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ORIGINAL RESEARCH

Economic Evaluation of Remote Monitoring for Implantable Cardiac Devices: Evidence from a Remote-Care Study

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Background: The adoption of remote monitoring (RM) is especially relevant for patients with implantable cardiac devices due to their high risk of hospitalization and the need for frequent outpatient visits. Though RM can help with early detection of cardiac episodes, it may also increase the number of tasks healthcare providers engage in to monitor patients' health. The adoption of RM may increase healthcare providers' workloads, potentially impacting the quality of care and increasing the risk of clinician-provider burnout. Little is known about the link between RM adoption and changes in healthcare providers' workloads.

Methods: Using data from a non-randomized clinical trial conducted in 2021–2022 at a University Hospital in Korea, we examined the relationship between RM adoption and changes in patient time savings and healthcare providers' workloads. The clinical trial included patients with a cardiac implantable electronic device compatible with the Biotronik Home Monitoring System.

Results: For patients, RM was associated with a 41-minute decrease in total visit duration, attributed to reductions in both wait time (37 minutes; P<0.001) and total examination time (3.7 minutes; P=0.137). For healthcare providers, RM was linked to an increase in overall workload by 107.9 minutes per patient. The increase was primarily due to managing RM alerts (91.8 minutes) and preparing monthly patient reports (19.9 minutes). Our findings suggest that RM was associated with a decrease of 1540 KRW (44%) in average cost of care per minute.

Conclusion: RM is associated with time-saving patient benefits and increased healthcare providers' workloads. Even though this was a single-center study with a small number of patients, our research highlights the importance of carefully examining changes in healthcare staff workloads linked to the adoption of RM within the national health insurance system.

Keywords: digital health, telemedicine, remote patient monitoring

Introduction

Remote patient monitoring (RM) has the potential to offer various benefits, including increases in patient satisfaction,[1,2] cost and time savings for patients,[3–9] and prompt response by medical providers in case of emergencies.[10,11] On the other hand, RM adoption may increase healthcare provider workload due to the additional tasks the activity entails and can thus affect the quality of care and increase burnout risk.[12] Yet, there is limited evidence on how RM affects the workload of healthcare providers when adopting the technology in a clinical setting.[13]

This study examines the efficacy of RM for patients and its implications on clinician workload in Korea. RM adoption is particularly relevant for patients with cardiac problems because they are at higher risk of hospitalization and readmission, as well as requiring more outpatient visits.[14] These increased risks and frequent visits highlight the potential benefits of adopting real-time patient status monitoring to improve health outcomes.

RM adoption is particularly relevant in Korea, where there are frequent annual medical visits and high patient concentrations in tertiary hospitals.[15,16] More than 70% of medical expenses for cardiovascular diseases reimbursed by

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the National Health Insurance system are sourced from tertiary hospitals. These may be driven by factors such as the patient's ability to seek medical services without the need for referrals and high-cost sharing covered by the national health insurance for procedures related to cardiocerebrovascular disease.[17]

Direct doctor-to-patient telehealth services are strictly prohibited in the country for several reasons, such as widespread data privacy concerns and strict requirements for covered medical services in the national insurance system.[18] In response to the COVID-19 pandemic, doctor-to-patient telemonitoring was only temporarily permitted between December 2020 and May 2023 under an amendment to the Infectious Disease Control and Prevention Act.[18,19] These strict telemedicine restrictions and healthcare challenges create a unique setting for examining the adoption of remote monitoring in Korea.

Study Design

This study was a non-randomized clinical trial that employed a hybrid approach involving in-person checks and RM to assess patient status and device performance. This study was conducted at a University Hospital in Korea from 2021 to 2022. 102 study participants were implanted with a Biotronik Home Monitoring-compatible cardiac implantable electronic device (CIED) at least six months before the start of the study. The types of cardiac devices enrolled in this study were Evia and Enitra 8 for pacemakers and Intica 7 and Rivacor 7 for ICDs/CRT-Ds. The implantable Biotronik products used in this study period are similar to those used in other countries (Appendix Table 1). Details of the study protocols are registered on ClinicalTrials.gov under the study ID NCT04557111 (REMOTE-CARE Study).

The study participants received a mobile CardioMessenger (CM) Smart device that wirelessly collected, encoded, and transmitted their biometric information to clinicians. The CM received daily information from a paired CIED via a trans server and data module. Automatic alerts were sent to clinicians for pre-scheduled CIED auto-checkups and when changes in a patient's rhythm or device alterations were detected. RM alerts were defined as any arrhythmic or pacing rate change events or lead or device-related alerts, atrial burden alerts above 25% each day, bi-ventricular pacing % (CRT), and any therapeutic alerts generated from implantable cardioverter defibrillator/cardiac resynchronization therapy with defibrillators (ICD/CRTs). During the study period, clinicians reviewed RM alerts for three hours, three days a week.

Healthcare providers monitored these alerts and provided necessary medical interventions based on the alert's severity. They promptly arranged for hospital admission or contacted the patient/their guardian at 8:00 a.m. on the following workday for actionable alerts. Non-actionable alerts were addressed from 12:30 to 1:30 p.m. on workdays. To ensure the smooth operation of patients' remote transmissions, clinicians reviewed RM alerts and other device parameters for one hour, three days a week over the 12-month post-RM period. The clinicians also prepared monthly reports to provide information on patients' health conditions. The report comprehensively summarized the patients' heart status, cardiac device status, alerts generated by the implanted devices, and follow-up schedules. The study participants were asked to report their preferred modes of communication, such as text messages and e-mail, to receive these reports at enrollment.

Furthermore, the study reduced the frequency of routine follow-up visits to assess the feasibility of transitioning to an alert-based patient care model focusing on clinic visits for actionable events. Given that ICD/CRT-D patients face a higher risk of severe cardiac events than those with pacemakers, the changes in the recommended intervals for in-person follow-up visits varied by device type, following recent guidelines on RM adoption with cardiac patients.[20,21] Pacemaker patients were recommended to attend follow-up visits between every 5–6 months to one year and patients with ICD/CRT were recommended to attend every 2–3 months to 4–6 months. Patients were allowed to schedule an outpatient appointment at any time if they were concerned about being unable to see medical staff.

Data and Statistical Analysis

Our primary data source was the Electronic Medical Record System, which contains comprehensive information regarding the patient's medical histories and details of each hospital visit. The information included visit duration, clinic consultation time, and medical costs.

To assess any changes in clinician work activity associated with RM, we collected the following information: (1) the total examination length and non-examination time per visit from the electronic medical record system and (2) the time clinicians spent preparing monthly RM reports per patient. Clinicians recorded the second measure in self-reported diaries and documented the minutes spent preparing monthly RM reports per patient. Periodic EGM alerts were excluded from the analysis. The average alert review time was 91.8 minutes per patient (3 hours*52 weeks/102 study participants), reviewing the study participants' RM alerts and vital signs. Based on this information, the average cost of care per minute over 12 months during the pre-and post-RM period was calculated by dividing the total charges for healthcare services by the total time spent providing medical services per patient. Further, the total clinician time spent per patient is calculated as the average time clinicians spent per patient during the pre-and post-RM to examine the association between RM adoption and changes in clinician workload under the study design.

A two-sided *t*-test was used to compare the outcomes measured during the 12-month pre- and post-RM periods. Statistical significance was considered at a p-value of less than 0.05, indicating a meaningful difference between the two periods. Stata version 18 (StataCorp LLC, College Station, TX, USA) was used to perform the statistical analyses. Data were analyzed from November 2022 to September 2023.

Results

The analytic sample consisted of 97 study participants: 79 with pacemakers, 15 with ICD, and 3 with CRT-D. Five out of the initial 102 study participants were excluded from the analysis due to causes of death unrelated to cardiac issues during the follow-up period. Table 1 presents the baseline characteristics of study participants at enrollment in the analytic sample.

We started the analysis by exploring the potential time savings that RM adoption could offer to healthcare providers. In Table 2, RM was associated with a decrease of one (P<0.001) routine follow-up visit per patient (Supplementary Figure 1).[8] Similarly, RM was linked to a 41-minute decrease in total visit duration per patient, attributed to decreases in both total non-examination time (37 minutes; P<0.001) and examination time (3.7 minutes; P=0.137). In Panel (a) of Figure 1, the decrease in total visit length varied by device type: 48.8 minutes (P<0.001) for pacemaker patients and 7.1 minutes (P=0.81) for patients with ICD/CRT-D. The decrease in total examination time associated with RM was similar across device types.

We examined whether RM was associated with time savings per visit. As healthcare providers receive more timely information about patients' health through RM, they could preemptively assess the need for services such as device programming, which may lead to shorter average visit durations. In Table 2 and Panels (b)-(c) of Figure 1, RM was associated with 3.9 minutes (P=0.0403) and 4.2 minutes (P=0.023) decrease in the average visit length and wait time, respectively — the changes in average visit length varied by device type. In Appendix Figure 1, pacemaker patients saw

Table 1 Baseline Characteristics of Study Participants

Patient Characteristics	All	Device Type	
		Pacemaker	ICD/CRT-D
Age at Enrollment	69.6	72.4	56.9
Female	55.7%	60.8%	33.3%
Arrhythmia	15.5%	0.0%	33.3%
Open Heart Surgery	4.1%	5.1%	0.0%
Warfarin	0.1%	6.3%	0.0%
Antiplatelet	14.4%	13.9%	16.7%
Stroke/Cerebrovascular Accident	9.3%	10.1%	5.6%
N	97	79	18

Abbreviations: ICD, Implantable cardioverter defibrillator (ICD); ILR: implantable loop recorder, PM, Pacemaker.

Table 2 Changes in Primary Outcomes Between Pre-RM and Post-RM

	Mean	95% CI	Difference (95% CI)	P-value
(1) Total outpatient visits over 12 months				
Pre-RM Post-RM	3.68 2.691	(3.322, 4.039) (2.398, 2.984)	−0.99 (−1.394, −0.585)	<0.001
(2) Total visit length per patient (in minutes)				
Pre-RM Post-RM	138.289 97.237	(121.447, 155.131) (80.536, 113.938)	−41.052 (−62.346, −19.757)	<0.001
(3) Total non-examination time per patient (in minutes)				
Pre-RM Post-RM	120.711 83.402	(105.269, 136.154) (68.285, 98.519)	−37.309 (−57.438, −17.181)	<0.001
(4) Total examination time per patient (in minutes)				
Pre-RM Post-RM	17.577 13.835	(14.36, 20.795) (9.537, 18.133)	−3.742 (−8.693, 1.208)	0.137
(5) Average visit duration per visit (in minutes)				
Pre-RM Post-RM	38.141 34.256	(31.163, 37.349) (35.150, 41.132)	−3.885 (−7.595, −0.176)	0.0403
(6) Average wait time per visit (in minutes)				
Pre-RM Post-RM	33.480 29.318	(30.469, 36.491) (26.581, 32.055)	−4.162 (−7.743, −0.580)	0.023

Abbreviations: CI, confidence interval; RM, remote monitoring.

a decrease in the average visit length by 5.6 minutes (P = 0.009). ICD/CRT-D patients experienced an increase of 3.9 minutes (P = 0.34) post-RM period.

Next, we explore the changes in the time healthcare providers spent per patient before and after RM adoption. We initially looked at additional tasks assigned to healthcare providers after adopting RM. First, healthcare providers spent 91.8 minutes per patient to manage RM alerts and other device parameters for all patients during the study period. Healthcare providers received 1270 alerts in total and reviewed 12.5 alerts per patient on average per day (Panel (a) of Figure 2).[8] The severity of alerts differed across device types. In Panel (b) of Figure 2, ICD/CRT-D patients had a higher share of actionable alerts (6.3%) than pacemaker patients (0.1%).

Second, healthcare providers allocated 19.9 minutes per patient to prepare monthly RM summary reports. In Figure 3, the average time spent on monthly report preparation was similar across patient device types: 19.7 minutes for pacemaker patients and 20.5 minutes for ICD/CRT-D patients. These results suggest that healthcare providers devoted an average of 111.7 minutes per patient to managing the supplementary tasks required after the RM adoption. This increase exceeds the 3.7 minute decrease in total examination time per patient associated with RM adoption (Table 2). In Panel (a) of Figure 4, RM was linked to a 107.9 increase (P<0.001) in the average time health care providers dedicated to each patient. The increase in total time spent per patient remained consistent across the device types: 107.8 minutes (P<0.001) for pacemaker patients and 108 minutes (P<0.001) for ICD/CRT-D patients.

Discussion

Our research on the adoption of RM in patients with cardiac problems has revealed significant cost and time savings, along with increased patient satisfaction. These findings contribute to the growing body of literature on the cost-effectiveness of RM, particularly in the context of chronic conditions. The financial benefits of RM adoption are clear, providing reassurance about its potential to alleviate healthcare costs.

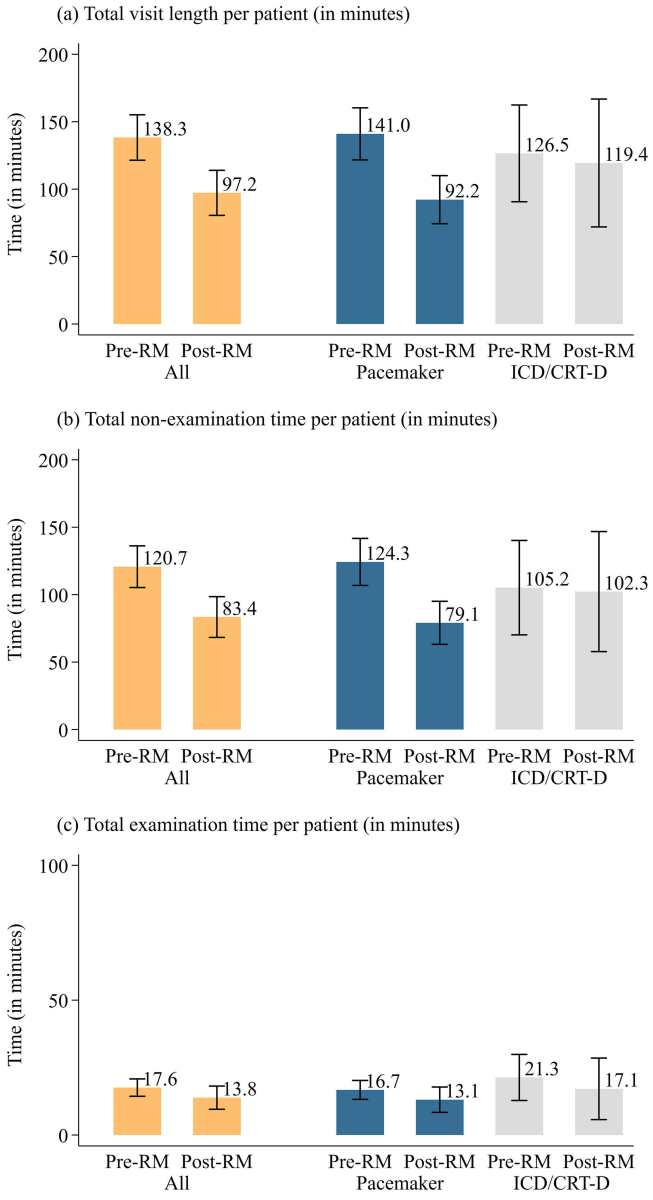

Figure 1 Changes in total visit length, total wait time, and total examination time.
Notes: (**a**) presents average total visit length per patient over 12 months during the pre- and post-RM period. (**b**) presents average total wait time (in minutes) per patient over 12 months during the pre- and post-RM period. (**c**) presents average total examination time (in minutes) per patient over 12 months during the pre- and post-RM period.
Abbreviations: RM, remote monitoring; ICD, implantable cardioverter defibrillator; CRT-D, cardiac resynchronization therapy with defibrillators.

Our findings suggest that RM has the potential to revolutionize healthcare delivery by reducing the need for in-person visits. Healthcare providers can use RM to efficiently deliver necessary medical services, thereby reducing the burden of frequent in-person consultations. This is particularly relevant in Korea, where the average number of medical consultations exceeds the OECD average, but outpatient consultation fees are lower due to the prevailing minimum wage.[22,23] This may encourage physicians to see more patients and conduct shorter consultations, often referred to as "three-minute consultations".

To examine the implications of introducing billing codes for RM in the national health insurance system, we calculated the average cost of care per linked patient before and after RM adoption. RM adoption was linked to a decrease of 1540 KRW (or 44%) in the average cost of care per minute (P<0.001, Panel (b) Figure 4). The decrease in average costs associated with RM adoption varied by device type: 1492 KRW per minute (P<0.001) for pacemaker patients but 1747 KRW per minute (P=0.004) for ICD/CRT-D patients.

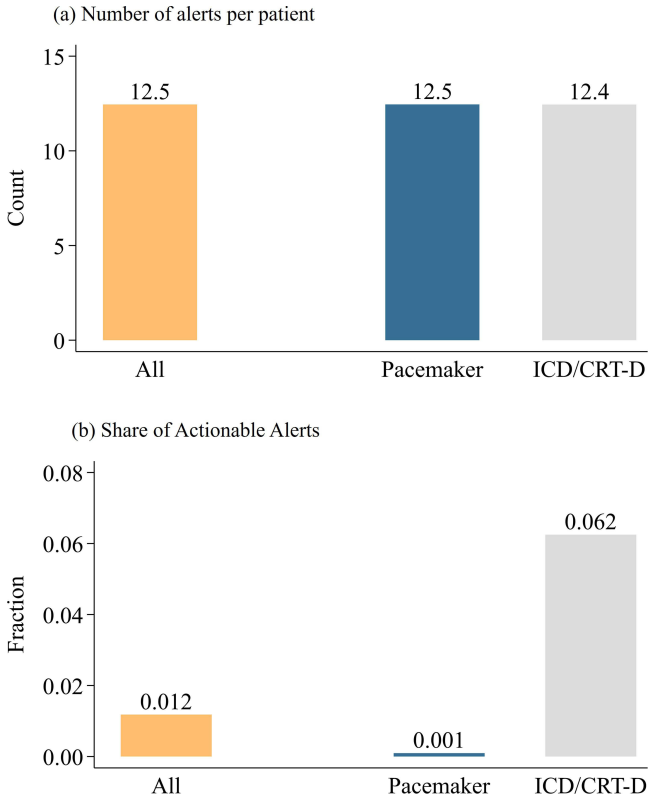

Figure 2 Number of alerts per patient and share of actionable alerts.
Notes: (**a**) presents the average daily number of RM alerts per patient over 12 months during the pre- and post-RM period. (**b**) presents the proportion of actionable RM alerts received during the post-RM period.
Abbreviations: RM, remote monitoring; ICD, implantable cardioverter defibrillator; CRT-D, cardiac resynchronization therapy with defibrillators.

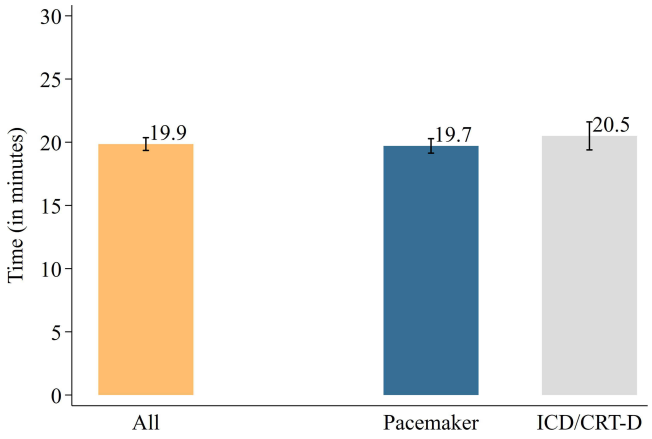

Figure 3 Time spent on RM report preparation per patient.
Notes: (**a**) presents the average time spent on monthly report preparation dedicated to each patient over 12 months during the post-RM period. (**b**) presents the average cost of care per minute over 12 months during the pre- and post-RM period.
Abbreviations: RM, remote monitoring; ICD, implantable cardioverter defibrillator; CRT-D, cardiac resynchronization therapy with defibrillators.

This study highlights the importance of examining changes in healthcare staff workloads when evaluating the effectiveness of adopting RM. The findings of this study must be interpreted with the following caveats. First, the overrepresentation of pacemaker patients in the sample restricts the applicability of results to the broader implantable electronic device population. Second, the 12-month post-RM assessment period in the current study design may not adequately capture outcomes that become more relevant in later follow-ups, such as mortality outcomes. Future research

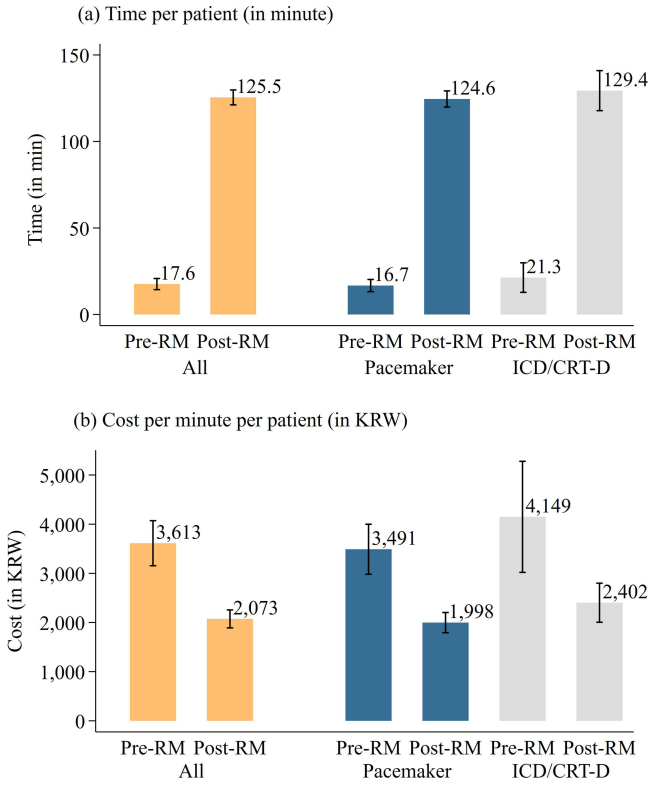

Figure 4 Clinician time allocation and cost of care per minute.
Notes: (**a**) presents the average time health care providers dedicated to each patient over 12 months during the pre- and post-RM period. (**b**) presents the average cost of care per minute over 12 months during the pre- and post-RM period.
Abbreviations: RM, remote monitoring; ICD, implantable cardioverter defibrillator; CRT-D, cardiac resynchronization therapy with defibrillators.

is needed to better track patient outcomes and healthcare worker workloads over time and better understand the implications of RM adoption for long-term outcomes. Third, the generalizability of our findings is limited due to the small sample size and the scope of services added to healthcare providers' tasks after adopting RM. For instance, changes in patient satisfaction and clinician time allocation linked to RM could vary with the extent of relevant information provided to the study participants, such as those summarized in monthly patient status reports. Future studies can address this concern by exploring the scope of necessary services needed to accompany RM adoption to ensure enhanced patient satisfaction and health outcomes.

Data Sharing Statement

Data used in this study is available from the corresponding author (youmi0607@naver.com) upon reasonable request to bona fide researchers.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis, and interpretation, or all these areas; took part in drafting, revising, or critically

reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors report no conflicts of interest in this work.

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