REMOTE PATIENT MONITORING (RPM) THROUGH WEARABLES: A PARADIGM SHIFT IN DSS FOR IMPROVED HEALTHCARE OUTCOMES

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Abstract- **The integration of Remote Patient Monitoring (RPM) through wearables with Decision Support Systems (DSS) marks a transformative paradigm shift in healthcare decision-making. This paper explores the role of DSS in healthcare, its evolution into Clinical Decision Support Systems (CDSS), and subsequently delves into the integration of RPM through wearables. The objective is to understand how this integration contributes to improved healthcare outcomes. The findings reveal the significant impact of real-time monitoring, challenges in implementation, and potential solutions. The paper concludes with insights into future trends and implications for healthcare decision support.**

Keywords: **Decision Support Systems, Clinical Decision Support Systems, Remote Patient Monitoring, Wearables, Healthcare Decision Support, Paradigm Shift, Continuous Care.**

1.0 INTRODUCTION

In the dynamic landscape of healthcare, the convergence of technology and decision-making has become paramount. Decision Support Systems (DSS) serve as linchpins in this evolution, facilitating informed choices amidst the intricate and often unpredictable healthcare environment. This introduction unravels the foundational concepts of DSS, tracing its transformative journey into Clinical Decision Support Systems (CDSS), and eventually, delving into the revolutionary integration of Remote Patient Monitoring (RPM) through wearables.

At the heart of healthcare decision-making lies the robust framework of Decision Support Systems (DSS). These sophisticated software applications navigate the complexities of clinical and managerial decisions, offering a symbiotic blend of data, models, and analytical tools. DSS is not just a technological enabler; it is a strategic partner empowering healthcare professionals, administrators, and policymakers with nuanced insights for evidence-based practices and elevated patient care. This is supported by [1], who discusses the role of DSS in healthcare, and [2], who highlights the effectiveness of DSS in solving unstructured and semi-structured problems. [3] underscore the importance of DSS in healthcare, focusing on its role in smart healthcare.

The journey from conventional DSS to the specialized realm of Clinical Decision Support Systems (CDSS) marks a significant progression. CDSS pivots towards the clinical domain, infusing medical knowledge, patient data, and advanced algorithms into decision-making processes. This evolution brings forth a tailored approach, aligning with the intricacies of clinical scenarios. [4] briefly describe CDSS as a crucial tool in modern healthcare, providing intelligent filtering and patient-specific evaluations to enhance patient care. CDSS extends a helping hand to healthcare professionals in real-time, providing diagnostic support, treatment recommendations, and ensuring adherence to evidence-based practices. It is a steadfast companion at the point of care, enhancing the decision-making process of clinicians. [5] demonstrated that CDSS can enhance guideline adherence and healthcare quality, and improve health outcomes.

As the technological canvas expands, the concept of Remote Patient Monitoring (RPM) emerges as a transformative force in modern healthcare. RPM, defined by its continuous and remote monitoring capabilities, becomes particularly significant in the management of chronic conditions and postoperative care. Central to the RPM narrative is the integration of wearable technology. These devices act as conduits for real-time health data, capturing a holistic view of patient well-being. Wearables, ranging from smartwatches to biosensors, transcend the confines of traditional care settings, enabling continuous monitoring and fostering a paradigm shift in healthcare decision support.

The synergy between wearables, DSS, and RPM forms the nucleus of this paper. This integration signifies more than a technological merger; it represents a paradigm shift in healthcare decision support. Wearables bridge the gap between CDSS and real-time patient monitoring, paving the way for comprehensive and continuous care. Examining specific instances where wearables contribute to RPM sheds light on the practical applications of this integration.

From monitoring heart rates to tracking activity levels, wearables offer a multifaceted approach to collecting vital health data.

This Paper lays the foundation for a journey through the evolution of DSS into CDSS, culminating in the paradigm shift ushered in by the integration of RPM through wearables. It sets the stage for a comprehensive exploration of the benefits, challenges in applications of RPM through wearables; finally, we propose strategic solutions for these challenges and contributions to knowledge that arise from this transformative synergy.

2.0 REVIEW OF RELATED LITERATURES

Decision Support Systems (DSS) are crucial tools in various fields. They typically consist of three main components: The Data Management Subsystem, Model Management Subsystem, and User Interface Subsystem [2]. These components work together to support decision makers by providing data, analysis, and user interaction. The analysis and design of DSS is a complex process that involves the use of appropriate methodologies and tools to model decision-making processes [6].

The nature of decision-making tasks and available resources influences the type of Decision Support System (DSS) to be used [7]. These can include Communication-driven DSS, Data-driven DSS, Document-driven DSS, Knowledge-driven DSS, and Model-driven DSS [8]. Task-specific DSS, such as those used in multi-level production systems, can be particularly effective when combined with Information and Communication Technologies (ICT) [9]. DSS can also be used in healthcare, where computational aspects and algorithms play a crucial role [10].

The DSS development involves several key phases, including "Intelligence", "Design", "Choice", and "Implementation" [2]. These phases help in identifying the problem, designing a solution, choosing the best alternative, and implementing the chosen solution. The "Intelligence" phase involves identifying the problem and collecting relevant data, while the "Design" phase focuses on creating a solution based on the data collected. The "Choice" phase involves evaluating and selecting the best solution, and the "Implementation" phase involves putting the chosen solution into action. These phases are essential in the development of DSS, as they help in ensuring that the system is effective and efficient in supporting decision-making processes.

A range of factors influence the functionality and effectiveness of decision support systems (DSS). In healthcare, top management support, perceived benefits, security, and compatibility are key factors [11]. For clinical decision support systems, ease of use, perceived benefit, and a facilitating environment are crucial [12]. In educational settings, interaction, compatibility, and time effectiveness are significant [13]. In the workplace, decision quality, risk, and system comprehension are important [14].

MIS (Management Information System) and DSS (Decision Support System) are two different types of information systems used within organizations. While they have some similarities, they also have distinct features and purposes see (figure 1).

MIS primarily focuses on providing routine information to support day-to-day operations, while DSS offers more interactive and analytical capabilities to aid in decision-making at higher levels. Both systems serve different purposes and are valuable in different contexts within an organization.

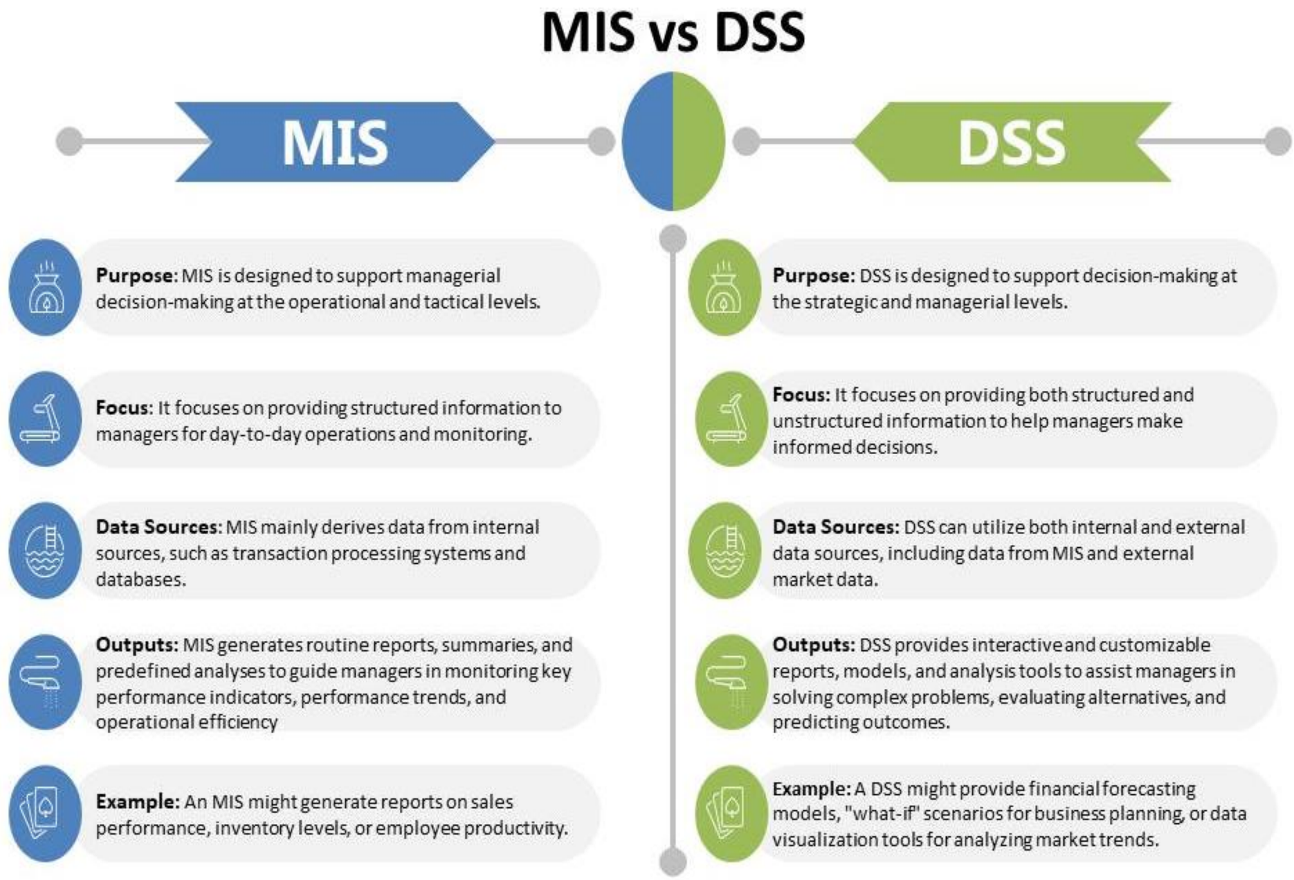


Figure 1 – MIS vs DSS

DSS are integral to healthcare decision-making, providing information, analysis, and interactive capabilities. They enhance patient care and safety by assisting with clinical decisions [15] contributing to evidence-based practices and improved patient care.

The integration of technology in healthcare processes through DSS, and the use of digital technologies such as electronic medical records, enterprise resource planning, and internet-of-things enabled medical wearables enhance data processing, process integration, generate insights, provide dynamic capabilities in healthcare, and further facilitate evidence-based decision-making [16].

The evolving nature of Decision Support Systems (DSS) in healthcare is evident in their integration of new technologies, data sources, and analytical methodologies to address emerging challenges [10]. This evolution is particularly crucial in precision medicine, where DSS can help manage the complexity of decision-making by integrating all available data [17].

The transition from traditional decision support systems to Clinical Decision Support Systems (CDSS) has been a significant development in healthcare, with CDSS incorporating medical knowledge, patient data, and technology to assist in clinical decision-making [18]. Key components of CDSS include knowledge bases, inference engines, and user interfaces, with successful implementations in healthcare settings such as pediatrics and continuous-care [19]. Design features of CDSS, including interface, information, and interaction, are critical for their success [20].

Remote Patient Monitoring (RPM) is a critical component of modern healthcare, particularly in managing chronic conditions and postoperative care [21]. Wearables, such as smartwatches and fitness trackers, play a significant role in RPM by capturing real-time health data and contributing to a more comprehensive patient profile [22]. These technologies have been shown to be effective in improving patient outcomes and reducing healthcare costs [23].

Wearable devices have emerged as a key tool in healthcare, bridging the gap between clinical decision support systems (CDSS) and remote patient monitoring (RPM) providing real-time data to inform clinical decisions [24]. These devices can capture a range of data, including heart rate, activity levels, and glucose levels and vital signs [25]. They have been particularly effective in monitoring vital signs beyond traditional care settings [26]. The potential of wearables in healthcare is significant, with the ability to improve patient outcomes and facilitate early disease detection [27].

3.0 CURRENT TRENDS IN RPM THROUGH WEARABLES

As we look forward to the future of healthcare decision support, particularly in the realm of Remote Patient Monitoring (RPM) through wearables, it becomes imperative to anticipate and understand emerging trends that will shape the landscape, the integration of Artificial Intelligence (AI) and Machine Learning (ML) emerges as a transformative force. This convergence amplifies the capabilities of Remote Patient Monitoring (RPM) through wearables and Decision Support Systems (DSS). Machine learning algorithms, as demonstrated by studies by [28] enable more precise predictions and personalized recommendations based on patient data. The implications include enhanced predictive analytics, allowing for proactive interventions, and personalized decision support, tailoring healthcare strategies to individual patient needs.

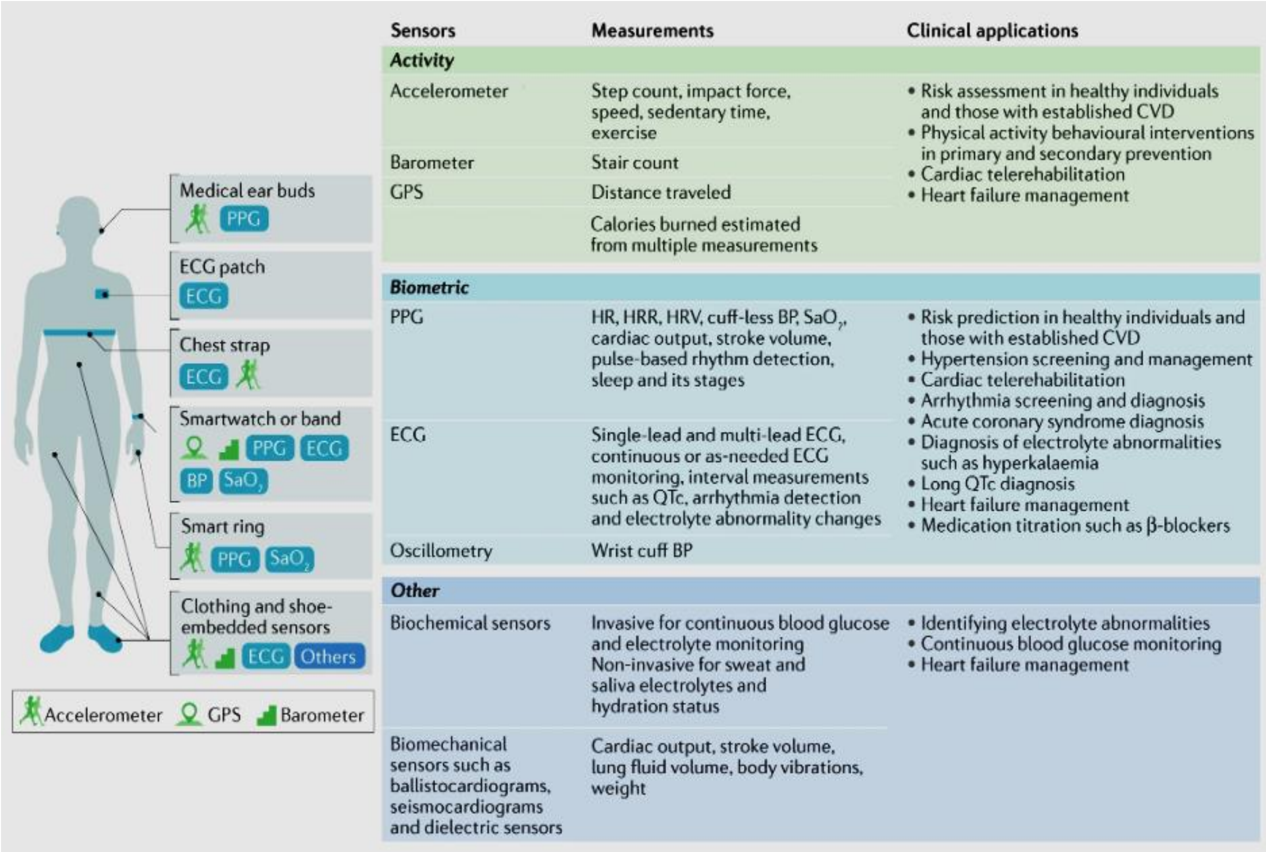
Patient-centric technologies, closely integrated with wearables, redefine the patient-provider relationship and healthcare delivery. The shift towards patient empowerment is evident as individuals actively participate in their care through real-time communication and data contribution. Anchored in the principles of patient engagement, as highlighted by [29], these technologies foster improved adherence, outcomes, and shared decision-making between patients and healthcare providers. The future landscape thus envisions a healthcare ecosystem where advanced analytics, patient empowerment, and collaborative decision-making intertwine to shape more proactive, personalized, and effective healthcare decision support.

4.0 APPLICATIONS OF RPM THROUGH WEARABLES IN DSS

Recent research has highlighted the potential of wearable devices in chronic disease management, particularly in diabetes. These devices, equipped with glucose monitoring sensors, provide continuous data streams to decision support systems, enabling healthcare providers to closely monitor blood glucose levels and identify trends indicating poor glycemic control [30]. The use of these devices has shown early promise, with the potential to benefit patients, healthcare professionals, and researchers [30]. Continuous glucose monitoring (CGM) sensors, in particular, have been found to improve the safety and effectiveness of diabetes therapy, reduce hypoglycemia, and decrease glycemic variability [31]. The combination of wearable devices with artificial intelligence techniques has been shown to assist in diabetes management and prevent complications [32].

Remote pulmonary rehabilitation, facilitated by wearable devices with respiratory sensors, has been shown to be feasible, safe, and effective in improving exercise tolerance, dyspnea, and quality of life in patients with chronic respiratory conditions such as COPD [33]. The integration of real-time respiratory data into decision support systems (DSS) has further enhanced the personalization of rehabilitation programs, allowing healthcare providers to adjust exercise regimens, track lung function, and provide timely feedback to patients [34]. The use of telehealth services, including teleassessment and telemonitoring, has been well-received by patients and has shown positive outcomes in reducing exacerbations and improving self-management [35]. Wearable physiological monitoring systems have been successfully applied in pulmonary rehabilitation research, providing accurate and unobtrusive acquisition of vital signs for individualized therapy [36]. The use of a wearable sensor device for monitoring respiratory impedance has also been proposed, offering a potential solution for remote monitoring and treatment adaptation [37].

Our focus is on telecardiology, wearable devices equipped with activity trackers, heart rate monitors and ECG sensors continuously collect real-time data on cardiac activity. In heart failure management, wearable devices monitoring vital signs, such as blood pressure and fluid levels are also employed. These devices (Figure 2) have been found to be effective in detecting and predicting cardiovascular diseases [25]. This data, seamlessly integrated into DSS, enables cardiologists to monitor patients remotely. Rapid detection of irregularities in heart rhythms or early signs of cardiac events, elevated blood pressure allows for immediate decision support, guiding healthcare professionals to recommend interventions, adjust medications, recommend dietary changes or advise lifestyle changes in a timely manner. This proactive approach helps prevent exacerbations, reducing the need for hospital admissions and ensuring more cost-effective and patient-centric care. Patients receive personalized insights and recommendations based on their activity levels, fostering engagement and empowering them to make informed decisions about their health. This approach promotes sustained lifestyle changes and active participation in weight management.



Sensors	Measurements	Clinical applications
Activity		
Accelerometer	Step count, impact force, speed, sedentary time, exercise	• Risk assessment in healthy individuals and those with established CVD • Physical activity behavioural interventions in primary and secondary prevention • Cardiac telerehabilitation • Heart failure management
Barometer	Stair count	
GPS	Distance traveled	
	Calories burned estimated from multiple measurements	
Biometric		
PPG	HR, HRR, HRV, cuff-less BP, SaO_2, cardiac output, stroke volume, pulse-based rhythm detection, sleep and its stages	• Risk prediction in healthy individuals and those with established CVD • Hypertension screening and management • Cardiac telerehabilitation • Arrhythmia screening and diagnosis • Acute coronary syndrome diagnosis • Diagnosis of electrolyte abnormalities such as hyperkalaemia • Long QTc diagnosis • Heart failure management • Medication titration such as β-blockers
ECG	Single-lead and multi-lead ECG, continuous or as-needed ECG monitoring, interval measurements such as QTc, arrhythmia detection and electrolyte abnormality changes	
Oscillometry	Wrist cuff BP	
Other		
Biochemical sensors	Invasive for continuous blood glucose and electrolyte monitoring Non-invasive for sweat and saliva electrolytes and hydration status	• Identifying electrolyte abnormalities • Continuous blood glucose monitoring • Heart failure management
Biomechanical sensors such as ballistocardiograms, seismocardiograms and dielectric sensors	Cardiac output, stroke volume, lung fluid volume, body vibrations, weight	

Figure 2 shows summary of common commercial smart wearables, where they are worn on the body, their built-in sensors, and the different types of measurements collected by each sensor and their various cardiovascular clinical applications. BP, blood pressure; CVD, cardiovascular disease; ECG, electrocardiogram; GPS, Global Positioning System; HR, heart rate; HRR, heart rate recovery; HRV, heart rate variability; PPG, photoplethysmography; SaO_2, oxygen saturation.

4.1 Integrating of Wearables into DSS for RPM Data flow

The integration of wearables into DSS represents a closed-loop system (figure 3) where continuous monitoring, analysis, and decision support contribute to more personalized and proactive healthcare.

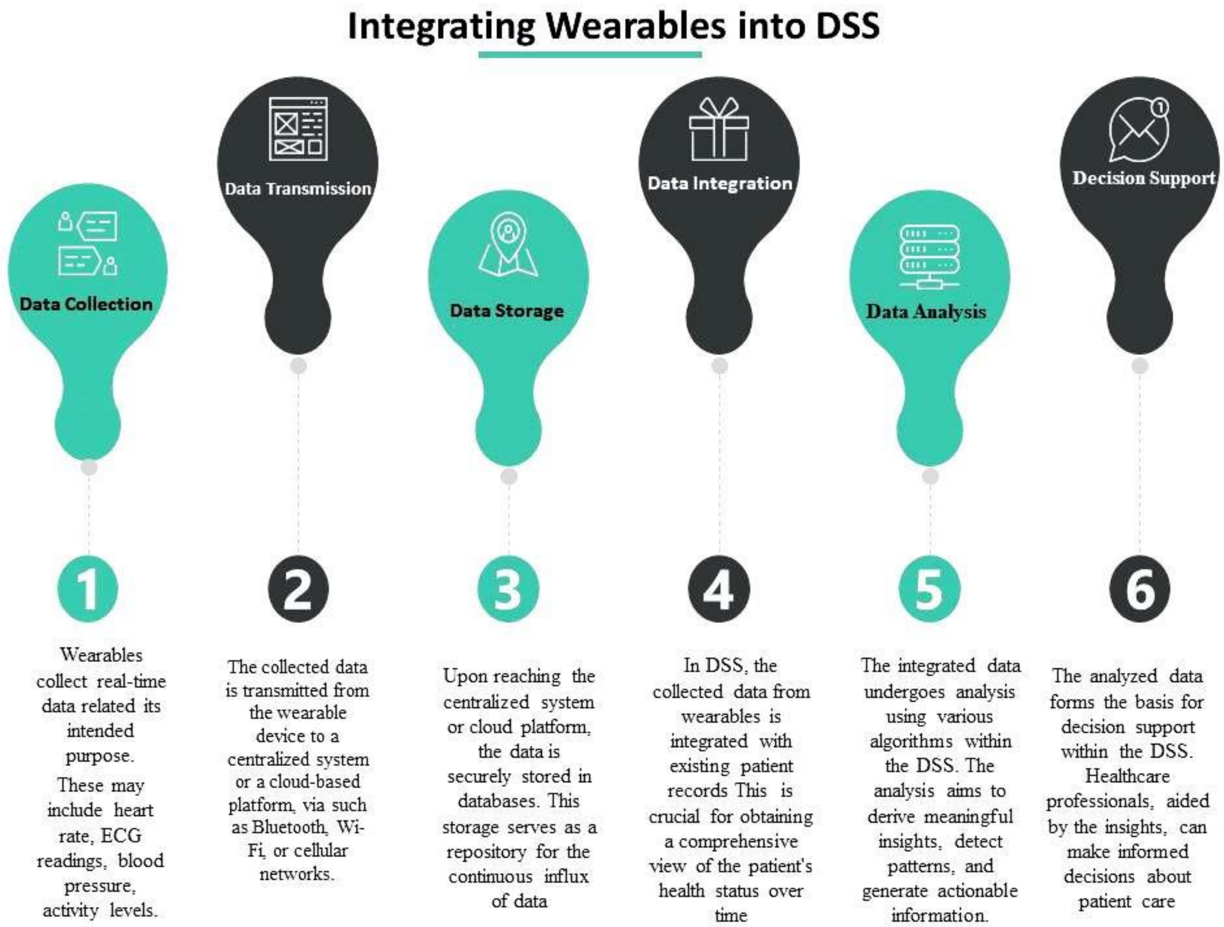


Figure 3 - Data flow for integrating wearables into DSS for RPM

4.2 Challenges in integrating wearables into DSS

The integration of wearables into Decision Support Systems (DSS) for Remote Patient Monitoring (RPM) presents a multifaceted landscape of challenges that necessitate careful consideration to realize the full potential of these technologies. Primarily, concerns regarding data security loom large [43], emphasizing the critical importance of safeguarding sensitive health data collected by wearables. The risk of unauthorized access, data breaches, and potential cyberattacks underscores the need for robust encryption, authentication measures, and secure data transmission channels. Simultaneously, privacy concerns emerge as a pivotal challenge, as wearables capture personal health information, necessitating a delicate balance between leveraging data for medical insights and ensuring stringent privacy safeguards. Interoperability issues further compound these challenges, stemming from the diverse array of wearables with distinct data formats and standards [38]. Achieving seamless communication between wearables and various DSS platforms becomes a significant obstacle, potentially hindering the aggregation and analysis of patient data from different devices.

Additional hurdles contribute to the complexity of integrating wearables into DSS for RPM. Ensuring the accuracy and reliability of data remains paramount [39], demanding attention to factors such as sensor calibration and user adherence to maintain the integrity of collected information [40]. Battery life and device wearability pose practical challenges, requiring solutions to address interruptions caused by frequent recharging and enhance user comfort for sustained wear. Managing the substantial volume of generated data is a formidable task, necessitating robust infrastructure, storage capabilities, and computational resources to prevent data overload. Regulatory compliance introduces a layer of complexity, requiring meticulous attention to legal and ethical considerations. User adoption and engagement emerge as crucial challenges, emphasizing the need to incentivize consistent usage and convey the significance of continuous monitoring to users. The cost and accessibility of wearables present economic and equity challenges, demanding a delicate balance between affordability and ensuring broad access. Finally, issues surrounding data ownership and consent underscore ethical considerations, emphasizing the need for transparent practices and clear communication regarding the utilization of health data. Addressing this comprehensive array of challenges necessitates a holistic approach, combining technological innovations, regulatory frameworks, user education, and collaborative efforts across the healthcare ecosystem.

4.3 Solutions and strategies to overcome challenges, ensuring effective implementation of RPM through wearables

Addressing the challenges in integrating wearables into Decision Support Systems (DSS) for Remote Patient Monitoring (RPM) requires a holistic and strategic approach. Data security, privacy concerns, and interoperability issues demand technological innovations and solutions [41]. Advanced encryption, robust authentication, and secure data transmission channels tackle data security, while explicit informed consent and anonymization techniques address privacy, fostering trust. Standardization efforts and open APIs overcome interoperability challenges, ensuring seamless communication between diverse wearables and DSS. Simultaneously, enhancing data accuracy and reliability involves advanced sensor calibration, proper device placement, and incentivizing user adherence through user-friendly interfaces and real-time feedback mechanisms. Technological advancements in energy-efficient sensors extend battery life, and a focus on user comfort and adaptability promotes sustained wearability. Additionally, mitigating challenges associated with data volume and overload necessitates scalable cloud-based solutions, edge computing, and advanced data management techniques prioritizing clinical relevance.

Regulatory compliance is vital in this multifaceted landscape, requiring a robust governance framework adhering to healthcare regulations. Regular updates and collaboration with regulatory bodies ensure ongoing compliance, maintaining a high standard of ethical data handling. User adoption and engagement are facilitated through gamification, personalized health insights, and continuous education. Wearables designed to seamlessly integrate into users' routines and provide tangible benefits through decision support contribute to sustained interest. Ensuring cost-effectiveness and accessibility involves leveraging economies of scale, fostering public-private partnerships, and exploring innovative funding models, including subsidized programs for underserved populations. This comprehensive and interconnected approach aligns technological advancements with strategic solutions, paving the way for a successful integration of wearables into DSS for enhanced RPM.

In addition, this paper proposes an exploration of a blockchain-based decentralized identity and consent management system. This innovative solution ensures patients' ownership and control over their health data, granting explicit consent while maintaining a transparent and immutable record of data access. Blockchain technology enhances data security, privacy, and establishes a foundation for a trustworthy and patient-centric healthcare ecosystem.

5.0 Contributions to Knowledge

This paper makes significant contributions to the field of healthcare decision support by addressing the integration of wearables into Decision Support Systems (DSS) for Remote Patient Monitoring (RPM). The exploration of a closed-loop system, where wearables continuously monitor patients, and the data feeds into DSS for personalized healthcare, offers a transformative perspective. The proposal of a blockchain-based decentralized identity and consent management system addresses crucial issues of data security and patient control over health information. By providing real-world applications, such as continuous glucose monitoring and remote pulmonary rehabilitation, the paper goes beyond theoretical discussions, showcasing the practical implications of wearables in healthcare decision support. The comprehensive examination of challenges and innovative solutions, ranging from technological advancements to regulatory frameworks, contributes valuable insights to the evolving landscape. In doing so, the paper fills a knowledge gap by synthesizing insights from DSS, Clinical Decision Support Systems, and RPM through wearables, offering a holistic understanding and laying the groundwork for future research and implementation in this interdisciplinary domain.

5.1 Conclusions and future work

The conclusion of this paper consolidates the findings and insights drawn from the comprehensive exploration of integrating wearables into Decision Support Systems (DSS) for Remote Patient Monitoring (RPM). It emphasizes the transformative impact of this integration on healthcare decision support, providing a nuanced understanding of the challenges, solutions, and real-world applications. The proposed blockchain-based decentralized identity and consent management system stands out as a novel contribution, ensuring data security and patient-centric control. The paper concludes by underlining the potential for wearables to bridge the gap between clinical decision support systems and continuous patient monitoring, ushering in a paradigm shift in healthcare decision-making.

In terms of future work, the paper suggests avenues for further research and development. It highlights the need for continued exploration of emerging trends, such as the integration of artificial intelligence and machine learning in RPM through wearables. The role of patient-centric technologies and their impact on healthcare delivery is identified as a critical area for future investigation. Additionally, the paper encourages ongoing research into the broader implications of wearables in decision support, considering diverse healthcare contexts and patient populations. The proposed blockchain solution opens the door for further exploration of decentralized technologies in healthcare data management. Overall, the paper sets the stage for a dynamic and evolving field, calling for continued inquiry and innovation at the intersection of wearables, DSS, and healthcare decision support.

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