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Exercise-Based Cardiac Rehabilitation for the 21st Century

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Abstract Exercise-based cardiac rehabilitation (CR) is efficacious in reducing mortality and hospital admissions; however it remains inaccessible to large proportions of the patient population. Removal of attendance barriers for hospital or centre-based CR has seen the promotion of home-based CR. Delivery of safe and appropriately prescribed exercise in the home was first documented 25 years ago, with the utilisation of fixed land-line telecommunications to monitor ECG. The advent of miniature ECG sensors, in conjunction with smartphones, now enables CR to be delivered with greater flexibility with regard to location, time and format, while retaining the capacity for real-time patient monitoring. A range of new systems allow other signals including speed, location, pulse oximetry, and respiration to be monitored and these may have application in CR. There is compelling evidence that telemonitored-based CR is an effective alternative to traditional CR practice. The long-standing barrier of access to centre-based CR, combined with new delivery platforms, raises the question of when telemonitored-based CR could replace conventional approaches as the standard practice.

Keywords Cardiac rehabilitation · Exercise · Remote- and real-time monitoring

Introduction

This paper reviews research and development work that could enable more flexible, convenient and (at least for specific groups) potentially more effective and contemporary forms of cardiac rehabilitation. The need for new approaches is underlined by both the shortcomings of traditional programs, reviewed below, and the continuing burden of coronary heart disease, which remains the leading cause of death in the OECD, accounting for 117.5 (males) and 60.4 (females) deaths per 100,000 people in 2009 [1].

The World Health Organisation has defined cardiac rehabilitation (CR) as the "coordinated sum of interventions required to ensure the best physical, psychological and social conditions so that patients with CVD may, by their own efforts, preserve or resume optimal functioning in society and, through improved health behaviours, slow or reverse progression of disease" [2]. Analysis of prospective data has shown that attendance at CR substantially improves 5 year survival rates [3]. Cardiac rehabilitation results in fewer cardiovascular related events, fewer readmissions to hospital and shorter length of stay [4–7].

International clinical guidelines consistently identify exercise as a central component of CR [8–10, 22], with its efficacy in reducing mortality and hospital admissions highlighted in a Cochrane review of 47 studies and over 10,000 patients [11•].

CR is also cost-effective. The UK Health Department, for example, estimates that the secondary prevention costs for each life year gained are £1957 for CR, £3398 for angiotensin-converting enzyme inhibitors, £4601 for statins, £3239 for coronary artery bypass grafting, and between £3845 and £5889 for angioplasty [12].

Limitations of Conventional Programs

Despite compelling evidence for the benefits of CR, in many countries there are regions and groups with little or no access to structured programs, and programs are consistently underutilized even where they are available [3, 12–16].

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Reported barriers to CR include geographical limitations, lack of adequate transport, low referral rates, failure of patients to attend despite referral, the absence of a structured CR program and coordinator and factors related to age [3, 15–19, 47]. Rural populations have lower rates of participation in CR, though one report indicates that it is transport rather than rural living per se which is a key determinant [20]. Various indigenous and minority groups may also face particular barriers to their involvement in CR, with poorer recording of clinical data and lower referral rates as reported factors [21, 22, 23•] Valencia, Savage et al. 2011.

This voluminous literature outlining such obstacles has recently been reviewed, with over a thousand reports identified and 34 unique studies from eight countries given specific attention. The reviewers note the "vast amount of qualitative studies" and urge that "future research would best be directed at investigating strategies to overcome these barriers" [24•].

Alternative Approaches to Standard CR

Home-based CR has achieved growing acceptance as being comparable in terms of clinical outcomes to centre-based programs [25], exemplified in a recent UK randomised controlled trial (RCT) involving 525 patients that showed similar improvements across a range of measures [26]. One US study even reported more sustained benefits for home-based rehabilitation, and also estimated the cost to be less than one-fifth of hospital-based programs [27]. However, there are challenges for home-based rehabilitation, including the appropriate monitoring of exercise and ensuring patient safety. While CR is in general very safe, with one case of ventricular fibrillation and one myocardial infarction every 111,966 and 294,118 patient-hours, respectively [28], there are still benefits for ECG monitoring in the early stages of rehabilitation and for higher risk patients [29]. In general, forms of home-based CR that incorporate physiological monitoring and some level of patient support and interaction would seem to be particularly important – program characteristics that require the use of appropriate communications technology.

Early steps towards monitored home-based CR took the form of trans-telephonic transmission of exercise ECG, and was first trialed more than 25 years ago [30]. However, despite positive outcomes [31–35] the only commercially available system (Scottcare ®) restricted users to a landline and thus to a fixed indoor location.

Mobile Devices for Flexible CR Programs

The twenty first century has seen a rapid expansion of the cellular (mobile) phone network with more cellular subscriptions than people in the developed world (128 %), and nearly full coverage (89 %) in the developing nations. More specifically, 75 % of developed country inhabitants have mobile broadband access, as do 20 % of people living in developing countries [36]. This uptake of cellular phones with internet access has removed the barrier of technology being tied to a fixed land-line. A recent review has outlined a wide array of sensors, recording and transmission systems, and clinical applications for mobile and wearable devices to support rehabilitation [37]. Nevertheless, there remains a paucity of published research applying such technology to real-time monitoring in CR.

A Polish group [38] has undertaken studies that include large RCT [39•] of heart failure patients who underwent 8 weeks of either standard CR or home-based tele-monitored walking-based CR. Patients in the latter group wore a portable ECG recorder (EHO, ProPlus, Poland) that was used to transmit pre-exercise ECG (three-lead), post-exercise ECG on completion of exercise if uneventful, and ECG at other times as needed. No real-time ECG monitoring was undertaken during the exercise. Patients in the home-based tele-monitored group showed significant improvements in health-related measures including the 6 min walk test (6MWT) distance (418 increasing to 462 m on average), quality of life (the SF-36; 70.5 increasing to 79.3), and peak oxygen consumption (17.8 increasing to 19.7 $ml \cdot kg^{-1} \cdot min^{-1}$).

These improvements were not significantly different from those seen in the standard CR arm of the study. A subsequent analysis of 75 patients from this study analysed the frequency and type of ECG irregularities detected. These comprised mostly singular ventricular ectopic beats, which were ten times more common than the next most frequent (supraventricular premature beats), paroxysmal atrial fibrillationin one case (at rest, pre-exercise) and supraventricular tachycardia were noted as isolated incidents. This group has advocated a model of home-based tele-monitored CR for heart failure patients on the basis of these findings and other reports [38].

The current authors have also published a study that investigated the feasibility of the provision of continuous streaming of a single lead ECG, tri-axial accelerometry and GPS data.

The ECG and accelerometry device (Alive Technologies, Australia) streamed data at 300 Hz and 75 Hz respectively, via a mobile phone, to a monitoring centre where it was reviewed in real-time by an exercise physiologist, with phone contact before, after and, if needed during outdoor walking sessions [40•]. Patients improved their 6 min walk (6MWT) distances significantly from pre-intervention to post-intervention (524 increasing to 637 m on average) and reported significantly lower levels of cardiac depression and higher physical health-related quality of life scores. One aspect of this study is that it was undertaken in an exclusively remote manner. Patient recruitment, instruction in equipment use, 6MWT, and all communication was undertaken at a distance. This simulates closely the conditions of real clinical interventions, particularly for rural and other isolated populations. Subsequently this system has been implemented in a trial of patients with a range of chronic disease states, located in rural or remote areas of Australia, who were referred by their doctor for exercise rehabilitation [41].

Monitoring Additional Physiological and Motion Signals

While ECG is of clear relevance as a monitoring tool in CR, it is clear that other signals could be monitored in a similar fashion and may augment information about the patient's status and progress. This includes information on location and walking speed via GPS [42], which can provide functional performance data as well as enabling appropriate selection (and progression) of routes. Additional physiological signals can be obtained in addition to ECG. For example, Tang and colleagues report on the feasibility and validity of Bluetooth-enabled pulse oximetry as a monitoring method for exercise in pulmonary rehabilitation patients [43]. They report high levels of agreement between data obtained remotely and those ascertained directly by a therapist.

Their study included a proprietary tele-rehabilitation system allowing video-conferencing and remote consultation (eHAB), and was conducted indoors using a local Wi-Fi connection rather than live transmission of signals over the mobile network (data transmission rates were comparable to those used in the 3G/HSDPA network available virtually throughout Australia). The ability to detect exercise-related peripheral oxygen de-saturation has the potential to provide more broadly-based monitoring of the patient's status and response to exercise.

Other research teams, principally those from medical and rehabilitation engineering and information technology, have reported on the potential for new forms of sensors and systems that may be well suited to the requirements of CR. For example, Di Rienzo and colleagues have developed a textile-based wearable system that permits ECG to be recorded. The electrodes are knitted into the fabric and are kept in contact purely through compression against the skin. The garment also incorporates a textile-based plethysmograph for the measurement of respiratory frequency. The authors report high levels of agreement between the ECG findings using this system and those obtained by traditional ECG [44].

Many patients undergoing CR may have specific co-morbid conditions, such as neurological movement and balance disorders. The application of wearable sensors has the potential to enable simultaneous monitoring for such conditions. One example is a system of wearable inertial motion units (IMUs) capable of detecting falls and motion, undertaking standardized clinical balance and mobility tests, as well as providing feedback for motor learning and rehabilitation [45]. In addition, even more broadly-based monitoring systems are under development that can guide and monitor specific exercises and activities as well as being used for patient assessment. An example of this is the CAROLS system devised for CR (as reported by Lu and colleagues [46]), which as well as incorporating sensors for ECG, respiration, and motion, includes software to guide game-based forms of exercise including dance, Tai-chi, and lower extremity exercises [46].

Many other developments of remote monitoring technology for use in CR are in progress. For example a three-country trial of remotely monitored exercise (using a Guided Exercise System) compared with usual care is in progress and has been registered with the UK Clinical Trial Network (UKCRN 2013 [47]). It is anticipated that more trials will be undertaken in the near future, while at the same time there will be multiple reports of novel sensor and transmission systems capable of supporting tele-monitored CR in the development and early clinical testing stages.

Conclusions and Future Directions

CR has become an established and standard form of care for the recovering cardiac patient; however, it was developed at a time when hospital or centre-based rehabilitation was the only feasible model. This has proven of great benefit to millions of patients over several decades, but the plethora of studies indicating how much this model limits access has led to ever stronger calls to develop new approaches.

The evaluation of home-based CR has established its efficacy, safety and generated initial evidence that it can be cost-effective. The opportunity that is now enabled with the advent of portable and wearable sensor technology is to provide CR in highly customized ways, that are flexible in format, timing and location, but without sacrificing appropriate monitoring for ensuring safety, guiding exercise, and providing motivation and support. Along with this opportunity there remains a need for appropriate research. In common with Neubeck and colleagues [24•], we urge a shift from the increasingly redundant reports of barriers to participation in CR and a more specific focus on solutions to those barriers.

Finally, we also raise an ethical question regarding the future of CR. With such strong evidence for the efficacy of exercise-based CR, and such clear indications that conventional centre-based CR models in effect deny these benefits to many clinically eligible patients, what threshold of research evidence must be reached in order for policy-makers to adopt tele-monitored CR as the new standard, rather than as a technological novelty?

Compliance with Ethics Guidelines

Conflict of Interest Charles Worringham has received grant support for his institution from the Australian Research Council Linkage Grant.
Ian B. Stewart declares he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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