Activity and Heart Rate-based Measures for Outpatient Cardiac Rehabilitation

N. P. Bidargaddi, A. Sarela
Australian E-Health Research Centre, ICT Centre, Commonwealth Scientific and Industrial Research Organization, Brisbane, Queensland, Australia

Summary

Objectives: Derive activity and heart rate (HR) monitor-based clinically relevant measures for outpatient cardiac rehabilitation (CR).
Methods: We are currently collecting activity/ECG data from patients undergoing cardiac rehabilitation over duration of six weeks. From these data sets, we a) derive various measures which can be used in assessing home-based CR patients remotely and b) investigate the usefulness of continuous ambulatory HR and heart rate variability (HRV) for various core components of CR.
Results: The information provided by these measures is interpreted according to the CR guidelines framework by American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR), thus showing how these tools can be used in assessing the progress of patients' condition. The usefulness and significance of these measures from a health care professional perspective is also presented by evaluating them against the existing hospital-based measures through examples.
Conclusions: Hospital-based CR programs, despite their clinical benefits are severely under-utilized and resource-demanding. Ambulatory monitoring technologies, which provide a means for continuous physiological monitoring of patients at home compared to hospital-based tools, can enable home-based CR. The clinically relevant measures derived from these tools not only reflect patients´ condition in a similar way as conventional tools but also show the continuous status of functional capacity (FC).

Keywords

Cardiac rehabilitation, ambulatory monitoring, physiological monitoring, heart rate, physical activity

Methods Inf Med 2008; 47: 208–216

doi:10.3414/ME9112

1. Introduction

Health care systems worldwide are facing an increasing challenge to monitor and timely intervene in preventing functional capacity (FC) loss of the aging population with chronic diseases. Cardiovascular disease is one of the leading chronic diseases among the aging population, burdening the global health and economy [1]. Cardiac rehabilitation (CR) programs at hospitals incorporating core components of nutritional counselling, aggressive risk factor management (lipids, blood pressure, weight, diabetes, and smoking), psychosocial interventions, physical activity and exercise training, baseline patient assessment, lifestyle modification and education programmes have been proved to be effective in improving the FC or health-related quality of life conditions of patients with cardiovascular disorders (CVD) [2, 3].

Patient's FC is determined by measuring the ability to carry out activities of daily living (ADL) independently. Various tools such as 6-minute walk test, sit to stand test, time to up and go test, etc. provide a quantitative measurement of FC. The objective of supervised exercise program component in CR is to improve FC. However, with the increasing ageing population and limited hospital resources, it is not sustainable to provide such programs in hospitals anymore. Cardiac rehabilitation programs are also severely under-utilized (only 18.7% of eligible patients participate in USA [4]). The main reasons are referral barriers (with only around 30% of eligible patients referred), patient barriers (negative perception of gym-based exercise group, preference for self-exercise and cost), lack of support from the system (resource shortages, competing demands) and lack of community support (not enough positive media messaging). In short, CR programs have to be shifted from hospital-centric mode to patient-centric mode, i.e., monitoring, interventions and assessment of the patients from their own homes. Home-based CR programs can thus serve as an alternative model for patients who do not prefer hospital-based model [5].

Telemonitoring technologies have been proposed as a viable solution to reduce hospital overloads [7]. Using such technologies, relevant data can be accessed remotely by health care professionals through the internet and mobile devices (illustrated in Fig. 1). This continuous information derived from patients' living environment is more informative than the snapshot information derived from the existing hospital-based measures. The existing measures to assess FC are standard tests carried out at various stages of the rehabilitation. Whereas the ambulatory-derived clinical measures from a free-living environment provide continuous and more physiologically representative information compared to the hospital-based measures. Through these measures the health care professionals can monitor the progress of the patients' condition remotely and intervene as required. The monitoring technologies should provide information which can address all core components of CR. The scope of this paper has been restricted to encompass only those components of CR which can be monitored using ambulatory activity and heart rate (HR) monitors.

Over the recent years, ambulatory accelerometers or HR monitors have been widely studied telemonitoring technologies for patient monitoring, due to their low cost and unobtrusive nature. Body accelerations can be measured by attaching accelerometers on one or more body segments (e.g., trunk, thigh, and shank). The body postures (i.e., standing, sitting, lying, etc.) can be recognized by analyzing these acceleration signals [8, 9]. Similarly, ambulatory HR monitors/ECG recorders worn on the chest either through a strap or ECG leads have been useful to obtain continuous cardiac functionality.

Nonetheless, the information recorded from either of these ambulatory technologies needs to be translated into clinically relevant information, i.e., measures which can show the patients' condition continuously. Previous studies in the ambulatory monitoring area have shown the usefulness of accelerometry technologies in identifying activities of daily living, posture transitions, metabolic expenditure, etc. However, they do not provide much insight on how the health care professionals should use this information in treating patients. It would be desirable to show the useful application of these measures in a cardiac rehabilitant guideline framework from a clinician perspective. For example, moderate to high intensity level energy expenditure tracked per day can be used as an indicator to assess if the patient meets the daily recommended energy target for cardiac rehabilitation (30 minutes or more of light to moderate (3.2-4.7 MET) physical activity on most days of the week). Such clinically relevant ambulatory measures to quantify FC can be derived from both the accelerometer-inferred activities and the ECG-derived features such as heart rate variability (HRV), HR distributions, etc. These measures can be used to assess patients in a home environment, thus enabling home-based CR. In this paper, we identify various measures derived from both accelerometer and ECG signals which can be used in assessing home-based cardiac rehabilitation patients remotely. The usefulness and significance of these measures from a health care professional perspective is validated by evaluating them against the existing hospital-based measures. Furthermore, to the best of our knowledge this is one of the few studies to investigate the usefulness of continuous ambulatory HR and HRV [10] for various core components of cardiac rehabilitation [2]. Previous studies in this field have used only snap short HR, mainly at the start and end of the exercise [11, 12].

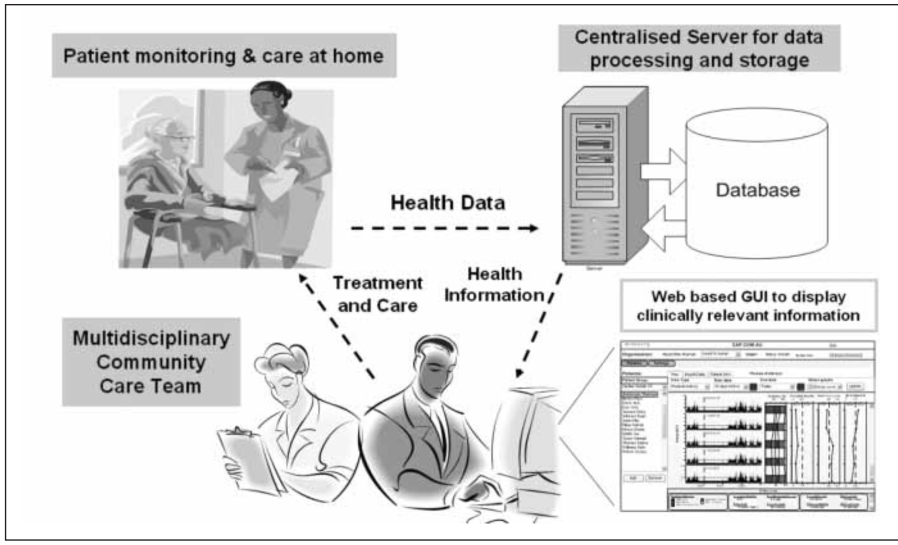

Fig. 1 Patient-centric care model envisioned through telemonitoring technologies. Details on this architecture are explained in [6].

The rest of the paper is organized as follows. In next section, we describe the cardiac rehabilitation program along with the existing measures to assess patients' FC. The clinically relevant ambulatory measures that indicate FC are presented in Section 3. The results and discussions are provided in sections 4 and 5, respectively.

2. Methods

2.1 Cardiac Rehabilitation Program

The rehabilitation program at North Lakes (QLD, Australia) is attended by patients who had surgery due to CVD (either angina (chest pain), coronary artery disease (blockages in the coronary arteries), heart attack (myocardial infarction), heart failure (reduced pump function or cardiomyopathy), coronary arterial bypass graft (CABG) and stent or angioplasty procedures). It is a second phase six-week outpatient hospital-based exercise training program designed to reduce risk of reoccurrence and improve FC. These patients attend exercise sessions twice a week at the hospital gym for duration of six weeks. In every session, patients perform six different exercises for a total duration of one hour. Typical exercises are: biking, rowing, walking on stairs, arms exercise, walking on treadmill, and working with exercise ball. The patient's condition and progress is also monitored during every exercise session by a physiotherapist. Each exercise activity lasts from three to seven minutes and the physiotherapist can vary the load setting and duration of the exercise to achieve optimum performance level for the patient. At the end of each exercise patients record their pulse rate, SPO2 (pulse oximetry), and the Borg scale (difficulty). The exercises are usually adjusted to maintain a steady Borg scale level of 11. Patients wear an accelerometer device for the entire period of rehabilitation. Due to the obtrusive nature of ECG leads patients wear them mainly during the rehabilitation session. The order and timing of the different activities during the session are manually recorded by the patient to enable identification of the activities from the raw signal. Figure 2 illustrates the three axis acceleration signals of a patient during a complete exercise session of cardiac rehabilitation. The characteristics of different activities are apparent in the collected raw signal. Ten-second sections of raw signals during high intensity and periodic activities: biking, rowing and walking along

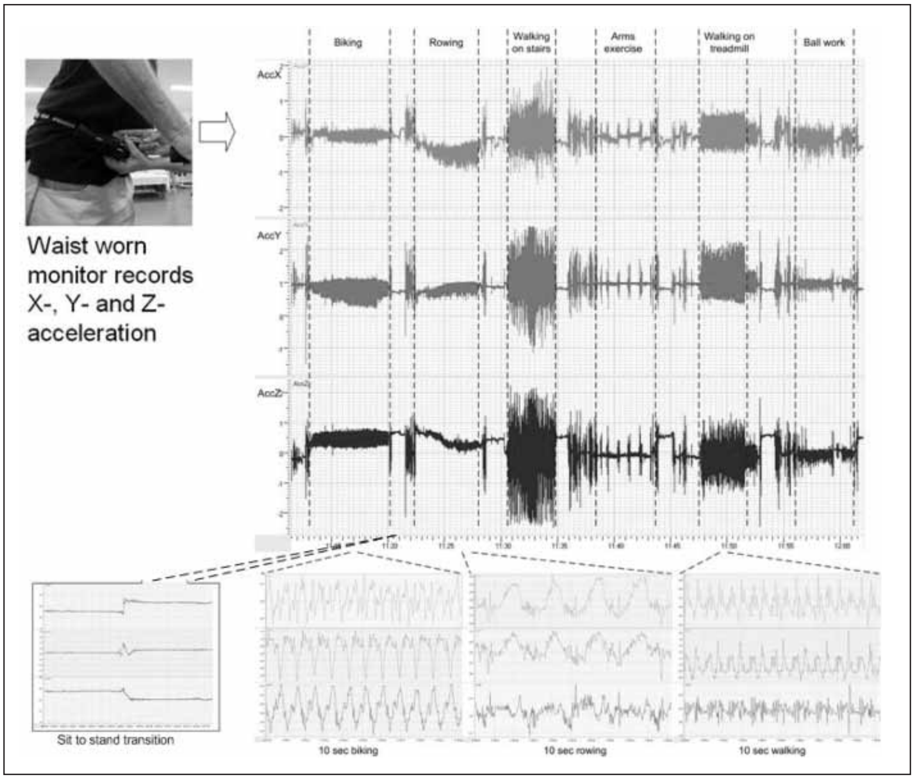

Fig. 2 Acceleration signals during a CR session for an arbitrarily chosen patient. The patient is performing six different exercise activities over an hour duration.

with a sit to stand transition are shown in details below the main graph. The activity signals show different patterns during each activity.

Currently, there are various measures used in rehabilitation to assess the progress of patients. In the rehabilitation program mentioned above the patient's condition of FC is assessed at the beginning and end of the program by using a six-minute walk test (6MWT), where the patient walks for six minutes and the travelled distance is measured along with their weight. A vast majority of the hospital-based rehabilitation measures usually quantify the progress using the information collected before and after rehabilitation program. They fail to take into account the role of intermediate information which represents the patient's activity style in between the sessions at their home or patients adherence to the CR guidelines such as the recommended 30-minute daily exercise, mentioned earlier. More realistic information on patient's condition can be obtained if the measures used to assess rehabilitation progress are derived using continuous information. In the next section, we discuss some of these continuous measures.

2.2 Ambulatory Rehabilitation Progress Measures

As discussed earlier, changes in the FC of a cardiac patient undergoing rehabilitation is widely assessed using both quantitative diagnostic tools such as 6MWT, time to up and go test, etc., or subjective tests such as self-reported questionnaires, etc. Studies have shown that the patients rate themselves on a higher functional level in the self-reported questionnaires than is observed objectively in the performance-based tests, thus undermining the importance of the questionnaires as a tool in assessing progress [13]. The quantitative functional tools are consistent and thus, overcome the inherent drawback of self-reporting questionnaires. Nonetheless, we can obtain continuous status of FC by deriving measures from ambulatory accelerometer and ECG signals. Each of these ambulatory tools ultimately provides an estimation of the FC which correlates with the variation in the pattern and intensities of daily living activities (such as walking, sleeping, posture transitions, exercise intensities, etc.) and autonomic balance (sympathetic versus parasympathetic).

Hence, we have identified following measures derived from ambulatory accelerometer and ECG signals which can act as continuous cardiac rehabilitation progress indicators.

2.2.1 Metabolic Expenditure

One of the main objectives of cardiac rehabilitation programs is to increase levels of physical activity of patients. An usually recommended level of physical activities to prevent adverse events among the patients is a minimum of 30-60 minutes of moderate activity, three to four times per week, supplemented by an increase in daily lifestyle activity [14]. Studies have shown that increase in metabolic expenditure during rehab session alone may not be sufficient to satisfy these recommendations. In [15] it was shown that the amount of physical activity was generally adequate on the days of rehab, but failed to reach target levels on non-rehab days. Other similar studies encourage patients to incorporate life-style physical activity and additional exercises during non-rehab days. We have derived metabolic expenditure from the accelerometer data which showed correlation greater than 0.88 with energy expenditure observed with simultaneous VO2 reference measurements. Ambulatory monitoring of metabolic expenditure which can be derived from accelerometer signals can provide a means to assist in achieving this goal. For example, in Figure 3 which shows continuous energy expenditure over 24 hours (21st and 22nd), we can see that the patient has performed around 30-minute exercise (an early morning walk in this case) of moderate intensity on 22nd. A physiotherapist would find information like this on patients' exercise behavior useful in counselling and tracking progress of the patients.

2.2.2 Mobility

It is vital to have a good level of mobility to achieve functional independence with a good quality of life. Changes in mobility of a patient as seen through various mobility tests such as 6MWT, 12MWT, etc. have been shown to correlate with changes in patients' FC [16]. Mobility can be quantified by measuring a) total daily walking duration, b) walking speed, c) frequency of daily walking and d) walking control through gait characteristics. Each of these measures can be derived continually by analyzing acceleration signals. For each walk activity detected we can calculate fractal dimensions which demonstrate a measure of gait control [17], thus providing continuous mobility control measures. We have developed techniques to discriminate walking from other high-intensity activities in accelerometer data using wavelet decomposition [18] (Sensitivity = 89.14% and specificity = 89.97% on data sets from CR patients). We further calculate fractal dimensions for every walking activity using wavelet approach and use it as a gait characteristic measure. Rehabilitation interventions that can be designed using these measures are beneficial for improving gait and functional independence among older persons [19].

2.2.3 Postural Transitions and Balance

The ability to rise from a chair (sit-to-stand transfer task) is considered as one of the most demanding functional tasks, an important indicator of daily-life functional independence for elderly people and as a risk factor for falls [8]. For example, the rate of rise in force (dF/dT) was significantly lower in stroke fallers than in stroke non-fallers and healthy subjects [20]. Deterioration in balance function clearly starts at relatively young ages and further accelerates from at about 60 years and upwards [21]. Various measures which can represent the trends in postural transitions and balance can be derived from accelerometer signals. We proposed techniques to detect transitions (sit to stand and stand to sit) automatically from accelerometer signal vector magnitude and calculate their durations. A statistically significant difference was found in sit-to-stand transition durations in elderly geriatric rehabilitation patients compared to healthy subjects (significance of a one-tailed t-test was P = 0.002) [22]. Thus, it is possible to assess the FC by continuously keeping track of transition durations and intervene based on the trends. However, detecting transitions accurately in an unconstrained free living environment using accelerometer signals from body-worn devices is very challenging due to the similar frequency characteristics of artefacts and noisy signals caused by rapid body movements.

A viable practical option to use the transition as a FC measure would be installing the transition detector as part of a chair/bed at home.

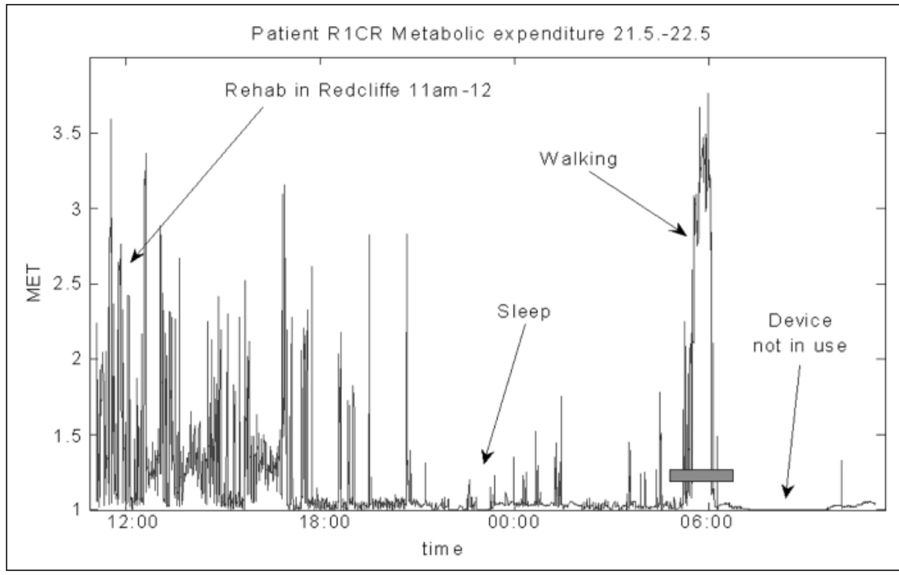

Fig. 3 Metabolic expenditure over two days for an arbitrarily chosen patient. This plot can act as an exercise behavior diagnostic tool.

2.2.4 Adverse Events

Cardiac patients have increased fear of falling due to diminished FC. The ability of accelerometers to discriminate falls from ADLs makes it suitable to detect falls occurring in elderly patients [23]. Detecting adverse events is vital to be able to attend to the patients in a timely fashion. The main problem in automatic fall detection systems based on accelerometers has been the number of false positives, which makes the practical application difficult. Usually the fall detection is proposed to be a part of an alarming system that would automatically summon help after a fall. If there are too many false alarms the system becomes a burden and is not useful. The future work should concentrate on greatly increasing the specificity of the fall detection in the real life situations. Alternatively, detecting the early signs of increased risk of fall by observing the dynamics between gait characteristics, physiological variations, environmental influences and psychosocial factors will complement the fall detection work.

2.2.5 ECG-derived Measures

Some of the clinically relevant measures which we can derive from ambulatory ECG or HR are a) HR distribution – such as resting HR or maximum HR and heart rate recovery (HRR) during exercise, b) HRV – root mean square difference of successive RR intervals (RMSSD), low and high frequency powers, etc., and c) respiratory rate. These measures are useful in assessing the patients' cardiac functionality. Ambulatory ECG-derived measures provide many useful features. For example, reduced HRV is associated with an increased risk factor for future cardiac events [12, 24]. The combination of ECG-derived measures and activity information provides complementary

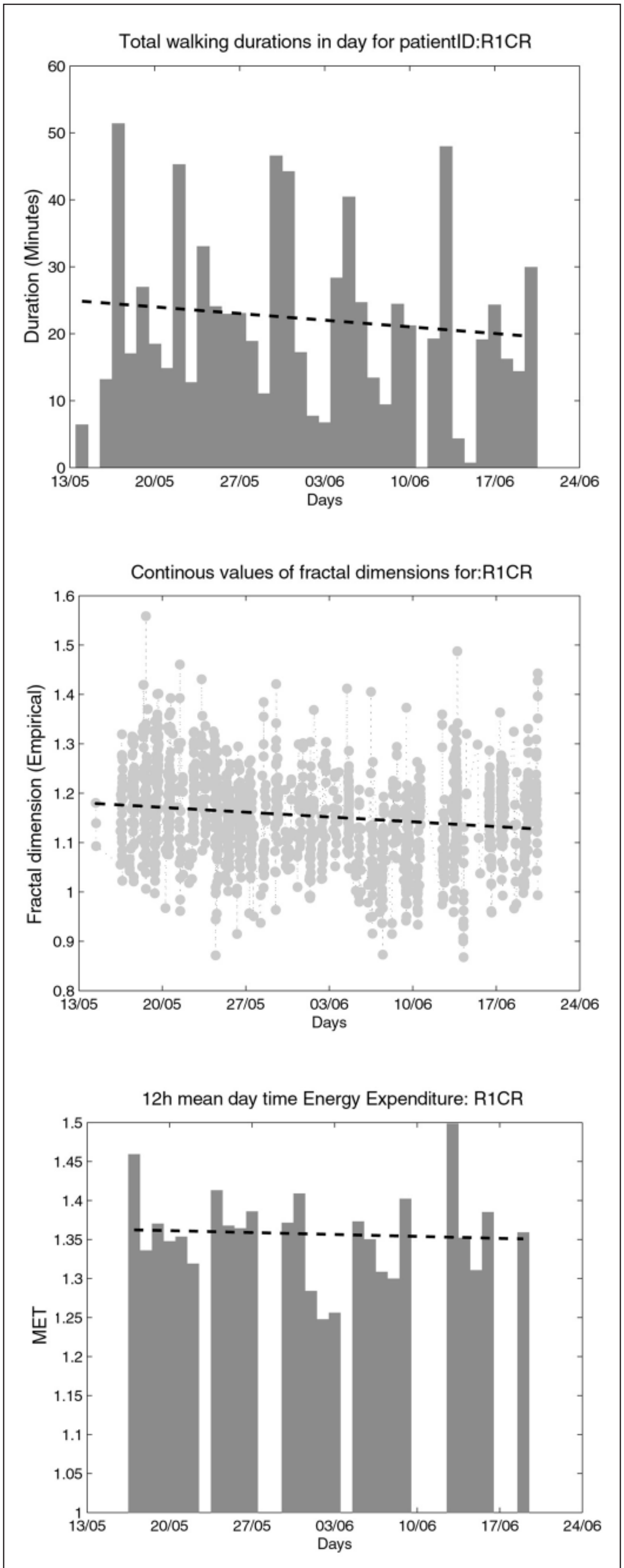

Fig. 4
Rehabilitation progress for a patient as indicated by walking durations (top), fractal dimensions (center) and energy expenditure (bottom) for the entire period. Lower values of fractal dimensions indicate improved gait characteristics.

information to follow-up clinically significant changes in patients' condition. For example, we can look at the trends in RMSSD during high-intensity activities to follow-up the patient's autonomic nervous system's parasympathetic performance or maximum HR and HRR, respectively, during and after high-intensity activities to follow-up the exercise tolerance. We can also identify the cardiac risk by tracking these HR-derived measures coupled with activity information either continuously or intermittently, through ambulatory ECG recordings. For example, RMSSD, a measure of parasympathetic response, is high during resting stage and low during exercise as sympathetic tone is dominant. Sympathetic response which leads to an increase in HR is also triggered by emotions, psycho-social factors and depression [25].

All these ambulatory measures provide clinically relevant information just like the standard measures used in hospital. The advantage is that they are collected remotely and not restricted to hospital-based test administration. Since these measures are obtained continuously, it is possible to follow a) the adherence to the guidelines, b) personalized treatment, and c) initiate timely interventions that aim to prevent loss of FC and to improve the quality of life of chronic disease patients. Interventions based on these measures are expected to reduce the patients' partial or total dependence for support in carrying out their activities of daily life (ADL). In the next section, we illustrate some of these measures obtained from an arbitrarily chosen patient.

3. Results

As part of a larger study we are currently collecting activity/ECG data from patients undergoing cardiac rehabilitation over duration of six weeks. We analyze the acceleration signals recorded with a three-axis accelerometer, which is mounted on the waist using a custom-made belt, close to the center of the mass of a person. The acceleration signals provide information on physical activities of the person. The accelerometer used here is part of a personal monitoring device: Alive Heart Monitor, marketed by Alive Technologies, Australia. It provides data for every spatial axis with sampling frequency of 75 Hz and a range of –2.7 to 2.7 g. We down-sample the acceleration signals to 25 Hz which is sufficient enough to contain all the frequencies for human activities. It also records ECG signals sampled at 300 Hz through a single lead. The patients wear this device continuously (except during showers, charging batteries, etc.) during the six-week cardiac rehabilitation period. They wear ECG leads only during first two days of every second week and during rehabilitation exercise sessions due to the obtrusive nature of the ECG leads. Also many patients were sensitive to the ECG electrodes. When fully charged the monitor logs continuous ECG and accelerometer data to an onboard SD memory card. The data logged on the SD memory card is downloaded twice a week by the physiotherapist when patients attend the rehab session for further analysis. The batteries were also changed at the same time.

We have derived activity information and the various significant measures described in Section 2 using acceleration data for the whole six weeks to look at trends in FC. Figure 4 shows total daily time spent in walking, gait characteristics of walking and metabolic expenditure over a period of six weeks for an arbitrarily chosen patient (ID:R1CR) participating in CR program. These plots show an overall improvement in the patient's performance. Even though the figure shows non-significant trends in total walking durations or metabolic expenditure, it provides an insight into patients' exercise (mainly walking) behavior. For instance, from this figure we can see that this patient has spent more than ten minutes walking almost every day of the week and more than 30 minutes at least once every week. Notably, the subject has gone for walks lasting more than 40 minutes on two consecutive days of third week. By looking at this information health care professionals can track if the patient has met the daily recommended level of activity for CR. For the same patient, the overall time spent in a day being active (includes activities like walking, exercise, gardening, etc.) has significantly increased as the rehabilitation progresses compared to inactive periods as shown in Figure 5. Box plot for the weekly variations of fractal dimensions for this patient which indicate gait characteristics are shown in Figure 6. There is a statistically significant change in means of fractal dimensions between weeks 2-3 and weeks 4-5, indicating an improvement in gait performance during this period (based on Analysis of Variance (ANOVA)). However, the fractal dimension means for week 1 and week 6 are not statistically different. If we use the conventional approach and assess the patients' rehab progress by looking at measures only at beginning and end of rehab, we might come to the conclusion that there is no progress and might miss the progress seen in between the rehab.

We also calculate HRV (RMSSD), respiratory rate, etc. using the ECG signals obtained during rehab session. The analysis is done using FirstBeat Pro software (Finland). The RMSSD during the exercise sessions for the same patient are shown in Figure 7. RMSSD is a measure of para-

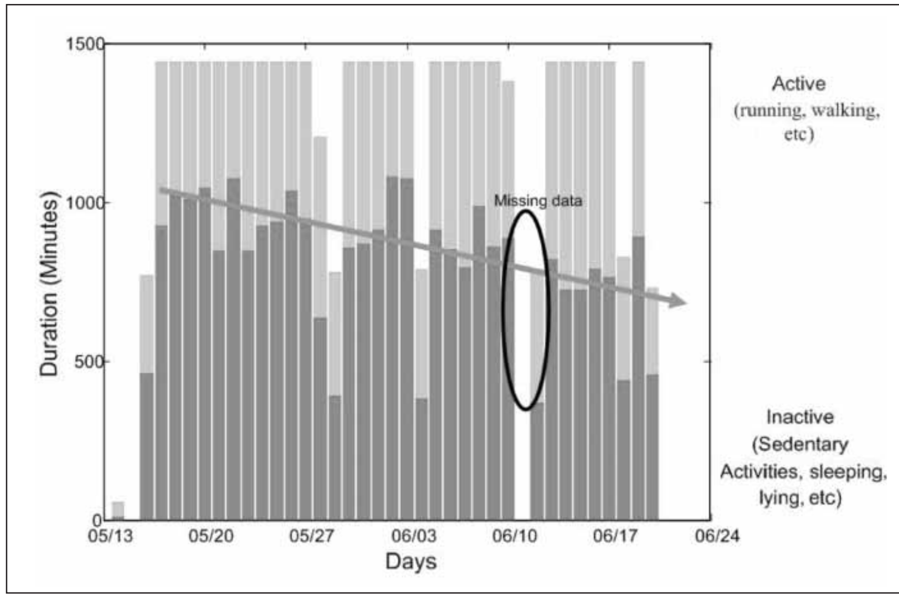

Fig. 5 Active-inactive ratio can provide an insight into changes in activity trends.

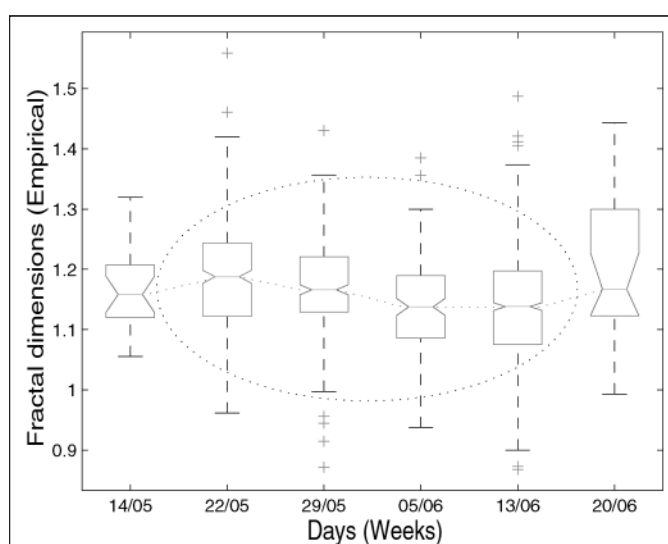

Fig. 6 Box plot of fractal dimensions for weeks 1-6 of the rehab

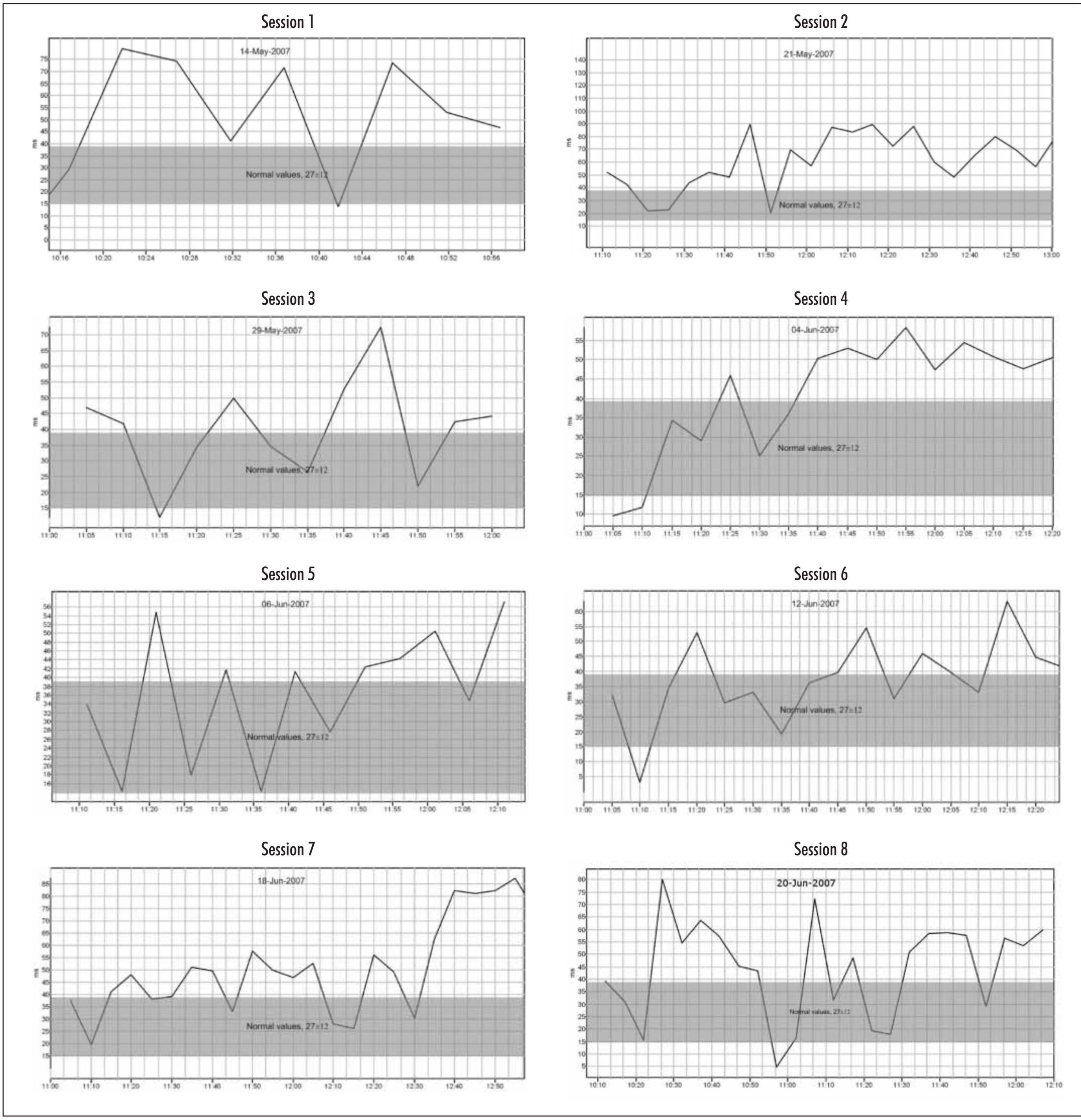

Fig. 7 RMSSD values during rehab sessions for a patient. Each figure represents one session. There were total eight sessions for this patient.

sympathetic response whose optimal values for a healthy individual are in the range of 27 ± 12 (shaded region in figures) [24, 26]. From Figure 7, we can see that the RMSSD curve during the early stages of rehab is further away from shaded region compared to the later stages. Besides showing the overall trends in RMSSD performance, this information can assist rehabilitation team to provide improved and personalized care by looking at intermittent variations in the RMSSD values. Figure 8 shows 24-hour RMSSD values for the same patient. The RMSSD values are usually higher during resting periods and predominantly low during high-intensity activities (including 1-hour rehab session at 11 a.m. and other high-intensity activities as seen in energy curve). The sympathetic response in this case is triggered due to exercise or high-intensity activity or some movements during inactive period. Here, the activity monitors assists us in identifying active and inactive periods. An autonomic imbalance can be measured if the RMSSD values were consistently low during the inactive periods, detected by activity monitor. Another interesting observation in Figure 8 is that the RMSSD values are progressively shifting towards higher values during different resting stages as the day progresses. The higher RMSSD values during night time compared to the day time might be due to good sleep at night.

Collective information provided by all these tools better reflects patients' overall FC than by individual tools. These tools will provide care providers complementary information to improve the care process.

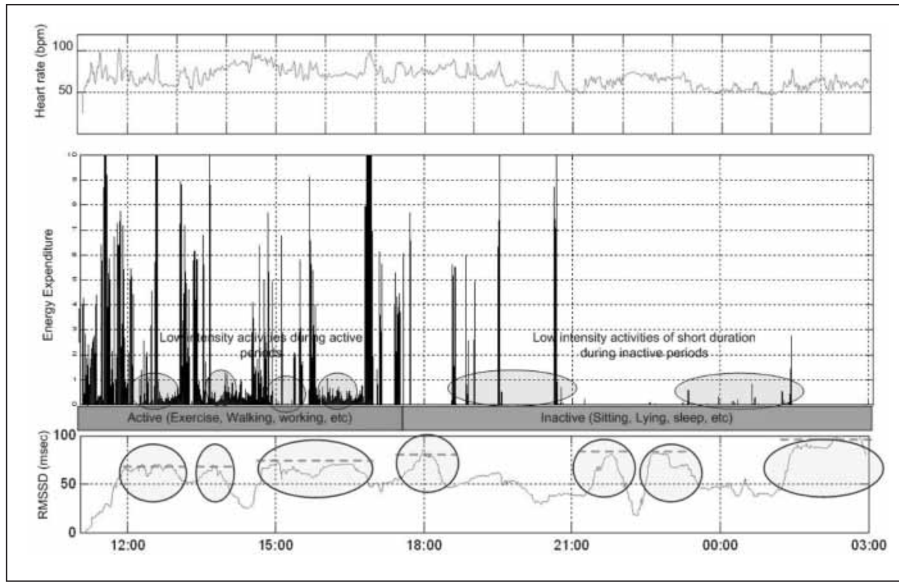

Fig. 8 Combination of RMSSD and activity information can act as an autonomic imbalance diagnostic tool.

4. Discussion

In this paper, we have described some of the useful measures that can be derived from ambulatory accelerometer and ECG data, which are useful in assessing the progress of outpatient cardiac rehabilitation. These measures can be used to monitor patient's exercise activities and physiological status in the free-living environment as well as the performance in the hospital rehabilitation sessions. Thus would enable assessments of FC that is required in the ongoing care for chronic disease patients. In addition, we can obtain continuous status of FC using these measures thus overcoming the drawback of conventional measures that are often evaluated only in the beginning and the end of the rehabilitation program. This enables timely interventions and care adjustments during the program addressing each patient's individual needs.

The described measures provide more comprehensive view on the patient's progress during the rehabilitation program compared to the traditional assessment using only the six-minute walk test. For example even if the patient doesn't seem to improve in terms of energy expenditure, her/his cardiac functionality might be improving in terms of RMSSD or HR measured during high-intensity activities. Our study indicates that by combining the movement activity information with the RMSSD or other HR-derived measure it is possible to create new clinically relevant information on the patient's FC during rehabilitation.

All the measurements performed in patient's free-living environment without professional supervision are challenging from the reliability point of view. There are several usability-related issues and problems that may lead to loss of data or otherwise corrupted measurements. The patient may choose not to use the device at all for a while, or the batteries may go empty, or the ECG may be noisy because of poor electrode contacts. These issues must be handled by careful design of the used devices and by developing the measurement algorithms to be insensitive to noisy and discontinuous data. The main reliability problem in our study was the incomplete data especially related to ECG measurement. The leads and electrodes irritated many patients and they chose not to use the measurement as often as was requested.

Currently, we are evaluating and refining these measures and developing related user interface methods to be used in practical cardiac rehabilitation programs. Our future work will be on providing clinical evidence in using these technologies to support home-based cardiac rehabilitation programs. We are planning to run a randomized controlled clinical trial to study if the technology-enabled CR, both in home or hospital environment, provides clinical outcomes or economical benefits. The secondary objective is to establish a sustainable technology-enabled home-based care model for chronic disease management.

Acknowledgment

We would like to thank the project team of North side Primary and Community Health Services, North side Health Service District, Queensland Health, Australia for their valuable contribution in collecting patient data from the clinical trial and providing the means to develop the Care Assessment Platform. We are greatly indebted to the patients who are participating in the evaluation of the tools described in this paper. Special thanks to Dr. I. Korhonen (VTT, Finland) for continued discussions and suggestions on this field which has helped us in improving our work.

References

1. Australian Institute of Health and Welfare 2002. In: Australia's health 2002. Canberra: AIHW; 2002. Available from: http://www.heartfoundation.org.au/document/NHF/World_trends.pdf.
2. Balady GJ, Williams MA, Ades PA, Bittner V, Comoss P, Foody JM, et al. Core components of cardiac rehabilitation/secondary prevention programs: 2007 update: a scientific statement from the American Heart Association Exercise, Cardiac

Rehabilitation, and Prevention Committee, the Council on Clinical Cardiology; the Councils on Cardiovascular Nursing, Epidemiology and Prevention, and Nutrition, Physical Activity, and Metabolism; and the American Association of Cardiovascular and Pulmonary Rehabilitation. Circulation 2007; 115 (20): 2675-2682.
3. Austin J, Williams R, Ross L, Moseley L, Hutchison S. Randomised controlled trial of cardiac rehabilitation in elderly patients with heart failure. Eur J Heart Fail 2005; 7 (3): 411-417. Available from: http://dx.doi.org/10.1016/j.ejheart.2004.10.004.
4. Thomas RJ. Cardiac rehabilitation/secondary prevention programs: a raft for the rapids: why have we missed the boat? Circulation 2007; 116 (15): 1644-1646. Available from: http://dx.doi.org/10.1161/CIRCULATIONAHA.107.728402.
5. Taylor RS, Watt A, Dalal HM, Evans PH, Campbell JL, Read KLQ, et al. Home-based cardiac rehabilitation versus hospital-based rehabilitation: a cost effectiveness analysis. Int J Cardiol 2007; 119 (2): 196-201. Available from: http://dx.doi.org/10.1016/j.ijcard.2006.07.218.
6. Sarela A, Bidargaddi NP, Karunanithi M. A Software Architecture and Data Model for Community-Based Healthcare Environments. In: Proc 2nd Intl Conf Pervasive Computing Technologies for Health Care (Pervasive Health 2008). Tampere, Finland; 2008. pp 1-6.
7. Par G, Jaana M, Sicotte C. Systematic review of home telemonitoring for chronic diseases: the evidence base. J Am Med Inform Assoc 2007; 14 (3): 269-277. Available from: http://dx.doi.org/10.1197/jamia.M2270.
8. Najafi B, Aminian K, Loew F, Blanc Y, Robert PA. Measurement of stand-sit and sit-stand transitions using a miniature gyroscope and its application in fall risk evaluation in the elderly. Biomedical Engineering, IEEE Transactions on. 2002; 49 (8): 843-851.
9. Karantonis DM, Narayanan MR, Mathie M, Lovell NH, Celler BG. Implementation of a real-time human movement classifier using a triaxial accelerometer for ambulatory monitoring. Information Technology in Biomedicine, IEEE Transactions on. 2006; 10 (1): 156-167.
10. Pinna GD, Maestri R, Torunski A, Danilowicz-Szymanowicz L, Szwoch M, Rovere MTL, et al. Heart rate variability measures: a fresh look at reliability. Clin Sci (Lond). 2007; 113 (3): 131-140. Available from: http://dx.doi.org/10.1042/CS20070055.
11. Zutz A, Ignaszewski A, Bates J, Lear SA. Utilization of the internet to deliver cardiac rehabilitation at a distance: a pilot study. Telemed J E Health 2007; 13 (3): 323-330. Available from: http://dx.doi.org/10.1089/tmj.2006.0051.
12. Sandercock GRH, Grocott-Mason R, Brodie DA. Changes in short-term measures of heart rate variability after eight weeks of cardiac rehabilitation. Clin Auton Res 2007; 17 (1): 39-45. Available from: http://dx.doi.org/10.1007/s10286–007–0392–5.
13. Langhammer B, Stanghelle JK. Co-variation of tests commonly used in stroke rehabilitation. Physiother Res Int 2006; 11 (4): 228-234.
14. Smith SC, Blair SN, Bonow RO, Brass LM, Cerqueira MD, Dracup K, et al. AHA/ACC Guidelines for Preventing Heart Attack and Death in Patients with Atherosclerotic Cardiovascular Disease: 2001 update. A statement for healthcare professionals from the American Heart Association and the American College of Cardiology. J Am Coll Cardiol 2001; 38 (5): 1581-1583.
15. Ayabe M, Brubaker PH, Dobrosielski D, Miller HS, Ishi K, Yahiro T, et al. The physical activity patterns of cardiac rehabilitation program participants. J Cardiopulm Rehabil 2004; 24 (2): 80-86.
16. Jordan K, Challis JH, Newell KM. Walking speed influences on gait cycle variability. Gait Posture 2007; 26 (1): 128-134. Available from: http://dx.doi.org/10.1016/j.gaitpost.2006.08.010.
17. Akay M, Sekine M, Tamura T, Higashi Y, Fujimoto T. Fractal dynamics of body motion in post-stroke hemiplegic patients during walking. J Neural Eng 2004; 1 (2): 111-116. Available from: http://dx.doi.org/10.1088/1741–2560/1/2/006.
18. Bidargaddi NP, Klingbeil L, Sarela A. Detecting walking activity in cardiac rehabilitation by using accelerometer. In: Proc Third Intl Conf Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP 2007). Melbourne, Australia; 2007. pp 1-7.
19. Hausdorff JM, Levy BR, Wei JY. The power of ageism on physical function of older persons: reversibility of age-related gait changes. J Am Geriatr Soc 1999; 47 (11): 1346-1349.
20. Cheng PT, Liaw MY, Wong MK, Tang FT, Lee MY, Lin PS. The sit-to-stand movement in stroke patients and its correlation with falling. Arch Phys Med Rehabil 1998 ;79 (9): 1043-1046.
21. Era P, Sainio P, Koskinen S, Haavisto P, Vaara M, Aromaa A. Postural balance in a random sample of 7,979 subjects aged 30 years and over. Gerontology 2006; 52 (4): 204-213. Available from: http://dx.doi.org/10.1159/000093652.
22. Bidargaddi NP, Klingbeil L, Sarela A, Cheung V, Karunanithi M, Yelland C, et al. Wavelet based approach for posture transition estimation using a waist worn accelerometer. In: Proc 29th Annual Intl Conf IEEE Eng Med Biol Soc (EMBC 2007). Lyon, France; 2007. pp 1-4.
23. Bourke AK, O'Brien JV, Lyons GM. Evaluation of a threshold based tri-axial accelerometer fall detection algorithm. Gait Posture 2007; 26 (2): 194-199. Available from: http://dx.doi.org/10.1016/j.gaitpost.2006.09.012.
24. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation 1996; 93 (5): 1043-1065.
25. Kamphuis MH, Geerlings MI, Dekker JM, Giampaoli S, Nissinen A, Grobbee DE, et al. Autonomic dysfunction: a link between depression and cardiovascular mortality? The FINE Study. Eur J Cardiovasc Prev Rehabil 2007; 14 (6): 796-802. Available from: http://dx.doi.org/10.1097/HJR.0b013e32829c7d0c.
26. Dewey FE, Freeman JV, Engel G, Oviedo R, Abrol N, Ahmed N, et al. Novel predictor of prognosis from exercise stress testing: heart rate variability response to the exercise treadmill test. Am Heart J. 2007; 153 (2): 281-288. Available from: http://dx.doi.org/10.1016/j.ahj.2006.11.001.

Correspondence to:
Dr. Niranjan P Bidargaddi
Australian E-Health Research Centre (AEHRC)
CSIRO ICT Centre
P. O. Box 10842, Level 20, 300 Adelaide Street
Brisbane 4000, QLD
Australia
E-mail: niranjan.bidargaddi@csiro.au