format by a cardiology faculty member and primarily followed a case-based learning approach. Educational materials consisted primarily of real clinical ECG recordings selected for their diagnostic relevance, which were presented together with brief clinical scenarios to facilitate contextual interpretation and clinical reasoning. During each session, residents reviewed 25 ECGs within clinically relevant scenarios and discussed the diagnostic reasoning underlying each pattern. Structured feedback was provided by the cardiology faculty member during the discussion of each ECG case, highlighting key diagnostic features and common interpretation errors. Over the four-week training period, residents analyzed a total of 100 ECGs under faculty supervision. Additional hands-on learning opportunities were provided during inpatient, outpatient, and elective rotations.
To ensure standardization of the training program, all sessions were conducted by the same cardiology faculty member using a predefined instructional structure, and each session included the same

number of ECG cases.

Post-Training Reassessment

Following the training program, residents were reassessed using the same 24 ECGs under identical conditions (multiple-choice format, 30-minute limit, no external resources). Pre- and post-training scores were compared to evaluate improvement.

Statistical Analysis

Data analysis was conducted using SPSS version 22 (SPSS, Inc., Chicago, Illinois). Descriptive statistics were calculated for all variables. Continuous variables were presented as mean ± standard deviation (SD) if normally distributed, and as median with interquartile range (IQR) if not. Categorical variables were expressed as frequencies and percentages.

Paired sample t-tests were performed to compare pre- and post-training scores. Pearson correlation analysis was used to evaluate the strength and direction of relationships between continuous variables. Statistical significance was set at a two-tailed p-value < 0.05.

3. Results

A total of 110 internal medicine residents from Gazi University Faculty of Medicine Hospital participated in the study. Among them, 48 (43%) were postgraduate year 1 residents, 23 (21%) were postgraduate year 2, 24 (22%) were postgraduate year 3, and 15 (14%) were postgraduate year 4. The cohort included 59 females (53%) and 51 males (47%).

The mean age of participants was 27 years (range: 25–31 years), with an average residency duration of 19.7 months (range: 2–47 months). Demographic characteristics of the participants are summarized in Table 1.

The mean baseline ECG interpretation score was 76.9/100 (range: 40–100). After the structured training program, the mean post-training ECG interpretation score increased to 86/100 (range: 60–100) ($p<0.0001$). Residents who had completed a cardiology rotation demonstrated significantly higher scores at both baseline and post-training assessments compared to those who had not ($p < 0.05$).

No significant differences were observed in post-training scores between male and female residents ($p = 0.53$) or between residents with and without prior emergency department experience ($p = 0.89$). Group comparisons are detailed in Table 2.

A positive correlation was observed between the postgraduate residency month and ECG interpretation scores for both baseline ($r = 0.398$, $p < 0.0005$) and post-training assessments ($r = 0.212$, $p = 0.027$). These findings underscore the influence of residency progression and cardiology rotation exposure on ECG interpretation proficiency.

Table 2. Analysis of Differences Between Groups After ECG Training

Group	Baseline ECG Score	Post-Training ECG Score	P value
Gender			
Female	75.5	84.5	0.53
Male	78.6	87.8	
Work Experience as a General Practitioner			
Yes	78	85.9	0.89
No	74.1	86.2	
Cardiology Rotation Status			
Yes	85.1	88.9	**<0.05**
No	72.3	84.4	

ECG: Electrocardiogram

Supplementary Table 1. Electrocardiogram Diagnoses

Number	Diagnosis
1	Sinus bradycardia
2	Atrial fibrillation
3	Supraventricular tachycardia
4	Ventricular tachycardia
5	Inferior Myocardial Infarction (MI) and Atrioventricular (AV) Block
6	Complete Atrioventricular (AV) Block
7	Left Ventricular Hypertrophy (LVH)
8	Hypokalemia
9	Pacemaker Electrocardiogram (Paced ECG)
10	Non-ST-Elevation Myocardial Infarction (NSTEMI)
11	Hyperkalemia
12	Normal Sinus Rhythm (NSR)
13	Anterior Myocardial Infarction (Anterior MI)
14	Sinus Tachycardia
15	Torsades de Pointes
16	Inferoposterior Myocardial Infarction (Inferoposterior MI)
17	Digoxin Toxicity
18	Left Bundle Branch Block (LBBB)
19	Atrial Flutter
20	Anterolateral Myocardial Infarction (Anterolateral MI)
21	Pulmonary Thromboembolism (PTE)
22	Atrioventricular Nodal Reentrant Tachycardia (AVNRT)
23	Hyperkalemia sine-wave pattern
24	Ventricular Fibrillation (VF)

4. Discussion

The pre-training ECG assessment accuracy rate of 76.9% aligns with previous studies, which report rates ranging from 36% to 80% (11), (12), (13), (14). This consistency highlights the variable baseline ECG interpretation skills among internal medicine residents, underscoring the importance of structured educational programs to address gaps and standardize competency levels.

A positive correlation between postgraduate training month and ECG interpretation performance was observed, consistent with prior findings by Gillespie et al. (15). This result reflects the incremental benefits of cumulative clinical exposure over time. Importantly, residents with prior cardiology rotations performed significantly better in both baseline and post-training assessments, supporting existing evidence that structured, specialty-specific education improves diagnostic accuracy (16). These findings emphasize the importance of cardiology rotations as a critical component of residency training and suggest that earlier and more frequent rotations could amplify learning outcomes. Similarly, previous studies have shown that physicians with greater clinical exposure and advanced training demonstrate superior ECG interpretation skills compared with less experienced clinicians. These observations support the integration of cardiology-focused training within internal medicine residency curricula to strengthen diagnostic competency in ECG interpretation (17).

The mean ECG interpretation score increased from 76.9 to 86 after the four-week training program. The structured training program employed in this study demonstrated significant improvements in residents' ECG interpretation scores, reinforcing the value of targeted educational interventions. By integrating faculty-led sessions, hands-on training, and focused discussions on clinically relevant ECG patterns, the program addressed key learning gaps. These results support the implementation of formalized ECG training as a standard part of internal medicine residency programs, particularly for addressing nephrology-specific challenges. These findings suggest that ECG education in internal medicine residency programs may benefit from structured, case-based training sessions combined with faculty-guided feedback and exposure to clinically relevant ECG patterns. In a 2011 U.S.-based prospective study, 223 medical students were evaluated. The findings indicated that an 8-week ECG course was more effective than self-directed learning in improving ECG interpretation skills (18). A randomized controlled trial conducted by Kashou et al. (2024) provided compelling evidence that lecture-based learning significantly enhances the effectiveness of ECG education and improves training outcomes (19). In another study, an ECG training program was conducted for internal medicine residents at the University at Buffalo. A significant improvement in ECG interpretation skills was observed following the training (6). Although interpretation scores significantly improved, these findings should be interpreted as evidence of educational effectiveness rather than direct proof of clinical outcome improvement.

Interestingly, no significant differences were observed between residents with and without prior emergency department experience. This suggests that sporadic ECG exposure in general clinical settings is insufficient to build robust interpretation skills. Instead, formalized, supervised training programs appear more effective at equipping residents with the necessary expertise. A study conducted in Australia found that senior doctors demonstrated superior performance in ECG interpretation compared to junior doctors (20).

However, this study has several limitations. Its single-center design may limit generalizability, as training practices and available resources may vary across institutions. Additionally, the focus on internal medicine residents does not account for the needs of other specialties. One important methodological limitation is the use of the same 24 ECG questions for both pre- and post-training assessments. Although identical testing conditions were maintained to ensure comparability, this approach may have introduced a potential test–retest (recall) bias, as participants might have benefited from prior exposure to the same ECGs. Parallel test forms were not used in order to maintain identical difficulty levels and diagnostic representation between assessments; however, future studies should consider validated parallel forms to minimize recall effects. Furthermore, this study did not aim to evaluate whether improved ECG interpretation directly translates into better clinical outcomes, which should be explored in

future research. Long-term retention of acquired skills was also not assessed, leaving uncertainty regarding the durability of the training effect.

5. Conclusion

This study's primary strength lies in its focus on improving ECG interpretation skills among internal medicine residents, particularly in the context of nephrology and hemodialysis patients. While previous studies in Turkey have largely focused on emergency medicine physicians and general practitioners, this study uniquely evaluates the impact of structured ECG training within the internal medicine residency framework.

To build upon these findings, future multicenter studies are needed to validate the results in more diverse settings and across different specialties. Such studies could explore the broader impact of structured ECG training programs, including variations in training formats and their potential to improve diagnostic accuracy and patient management. Additionally, integrating nephrology-specific ECG education earlier in residency could be assessed to determine its long-term educational benefits and its role in enhancing clinical outcomes for high-risk patient populations.

Ethical Approval and Study Period

The study was conducted from January 2025 to March 2025 in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Gazi University Rectorate (Approval Date: 31.12.2024; Research Code: 2024-1995).

References

1. Kligfield P, Gettes LS, Bailey JJ, Childers R, Deal BJ, Hancock EW, et al. Recommendations for the Standardization and Interpretation of the Electrocardiogram. Circulation. 2007;115(10):1306-24.
2. Wood G, Batt J, Appelboam A, Harris A, Wilson MR. Exploring the Impact of Expertise, Clinical History, and Visual Search on Electrocardiogram Interpretation. Medical Decision Making. 2014;34(1):75-83.
3. Training and Competency Evaluation for Interpretation of 12-Lead Electrocardiograms: Recommendations from the American College of Physicians*. Annals of Internal Medicine. 2003;138(9):747-50.
4. Rourke L, Jessica L, and Chatterly P. Conditions-Based Learning Theory as a Framework for Comparative-Effectiveness Reviews: A Worked Example. Teaching and Learning in Medicine. 2018;30(4):386-94.
5. Competency in Interpretation of 12-Lead Electrocardiograms: A Summary and Appraisal of Published Evidence. Annals of Internal Medicine. 2003;138(9):751-60.
6. Kaye MG, Khan HA, Gudleski GD, Yatsynovich Y, Graham SP, Kwiatkowski AV. Implementation of a longitudinal, near-peer ECG didactic curriculum in an internal medicine residency program and impact on ECG interpretation skills. BMC Med Educ. 2023;23(1):526.
7. Viljoen CA, Millar RS, Manning K, Hoevelmann J, Burch VC. Clinically contextualised ECG interpretation: the impact of prior clinical exposure and case vignettes on ECG diagnostic accuracy. BMC Med Educ. 2021;21(1):417.
8. Chaumont C, Morgat C, Ollitrault P, Brejoux C, Extramiana F, Milliez P, et al. How to improve medical students' ECG interpretation skills ? Multicenter survey and results of a comparative study evaluating a new educational approach. BMC Med Educ. 2024;24(1):979.
9. Thach TH, Blissett S, Sibbald M. Worked examples for teaching electrocardiogram interpretation: Salient or discriminatory features? Med Educ. 2020;54(8):720-6.
10. Makwana S, Sarvaiya H, Dalsaniya V. A Comparative Study of Case-Based Learning (CBL) Versus the Traditional Teaching Method for Enhanced Analysis and Interpretation of Electrocardiogram (ECG) Among Medical Students. Cureus. 2025;17(2):e79587.

11. Hatala R, Norman GR, Brooks LR. Impact of a clinical scenario on accuracy of electrocardiogram interpretation. Journal of General Internal Medicine. 1999;14(2):126-9.

12. White T, Woodmansey P, Ferguson DG, Channer KS. Improving the interpretation of electrocardiographs in an accident and emergency department. Postgraduate Medical Journal. 1995;71(833):132-5.

13. Pinkerton RE, Francis CK, Ljungquist KA, Howe GW. Electrocardiographic Training in Primary Care Residency Programs. JAMA. 1981;246(2):148-50.

14. Montgomery H, Hunter S, Morris S, Naunton-Morgan R, Marshall RM. Interpretation of electrocardiograms by doctors. BMJ. 1994;309(6968):1551-2.

15. Gillespie ND, Brett CT, Morrison WG, Pringle SD. Interpretation of the emergency electrocardiogram by junior hospital doctors. Journal of Accident & Emergency Medicine. 1996;13(6):395-7.

16. Cunningham JM, Johnson M, Kincaid T, Christensen W, Baker J, Turbyfill W, et al. The spacing effect: Improving electrocardiogram interpretation. The Clinical Teacher. 2024;21(1):e13626.

17. AlShakhs AA, AlAmeer AA, AlEsmaeel ZC, AlMotawa O, AlHaddad SM, AlHaddad HM, et al. Electrocardiogram Interpretation Competency of Primary Health Care Physicians: A Cross-Sectional Study. Healthcare (Basel). 2025;13(23).

18. Mahler SA, Wolcott CJ, Swoboda TK, Wang H, Arnold TC. Techniques for teaching electrocardiogram interpretation: self-directed learning is less effective than a workshop or lecture. Med Educ. 2011;45(4):347-53.

19. Kashou AH, Noseworthy PA, Beckman TJ, Anavekar NS, Cullen MW, Angstman KB, et al. EDUCATE: An international, randomized controlled trial for teaching electrocardiography. Curr Probl Cardiol. 2024;49(3):102409.

20. Cruz MF, Edwards J, Dinh MM, Barnes EH. The effect of clinical history on accuracy of electrocardiograph interpretation among doctors working in emergency departments. Medical Journal of Australia. 2012;197(3):161-5.