

Impact of Electrocardiography Device Integration into a Hospital Information System on Paper Use, Cost, and Data Accessibility

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Abstract

Objective: This study aimed to evaluate the impact of integrating electrocardiography (ECG) devices into a hospital information system (HIS) on paper use, cost outcomes, and data accessibility in outpatient clinical settings.

Methods: This retrospective observational study was conducted using outpatient data collected between 2017 and 2025. The pre-integration period (2017) was compared with the post-integration period (2018–2025). Outpatient visit volumes, total ECG examinations, repeat ECG rates, paper consumption, and associated costs were analyzed. ECG devices were integrated into the HIS via an HL7-based interface, enabling data transfer to the Picture Archiving and Communication System (PACS) and national health platforms. Data were analyzed using descriptive statistical methods and presented as counts and percentages. **Results:** In 2017, a total of 661,329 outpatient visits and 43,548 ECG examinations were recorded, with a repeat ECG rate of 20%. Following integration, ECG data became digitally accessible through the HIS and PACS. Paper-based processes were completely eliminated, resulting in the avoidance of paper-related costs in subsequent years. During the early post-integration period (2018–2021), repeat ECG rates ranged between 19% and 21%, whereas in the later period (2022–2025), they declined to a range of 9.9–11.2%.

Conclusion: Integration of ECG devices into the HIS eliminates paper-based processes, reduces operational costs, and enhances data accessibility for both healthcare professionals and patients. However, digital integration alone may not be sufficient to reduce repeat testing. These findings highlight the importance of integrated digital systems in improving efficiency and accessibility in healthcare delivery.

Keywords: Data accessibility; electrocardiography; health care costs; health informatics; hospital information systems; workflow efficiency.

Elektrokardiyografi Cihazlarının Hastane Bilgi Sistemine Entegrasyonunun Kağıt Kullanımı, Maliyet Ve Veri Erişilebilirliği Üzerindeki Etkisi

Özet

Amaç: Bu çalışmanın amacı, elektrokardiyografi (EKG) cihazlarının hastane bilgi sistemine (HBYS) entegrasyonunun poliklinik uygulamalarında kağıt kullanımı, maliyet çıktıları ve veri erişilebilirliği üzerindeki etkisini değerlendirmektir.

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Yöntem: Bu retrospektif gözlemsel çalışma, 2017–2025 yılları arasında poliklinik verileri kullanılarak gerçekleştirilmiştir. Entegrasyon öncesi dönem (2017) ile entegrasyon sonrası dönem (2018–2025) karşılaştırılmıştır. Çalışmada poliklinik başvuru sayıları, toplam EKG çekim sayıları, tekrar EKG oranları, kağıt kullanımı ve ilişkili maliyetler değerlendirilmiştir. EKG cihazları, HL7 tabanlı bir arayüz kullanılarak HBYS'ye entegre edilmiş ve verilerin Görüntü Saklama ve İletişim Sistemi (PACS) ile ulusal sağlık platformlarına aktarımı sağlanmıştır. Veriler tanımlayıcı istatistiksel yöntemler ile analiz edilmiş ve sayı ile yüzde olarak ifade edilmiştir.

Bulgular: 2017 yılında 661.329 poliklinik başvurusu ve 43.548 EKG çekimi gerçekleştirilmiş olup, tekrar EKG oranı %20 olarak belirlenmiştir. Entegrasyon sonrasında EKG verileri HBYS ve PACS üzerinden dijital olarak erişilebilir hale gelmiştir. Kağıt tabanlı süreçler ortadan kaldırılmış ve sonraki yıllarda kağıt kullanımına bağlı maliyetler önlenmiştir. Entegrasyonun erken döneminde (2018–2021) tekrar EKG oranları %19–21 aralığında seyrederken, sonraki dönemde (2022–2025) bu oran %9,9–11,2 aralığında gerçekleşmiştir.

Sonuç: EKG–HBYS entegrasyonu, kağıt tabanlı süreçleri ortadan kaldırarak operasyonel maliyetleri azaltmakta ve hem sağlık profesyonelleri hem de hastalar için veri erişilebilirliğini artırmaktadır. Bununla birlikte, dijital entegrasyon tek başına tekrar testleri azaltmak için yeterli olmayabilir. Bu bulgular, sağlık hizmetlerinde verimliliğin ve erişilebilirliğin artırılmasında entegre dijital sistemlerin önemini ortaya koymaktadır.

Anahtar sözcükler: Veri erişilebilirliği; elektrokardiyografi; sağlık hizmeti maliyetleri; sağlık bilimi; hastane bilgi sistemleri; iş akışı verimliliği.

Introduction

Electrocardiography (ECG) is one of the most fundamental and widely used diagnostic tools in the diagnosis and monitoring of cardiovascular diseases. Due to its high-volume utilization, particularly in outpatient settings, the organization of ECG workflows and the management of related data are of critical importance for healthcare systems. However, in conventional practice, the production and storage of ECG data in paper-based formats lead to several challenges, including the risk of data loss, limited accessibility, and inefficiencies in clinical workflows.^[1–3]

In paper-based ECG processes, reliance on patients to physically carry previous records complicates clinical decision-making and results in time loss. Furthermore, this approach restricts healthcare professionals' ability to rapidly access historical data, thereby weakening data continuity. In addition to operational inefficiencies, paper-based systems also result in recurring consumable costs.^[4,5]

In recent years, the integration of ECG devices into hospital information systems (HIS) has been proposed as a solution to mitigate these challenges. Through integrated systems, ECG data can be stored digitally, accessed simultaneously across different departments, and protected against data loss. This transformation not only accelerates clinical workflows but also enables healthcare professionals to access patient data in a faster and more comprehensive manner.^[2,3,6]

The integration of ECG devices into HIS contributes to improvements in clinical workflows by automating data collection, storage, and analysis processes. This integration reduces the need for manual data entry, standardizes clinical processes, and alleviates the workload of healthcare professionals.^[1–3] In addition, the availability of ECG data in structured and raw formats within electronic health records supports faster diagnosis and more effective clinical decision-making.^[2,4]

Moreover, interoperability standards such as HL7 and DICOM-web enable standardized and seamless data exchange between ECG devices and HISs, thereby improving interdepartmental data sharing and documentation quality.^[3,5,6] Evidence from clinical practice suggests that such integrations enhance data quality, accessibility, and management efficiency, ultimately contributing positively to patient care processes.^[1,2]

In the Turkish context, integration with the national digital health platform e-Nabız allows patients to directly access their own health data. This system enables individuals to securely manage their health information, access their records, and actively participate in their healthcare processes.^[6,7] As a result, patient engagement is increased, access to healthcare services is improved, and overall patient experience is enhanced.

Although direct evidence on cost impact remains limited, it is suggested that reductions in manual processes and improvements in workflow efficiency may lead to decreased operational costs.^[5,7] However, technical differences between devices and interoperability challenges across systems continue to pose barriers to full integration.^[1]

The economic implications of digital transformation in healthcare have also gained increasing attention. The transition from paper-based systems to digital platforms contributes to reduced operational costs and improved budget efficiency by enhancing workflows and minimizing errors.^[8] In particular, reductions in documentation time – especially among nursing staff – allow more time to be allocated to patient care, resulting in significant savings in both labor and consumable costs.^[9]

In high-volume diagnostic procedures such as ECG, digitalization has been shown to shorten reporting times, improve data accessibility, and optimize workflows, thereby increasing operational efficiency.^[10] Given the high frequency of such procedures, these improvements can translate into substantial time and cost savings at the system level.^[11]

Although evaluating the cost-effectiveness of digitalization may be challenging due to variations in implementation, digital platforms are recognized for enhancing collaboration among stakeholders and supporting value creation.^[12,13] This is particularly relevant when integrated with performance-based healthcare systems, contributing to the financial sustainability of healthcare services.

Overall, digital transformation supports both direct cost savings and long-term financial sustainability of healthcare systems by improving productivity, reducing error rates, and optimizing resource utilization.^[8,9,14]

The literature indicates that the integration of ECG data into digital health systems has significant implications for data accessibility, patient engagement, and clinical decision-making. In par-

ticular, integration with electronic health records facilitates rapid and simultaneous access to patient data, thereby improving clinical workflows and accelerating diagnostic processes.^[15–17] Furthermore, patient access to their own health data through digital platforms promotes engagement and supports self-management.^[15,16] In addition, the use of ECG data in conjunction with clinical decision support systems contributes to faster and more data-driven decision-making processes.

From the physician's perspective, digital systems optimize clinical workflows by reducing administrative workload and enabling more structured and effective patient communication.^[18,19] While digital health technologies make the patient–physician relationship more interactive, they also highlight the need for a balanced use of technology in clinical settings.^[20,21] Furthermore, advanced analytical approaches and digital health solutions contribute to personalized treatment planning, thereby enhancing patient safety and clinical decision-making.^[22]

Despite the existence of studies addressing the technical and operational aspects of ECG device integration, there is a limited number of real-world studies that simultaneously evaluate the direct cost savings associated with the elimination of paper use and the impact of this transformation on clinical workflows and data accessibility. In particular, the scarcity of studies comparing pre- and post-integration periods highlights an important gap in the literature.^[3,5,7]

Therefore, the aim of this study is to evaluate changes in paper consumption, associated cost implications, and improvements in data accessibility following the integration of ECG devices into a HIS, based on real-world data. The study seeks to provide a system-level perspective on the impact of digital transformation on operational efficiency and healthcare accessibility.

Materials and Methods

Study Design and Settings

This study was designed as a single-center, retrospective, observational system-level evaluation. The pre- and post-integration periods of ECG devices into the HIS were compared.

The study was conducted in a public hospital located in Istanbul, Türkiye, which has been in operation since 2014, provides secondary-level healthcare services, and has a capacity of 314 beds. The hospital covers approximately 66,000 m² of indoor space and includes outpatient clinics, inpatient wards, operating rooms, adult intensive care units, and palliative care services.

Only outpatient visits were included in the study, while emergency department visits were excluded from the analysis. The analyses covered ECG procedures performed using two ECG devices actively used in the institution.

The study period spanned from 2017 to 2025, with 2017 considered the baseline year representing the pre-integration period.

The study was approved by the Alanya University Ethics Committee (no: 02, date: February 04, 2025). This study was conducted in accordance with the Declaration of Helsinki. All procedures complied with the Declaration of Helsinki.

Data Source and Variables

The data used in this study were real-world data obtained from the hospital's HIS records and were analyzed at an aggregated level.

The dataset analyzed in this study:

- Has a longitudinal structure
- Includes all ECG procedures at the outpatient level
- Was constructed based on annual total outpatient visits and the number of patients undergoing ECG examinations.

The following variables were included in the analysis:

- Number of outpatient visits
- Total number of ECG examinations
- ECG utilization rate (%)
- Number and rate of repeat ECG examinations (%)
- Paper consumption
- Paper-related costs.

The ECG utilization rate was calculated as the ratio of the total number of ECG examinations to the total number of outpatient visits. Repeat ECG was defined as more than one ECG performed on the same patient within the same calendar year.

Integration Process

The integration of ECG devices into the HIS was implemented following the completion of integration planning. Within this scope, an HL7-based integration license was obtained for the ECG devices, and the system integration became operational in 2018.

Following integration, patient data generated during ECG procedures were automatically transferred to the digital environment. ECG records were integrated into the HIS via the Picture Archiving and Communication System (PACS) and made accessible through the system.

In addition, ECG data were aligned with the national health information system and transferred to digital platforms (e-Nabız) that allow patients to access their own health records.

Cost Calculation Approach

Institutional data were used to calculate ECG paper-related costs.

- For 2017, paper costs associated with ECG procedures were directly obtained from institutional accounting records.
- For the years 2018–2021, despite the elimination of paper use, paper costs were retrospectively estimated based on the actual number of ECG examinations performed in those years.

The following formula was used for cost calculation:

Total ECG paper cost = Annual number of ECG examinations × Unit cost of ECG paper

The “roll equivalent” approach was used to estimate paper consumption. The amount of thermal paper used per ECG examination was based on the technical specifications of the

Table 1. Annual distribution of outpatient visits, ECG utilization, and repeat ECG rates (2017–2025)

Year	Outpatient visits	Total ECGs	ECG rate (%)	Repeat ECGs	Repeat ECG rate (%)
2017	661,329	43,548	6.58	8,566	20.0
2018	718,378	42,515	5.91	7,987	19.0
2019	772,356	48,775	6.31	10,208	21.0
2020	450,869	30,461	6.75	5,705	19.0
2021	456,400	32,775	7.18	6,227	19.0
2022	780,000	20,954	2.69	2,357	11.2
2023	810,000	25,904	3.19	2,573	9.9
2024	845,000	27,623	3.27	2,797	10.1
2025	880,000	33,755	3.83	3,749	11.1

ECG: Electrocardiography.

standard ECG devices used in the study institution. Each ECG output corresponds to an approximately fixed length of thermal paper.

Based on institutional usage data and device outputs, it was assumed that approximately 100 ECG examinations correspond to one standard ECG paper roll. Costs were calculated in nominal Turkish Lira (₺), and no inflation adjustment was applied.

Although this approach allows for minor variability depending on patient and procedural factors, it was used as a practical method representing average consumption for high-volume procedures. However, this assumption may vary depending on device types and usage conditions and is therefore considered among the limitations of the study.

Statistical Analysis

Descriptive statistical methods were used in this study. Continuous variables were expressed as absolute values (n), percentages (%), and annual percentage changes.

The ECG utilization rate was calculated as follows:

$$\text{ECG utilization rate (\%)} = \left(\frac{\text{Total number of ECG examinations}}{\text{Total number of outpatient visits}} \right) \times 100$$

The repeat ECG rate was calculated as follows:

$$\text{Repeat ECG rate (\%)} = \left(\frac{\text{Number of repeat ECG examinations}}{\text{Total number of ECG examinations}} \right) \times 100$$

To evaluate year-to-year changes:

- Annual percentage change rates (%)
- Absolute differences (Δ) were calculated.

The following indicators were analyzed comparatively on a yearly basis:

- Number of outpatient visits
- Number of ECG examinations
- ECG utilization rate (%)
- Repeat ECG rate (%)
- Paper-related costs.

All analyses were conducted using aggregated data. Since patient-level data were not available, no inferential statistical tests were performed, and the analysis was limited to a descriptive level.

Results

Outpatient Visits and ECG Utilization

Between 2017 and 2025, outpatient visits, ECG utilization, and repeat ECG rates were analyzed and compared on a yearly basis.

In 2017, a total of 661,329 outpatient visits were recorded, and 43,548 patients (6.58%) underwent ECG examinations. In the same year, 8,566 patients (20%) had repeat ECG examinations. The number of outpatient visits was 718,378 in 2018, 772,356 in 2019, 450,869 in 2020, and 456,400 in 2021. For the years 2022, 2023, 2024, and 2025, outpatient visits were reported as 780,000, 810,000, 845,000, and 880,000, respectively.

The number of ECG examinations during the same period was 42,515 in 2018, 48,775 in 2019, 30,461 in 2020, and 32,775 in 2021. In 2022, 2023, 2024, and 2025, the number of ECG examinations was recorded as 20,954, 25,904, 27,623, and 33,755, respectively. ECG utilization rates were calculated as 5.91% in 2018, 6.31% in 2019, 6.75% in 2020, and 7.18% in 2021. These rates decreased to 2.69%, 3.19%, 3.27%, and 3.83% in 2022, 2023, 2024, and 2025, respectively.

Repeat ECG examinations were recorded as 7,987 (19%) in 2018, 10,208 (21%) in 2019, 5,705 (19%) in 2020, and 6,227 (19%) in 2021. In 2022, 2023, 2024, and 2025, repeat ECG examinations were 2,357 (11.2%), 2,573 (9.9%), 2,797 (10.1%), and 3,749 (11.1%), respectively (Table 1).

As illustrated in Figure 1, trends in ECG utilization over the study period are presented. While ECG utilization rates were relatively higher before and shortly after integration, a notable decline was observed starting in 2022. A similar downward trend is also evident in repeat ECG rates following 2022.

Paper Consumption and Cost Analysis

Paper consumption and cost data related to ECG procedures were evaluated annually between 2017 and 2025.

In 2017, a total of 43,548 ECG examinations resulted in the use of 435.48 roll equivalents of paper, corresponding to a cost of 3,074.49₺.

Between 2018 and 2021, the estimated paper consumption corresponding to the number of ECG examinations was calculated

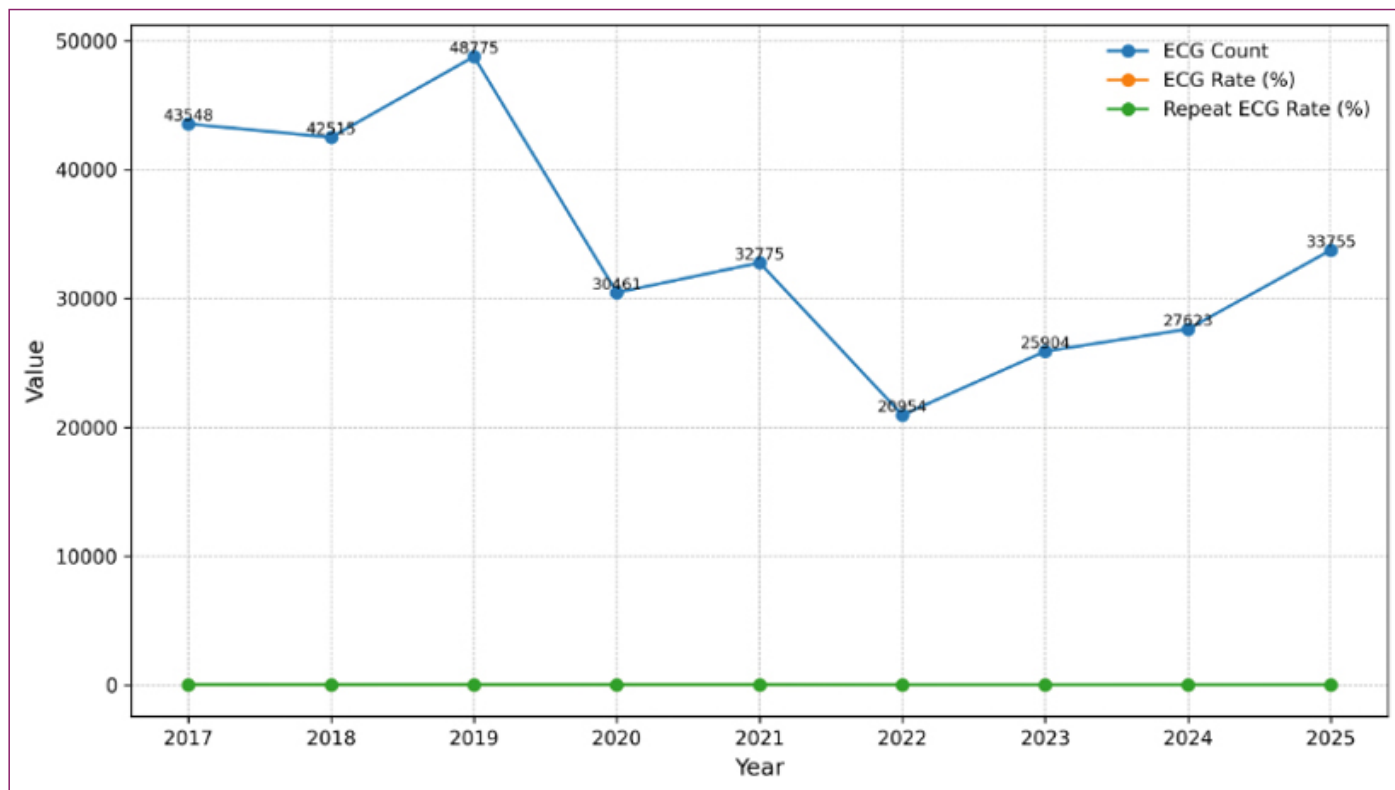


Figure 1. Trends in electrocardiography (ECG) utilization, ECG rate (%), and repeat ECG rate (%) between 2017 and 2025.

as 425.15, 487.75, 304.61, and 327.75 roll equivalents, respectively. The corresponding paper costs for these years were estimated as 3,316.17₺, 4,438.53₺, 5,635.29₺, and 7,177.73₺.

For the years 2022–2025, estimated paper consumption was calculated as 209.54, 259.04, 276.23, and 337.55 roll equivalents, respectively. The corresponding avoided costs were calculated as 30,467.12₺, 37,664.42₺, 40,163.84₺, and 49,079.77₺ (Table 2).

As shown in Figure 2, the elimination of paper use following system integration resulted in progressively increasing avoided costs over time.

System Integration and Data Accessibility

In 2017, ECG data were not integrated into digital systems; instead, they were stored in paper format, and access depended on patients presenting physical documents.

As of 2018, with the implementation of HL7-based integration, data obtained from ECG devices began to be transferred to the digital environment via the PACS. In the same year, ECG data became viewable through the HIS, and digital archiving processes were activated (Table 3).

Between 2018 and 2025, ECG–HIS integration was maintained continuously. HL7 integration remained actively in use, and data were centrally stored through PACS, with digital archiving processes sustained throughout this period. During this time, ECG data were accessible to clinical units via the HIS.

In addition, in the post-integration period, ECG data became accessible to patients through the national health platform (e-Nabız).

Table 3 presents the status of ECG–HIS integration components between 2017 and 2025.

Table 2. ECG-related paper consumption and cost analysis (2017–2025)

Year	Total ECGs	Paper usage (roll equivalent)	Observed Cost (₺)	Avoided Cost (₺)
2017	43,548	435.48	3,074.49	–
2018	42,515	425.15	–	3,316.17
2019	48,775	487.75	–	4,438.53
2020	30,461	304.61	–	5,635.29
2021	32,775	327.75	–	7,177.73
2022	20,954	209.54	–	30,467.12
2023	25,904	259.04	–	37,664.42
2024	27,623	276.23	–	40,163.84
2025	33,755	337.55	–	49,079.77

ECG: Electrocardiography.

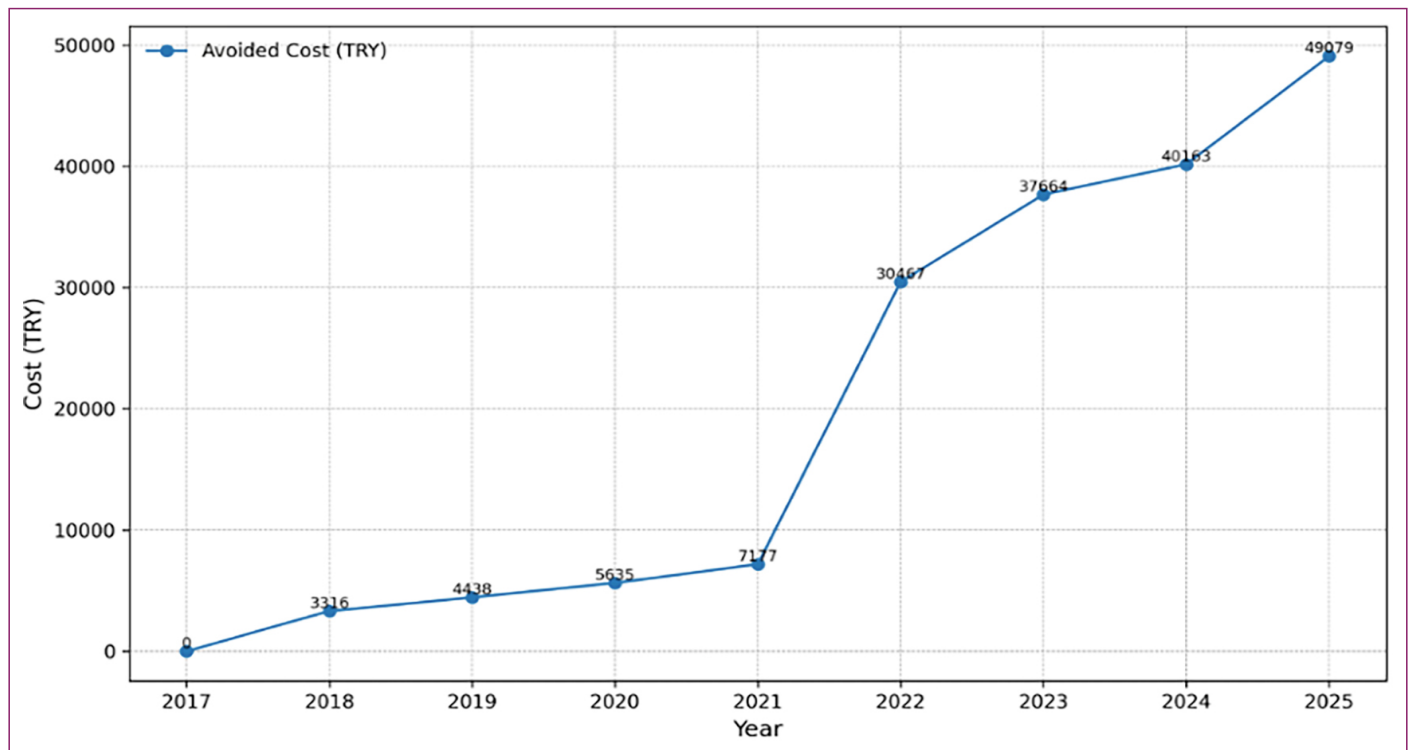


Figure 2. Trends in electrocardiography-related paper costs and avoided costs between 2017 and 2025.

Discussion

In this study, the system-level effects of integrating ECG devices into a HIS were evaluated in terms of paper use, cost outcomes, and clinical data accessibility. The findings indicate that digital integration has led to a substantial transformation in data management processes, eliminated paper-based workflows, and significantly improved access to ECG data.

One of the most notable findings of this study is the complete elimination of paper use in ECG procedures following integration. In the pre-integration period (2017), ECG records were produced and stored in paper format, resulting in continuous consumable costs and reliance on physical document management. In contrast, with the implementation of HL7-based data transfer and PACS-supported HIS integration, ECG data became digitally stored and accessible. This transformation not only eliminated paper usage but also simplified operational processes and contributed to cost reduction. These findings are consistent with the literature reporting that digital health systems improve workflow efficiency and reduce operational costs.^[5,7,10]

From a clinical perspective, one of the most significant contributions of integration is the improvement in data accessibility and continuity. In the pre-integration period, access to previous ECG records depended on patients presenting physical documents, which could lead to data loss and limited accessibility. Following integration, ECG data became instantly accessible through the HIS and PACS, enabling healthcare professionals to rapidly and comprehensively access patient history and thereby supporting clinical decision-making processes.

In addition, integration with the national health platform (e-Nabız) allows patients to directly access their ECG data, representing an important advancement in patient engagement. This development supports individuals’ active participation in their healthcare processes and improves access to health services.^[6,7]

In this study, no significant reduction in repeat ECG rates was observed during the early post-integration period. Although the literature suggests that the integration of medical devices with health information systems improves workflow efficiency and

Table 3. Implementation status of ECG–HIS integration components (2017–2025)

Parameter	Pre-integration (2017)	Post-integration (2018–2025)
HIS–ECG integration	No	Yes
HL7 integration	No	Active
PACS integration	No	Yes
Digital archiving	No	Yes
Clinical accessibility	Limited (patient-dependent)	Available across departments
Patient access via national platform	No	Yes

HIS: Hospital information system; ECG: Electrocardiography; PACS: Picture archiving and communication system.

data accessibility, it also emphasizes that digital access alone may not be sufficient to reduce repeated testing.^[1–5] This finding highlights the role of clinical decision-making processes and physician behavior, and is consistent with existing literature.

The definition of repeat ECG used in this study was based on more than one ECG performed on the same patient within the same calendar year and did not account for clinical indications. Therefore, medically necessary repeat examinations could not be distinguished from potentially unnecessary repetitions. This limitation should be considered an important methodological constraint when interpreting the findings.

The marked decline in ECG utilization observed in 2022 should not be directly attributed to system integration. This change may be associated with post-pandemic restructuring of healthcare delivery and shifts in patient utilization patterns. Furthermore, due to the single-center, observational design of the study and the absence of a control group, the findings should be interpreted as temporal and associative changes rather than causal effects.

From a healthcare system perspective, the digitalization of ECG processes provides significant operational advantages due to the high volume of procedures. The elimination of paper use not only reduces direct costs but also simplifies workflows and enhances workforce efficiency. In addition, the removal of physical document circulation may contribute indirectly to infection control.

The strengths of this study include the use of multi-year real-world data and the simultaneous evaluation of clinical, operational, and economic indicators. The availability of a pre-integration reference year also allows for a clearer assessment of system-level changes.

However, several limitations should be acknowledged. Since the analyses were conducted using aggregated institutional data, patient-level evaluation was not possible, and clinical factors influencing repeat ECG use could not be controlled.

In addition, the study design includes an imbalance between the pre- and post-integration periods. The pre-integration phase is represented by a single year (2017), whereas the post-integration period spans 8 years (2018–2025). This asymmetry may limit the comparability between periods and should be considered when interpreting temporal changes.

The cost analysis was limited to paper-related expenses, and broader cost components such as infrastructure investment, software licensing, maintenance, and training were not included. Therefore, the study represents a partial cost evaluation rather than a comprehensive economic assessment. In addition, costs were calculated using nominal values without adjustment for inflation. Considering the high inflation rates observed, particularly after 2021, part of the increase in avoided costs may be attributable to macroeconomic factors rather than purely operational changes.

Future studies should evaluate ECG–HIS integration in conjunction with clinical decision support systems and include patient-level analyses. In addition, investigating the direct effects of digital integration on clinical outcomes and patient safety would provide valuable contributions to the literature.

Conclusion

The integration of ECG devices into a HIS provides significant benefits in eliminating paper-based workflows, improving data accessibility, and reducing operational costs.

This study demonstrates that such integration facilitates rapid and comprehensive access to patient data for healthcare professionals and enhances system-level efficiency by streamlining clinical workflows. In addition, the integration of ECG data into digital platforms and national health systems supports patient engagement and improves access to healthcare services. However, digital integration alone appears insufficient to reduce repeated testing.

In conclusion, ECG–HIS integration represents an effective digital transformation approach for improving operational efficiency and data continuity in healthcare systems. Further improvements in clinical outcomes may require integration with clinical decision support systems.

Disclosures

Ethics Committee Approval: The study was approved by the Alanya University Ethics Committee (no: 02, date: 04/02/2025).

Informed Consent: Written informed consent was obtained.

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