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A comprehensive and personalized approach is a critical area for developing remote cardiac rehabilitation programs

Development of remote cardiac rehabilitation

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Abstract

In the evolving landscape of cardiac rehabilitation (CR), adopting digital technologies, including synchronous/real-time digital interventions and smart applications, has emerged as a transformative approach. These technologies offer real-time health data access, continuous vital sign monitoring, and personalized educational enhanced patient self-management and engagement. Despite their potential benefits, challenges and limitations exist, necessitating careful consideration.

Synchronous/real-time digital CR involves remote, two-way audiovisual communication, addressing issues of accessibility and promoting home-based interventions. Smart applications extend beyond traditional healthcare, providing real-time health data and fostering patient empowerment. Wearable devices and mobile apps enable continuous monitoring, tracking of rehabilitation outcomes, and facilitate lifestyle modifications crucial for cardiac health maintenance. As digital CR progresses, ensuring patient access, equitable implementation, and addressing the digital divide becomes paramount.

Artificial Intelligence (AI) holds promise in the early detection of cardiac events and tailoring patient-specific CR programs. However, challenges such as digital literacy, data privacy, and security must be addressed to ensure inclusive implementation. Moreover, the shift toward digital CR raises concerns about cost, safety, and potential depersonalization of therapeutic relationships.

The transformative shift towards technologically enabled CR necessitates further research, focusing not only on technological advancements but also on customization to meet diverse patient needs. Overcoming challenges related to cost, safety, data security, and potential depersonalization is crucial for the widespread adoption of digital CR. Future studies should explore integrating moral values into digital therapeutic relationships and ensure that digital CR is accessible, equitable, and seamlessly integrated into routine cardiac care. Theoretical frameworks that accommodate the dynamic quality of real-time monitoring and feedback feature of digital CR interventions should be considered to guide intervention development.

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Core Tip: Digital technologies have revolutionized cardiac rehabilitation (CR), offering flexible and novel approaches to care. The integration of digital health technologies and artificial intelligence (AI) in remote CR is transforming traditional paradigms, providing real-time access to health data, and enhancing patient self-management. Mobile and digital CR models, including synchronous/real-time digital interventions, are addressing accessibility barriers, and promoting equity in healthcare delivery. Despite the potential benefits, challenges such as the digital divide, cost, safety, and data security must be addressed. Future research should prioritize accessibility, equity, and the seamless integration of digital CR into routine cardiac care.

INTRODUCTION

Cardiac rehabilitation (CR) is a comprehensive program that includes risk factor management, exercise training, and optimization of psychosocial health [1,2]. It is recommended by guidelines for individuals with cardiovascular disease (CVD) [3]. Numerous studies have demonstrated that participation in CR programs following a cardiac event, such as myocardial infarction or percutaneous coronary intervention, is associated with improved health outcomes and reduced mortality rates [4,5]. Despite its well-established benefits, CR remains underutilized, and there exist significant differences in referral, admission, and completion rates [6]. With the increasing body of literature on the topic, there is a growing interest in exploring novel delivery models for

CR, particularly digital and remote approaches (Figure 1). These innovative models have the potential to enhance participation in CR programs, ultimately leading to better health outcomes for individuals with CVD [7]. Remote delivery of CR has received endorsement from international sources, including the European Association of Preventive Cardiology (EAPC) [8]. The EAPC has emphasized the importance of maintaining the delivery of core components of CR through tele-rehabilitation interventions during the COVID-19 pandemic. However, concerns have been raised regarding equity in the use of technology to ensure access to equitable access to outpatient care.

Research findings indicate that alternative delivery models for CR are not only safe but also yield similar effect as standard center-based CR programs [9-11]. However, significant questions remain unanswered regarding which specific remote CR models offer the most substantial benefits for individuals. In this editorial, we aim to provide an overview of various remote CR models and identify key research questions that demand attention. We propose strategies for addressing these questions, which can serve as a valuable solution for scientists, researchers, and clinicians in the field. Two central research focuses emerge as crucial: first, the development of personalized remote CR programs, and second, the implementation of comprehensive methodologies to ensure the delivery of core CR components. Establishing these essential priorities is vital to ensure the provision of high-quality remote CR programs and can serve as a basis for future investigations.

Adopting a comprehensive and personalized approach is crucial for enhancing remote CR programs. This includes addressing issues related to equity in technology access, ensuring that all individuals who could benefit from CR have equal opportunities to participate [12]. Additionally, these programs should prioritize individualized care, tailoring interventions to each patient's specific needs and preferences in both short and longer term [13]. Embracing innovative methods and technology, such as virtual, remote, or mobile CR, can enable the delivery of comprehensive and personalized care to a broader population [14], ultimately improving access and health outcomes for individuals with cardiovascular conditions [15].

SYNCHRONOUS/REAL-TIME DIGITAL CR

Synchronous/real-time digital CR represents a contemporary alternative mode of CR delivery defined by real-time, two-way, remote audiovisual communication between patients and CR staff [16]. This approach primarily relies on real-time communication *via* videoconferencing platforms and remote monitoring of vital signs, such as electrocardiography, blood pressure, and heart rate, to facilitate safe and comprehensive home-based digital CR interventions [17]. Data from recent literature support the feasibility of synchronous/real-time digital CR interventions in enhancing the overall cardiac profile *via* improvements in cardiorespiratory fitness, physical activity levels and quality of life [18].·Despite the initial investment required for digital infrastructure, the cost-effectiveness of digital CR is highly advocated [19]. Furthermore, several barriers to CR enrolment and attendance such as transportation costs, lack of free time and remote residence locations, can be effectively addressed through the implementation of synchronous/real-time digital CR interventions [20]. Additionally, incorporating digitally delivered CR interventions could serve as the sole alternative solution for the continuation of CR during pandemic circumstances in the foreseeing future [21]. Though, numerous logistical, ethical, and clinical issues arise with digital CR, primarily concerning the risk of online patients' personal data leakage, insufficient internet access and digital literacy. It is essential to prioritize underrepresented racial and ethnic groups, women and older patients for integration into digital synchronous CR [22]. Bearing in mind that the acceptance of digitally delivered CR services and interventions is generally high [23], there is a strong need to further investigate and incorporate synchronous digital CR into the routine of cardiac patients' secondary prevention routine.

SMART APPLICATIONS FOR CR

In the evolving landscape of remote CR, the transition toward mobile health technology interventions represents a transformative approach to providing more personalized and accessible cardiac care. These technologies extend beyond the

traditional healthcare setting, providing real-time access to health data and fostering patient empowerment in their care management. Wearable devices and mobile applications enable continuous monitoring of vital signs and physical activities, contributing directly to the enhancement of patient self-management [24,25]. This approach is particularly crucial in remote settings [25], where traditional healthcare resources are less accessible, emphasizing the need for patient-centered care that adapts to their lifestyle and environment. Mobile platforms not only facilitate the tracking of rehabilitation outcomes but also play a critical role in lifestyle modifications essential for cardiac health maintenance [26,27]. Additionally, the provision of customized educational content and reminders through these platforms ensures sustained patient engagement and informed participation in their rehabilitation journey [28]. The transition to mobile CR represents a significant move towards redefining patient care in cardiac rehabilitation, focusing on technology's role in enabling a more dynamic, responsive, and patient-tailored approach.

The integration of digital technologies in CR has sparked discussion about selecting appropriate measures for outcome evaluation, as traditional methods fall short in capturing the dynamic and real-time nature of digitalized interventions. Unlike the static measures from center-based CR trials, digital platforms offer granularity, real-time, and precision through automated, real-time tracking and analysis using sensors and monitors for heart rate, blood pressure and movement [18]. This is crucial as increased digital technology-based theories guiding interventional studies highlighted the dynamic qualities and emphasized the need to unpack the use of technology at home to explain the causal-effect relationship [29].

The formality of the digital CR intervention is diverse and changing rapidly, such as virtual reality, gamification, robot assisted, Chatbot (AI-powered). When researchers use digital technology to deliver CR, the focus is often on evaluating a specific technology such as a wearable device, certain virtual reality scenario, or mobile app, within short duration. The safety and ethical issues should be considered before recommending them as a new standard of care, such as discomfort (e.g., dizziness) from virtual reality and

depersonalization when over-relying on technology. Evaluating user experiences in home settings through qualitative research is crucial to ensure intervention fidelity and guide future developments.

Future opportunities for digital innovation in cardiac rehabilitation

Artificial intelligence (AI) applies to the use of Information and Communication Technologies (ICTs) for data-driven policy decision. AI has been broadly studied in various fields such as medicine [30] and economics [31] and is currently embedded in the CR implementation procedures. By engaging AI technology *via* wearable sensors (worn as wristbands or embedded in smartwatches), early detection of cardiac events is promoted, thereby enhancing the safety of home-based CR interventions, and improving clinician decision-making [32]. Additionally, AI tools offer real-time feedback and support to patients, which could contribute to the improvement of CR adherence, increase of patients' engagement and the proliferation of their overall cardiac profile [18,28]. The potential of the AI tools to analyze thoroughly the large amounts of data collected by ICT devices enables the provision of patient-tailored CR programs and serves as a cornerstone for improving health outcomes and quality of life. However, the incorporation of digital technology into the CR procedures raises several challenges to be addressed. Innovative technologies such AI might require digital literacy [29]. Consequently, those patients with limited digital literacy may be denied access to AI–based CR; thus, leading to health inequality. Furthermore, considering the importance of data privacy and security, measures should be taken to prevent the unethical use of patients' data and ensure transparency, fairness, and accountability in algorithmically automated decisions. AI can act as an alternative key component potential enough to improve the efficiency and effectiveness of home-based CR interventions [32]. However, further research is needed to maximize their comprehensive and optimal implementation.

Challenges and limitations

Digital technologies in CR offer a transformative shift from traditional supervised programs to proactive, remotely supported self-care approaches, enhancing accessibility

and sustainability. However, this rapid technological advancement risks deepening the digital divide, particularly impacting those with lower socio-economic and educational backgrounds, women, people with disabilities, and those with sensory or motor impairments [33]. Future research should focus not just on technological advancements but also on customizing these interventions to meet the diverse needs and preferences of these subgroups (Table 1). It is crucial to view technology to overcome barriers to CR participation, rather than as the central focus.

Moreover, the implementation of digital technologies in CR brings forth concerns about cost and safety [34]. The expenses associated with acquiring and maintaining advanced digital health tools can be substantial, potentially limiting their widespread adoption, especially in resource-constrained settings [35]. Additionally, ensuring safety while using these technologies remotely poses a significant challenge. This includes managing the risk of incorrect usage of equipment, ensuring accurate data transmission, and providing immediate assistance in case of adverse events during unsupervised exercise sessions [18].

Equally important is the concern over data security in digital CR [36]. As patient health information and sensitive data are transmitted and stored digitally, there is a heightened risk of data breaches and unauthorized access [37]. Ensuring the confidentiality, integrity, and availability of patient data is paramount, requiring robust cybersecurity measures and adherence to data protection regulations. This aspect is crucial to maintaining patient trust and the credibility of digital CR programs.

Furthermore, the scope of technology in CR could be broadened to include interventions aimed at preventing CVDs. This may involve managing risk factors in high-risk groups or individuals with metabolic syndrome [38]. Additionally, there is potential for extending CR to patients with co-morbid conditions, such as cancer, who may require cardio-oncology interventions. While CR is traditionally recognized for secondary prevention [39], expanding its application to primary or palliative care settings requires more evidence.
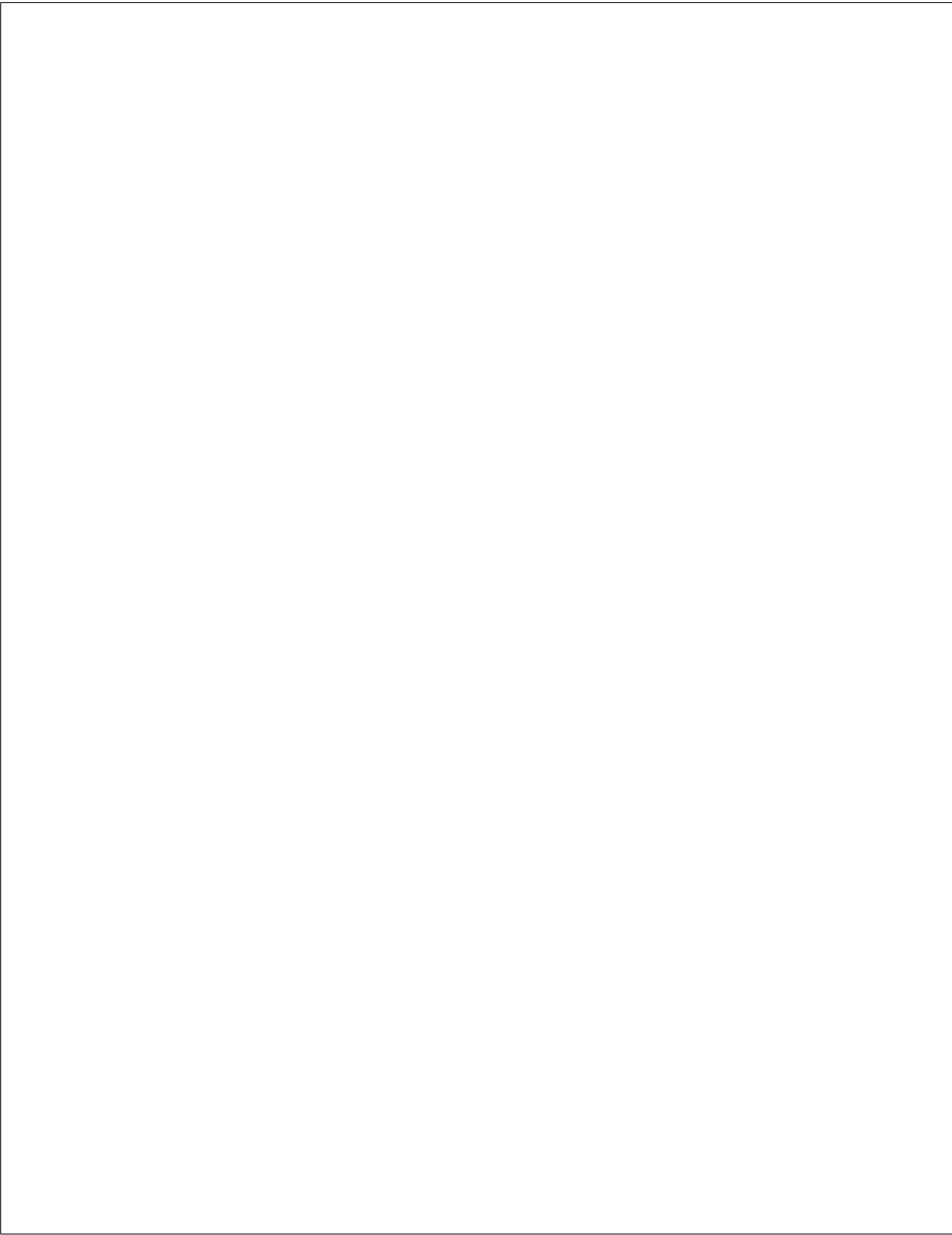
While the technologically enabled CR can also facilitate culturally sensitive communication and reduce stigma in mental health assessments and psychological interventions. However, this raises concerns about depersonalization, where authentic care and interpersonal connection in therapeutic relationships might be overshadowed by interactions with technology [40,41]. Future studies should explore ways to integrate moral values such as compassion and caring into digital therapeutic relationships, preserving the human element in healthcare [42].

CONCLUSION

CR has evolved significantly with the advent of digital technologies, offering novel and flexible approaches to delivering care. The integration of digital health technologies and AI in remote CR has transformed the traditional paradigms of cardiac care. These technologies provide real-time health data access, enable continuous monitoring of vital signs and physical activities, and offer personalized educational content, thereby enhancing patient self-management and engagement. The shift towards mobile and digital CR models, including synchronous/real-time digital interventions, addresses barriers such as physical access to care and promotes equity in healthcare delivery. However, adopting these technologies also presents challenges, including the need for digital literacy among patients and concerns regarding data privacy and security. Future research should ensure that digital CR is accessible, equitable, and effectively integrated into routine cardiac care (Table 1). This entails developing personalized remote CR programs and implementing comprehensive methodologies to deliver core CR components.

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