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A Review on Technical Aspects of Cardiopulmonary Exercise Testing

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ABSTRACT: Cardiopulmonary exercise testing (CPET) is a non-invasive way to evaluate both cardiac and pulmonary functions, linking performance of physiological parameters to the underlying metabolic process and provide guidelines for exercise capacity descriptors. The choice of parameters to be measured will depend on the goals of evaluation in the individual patients. The aim of this paper is to summarize all existing methodology available to evaluate the cardiopulmonary function on the scale of exercise with the description of common problems arises during research. The review focuses on the exercise physiology and methodology of functional exercise testing, indication, and interpretation. It can be used to measure the fitness of the individual or compare with others, to evaluate continues improvement in health, training prescription and in a medical diagnostic field.

KEYWORDS: Aerobic, Cardiopulmonary, Exercise protocol, Fitness, Incremental test and Workload.

I.INTRODUCTION

A popularity of diagnostic based on CPET is an increase in last decay, reason behind it provides an assessment of cumulative responses of pulmonary, cardiovascular, hematopoietic and skeletal muscle systems which are not easily reflected in normal condition [1]. The cardiopulmonary responses to exercise also reflects individual aerobic power (i.e. the ability in supplying oxygen to and removing carbon dioxide from working muscles). Most of the available research work related to CPET for diagnostic purpose focused on either factual data like age, sex, BMI (body mass Index), etc. and dynamic response like collected databases (signals) from the cardiovascular and pulmonary system at the time of exercise, before or after exercise. Dynamic response can be evaluated by defining various clinical indexes and variability in cardiopulmonary parameters. Parameters that reflect the exercise are morphological variation in ECG & PPG, Heart rate, Blood pressure, respiration rate, Time constant of Heart rate recovery, maximum oxygen uptake ($VO_{2\ max}$) and various ventilator parameters, it is evaluated in term of absolute value or percentage relative to pre-test conditions. Then apply various available algorithms or mathematics model related to signal processing for collecting the hidden information from the database.

Intensity and duration of exercise completely depend on researcher's objective behind the research. Generally, for uniformity in between subjects, most of the available work had used either Treadmill or ergometer instruments. Both have their own advantages for certain condition.

CPET is not only used to pre diagnose diseases condition but now it is also used to measure physical fitness of new recruitment staffs of a system where physical fitness is equally important.It is also used to measure fitness level of individual sports person or compare with others. But the real-time analysis of database for any purpose is the need of current but still, it is lacking in the research.

II.EXERCISE PHYSIOLOGY

Exercise physiology completely depends on amount and frequency of exercise with subject's age, sex, physical structure, the activity of daily living and environment condition. As physical work increase, oxygen requirement increase parallels with it and to meet the requirement of oxygen activity/function of cardiovascular and pulmonary system rise up to the capacity of the individual. Above a certain work rate oxygen consumption reaches a plateau. This

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is termed the maximal oxygen uptake (VO_{2max}). A considerable amount of research has focused on the factors that limit VO_{2max} [2].

Adenosine triphosphate (ATP) is the principal high energy phosphate molecule that enables muscle contraction. Energy supplies to muscle are initially provided from the immediate energy sources of ATP and phosphocreatine before other aspects of metabolism are activated, but during energy conversion, only 20-25% of energy converted into muscular work and remaining converted into heat which increases human body temperature [2]. Generally exercise level also presents in term of MET (the metabolic equivalent of task), it is defined as the ratio of metabolic rate (the rate of energy consumption) during a specific physical activity to a reference metabolic rate. 1 MET is equal to 58.2 W/m2. effect of exercise on the cardiopulmonary system also depends on the activity of daily living for example train athletes can sustain the same workload with nearly normal Heart rate because it has normally more stroke volume than normal persons.

III.EXERCISE EQUIPMENT AND PROTOCOL

The purpose of the exercised based study is to evaluate fitness by applying variable physiological stress. Generally, cycle ergometer or treadmill are used as an equipment for exercise.

Fig. 1 Cardiopulmonary exercise testing using treadmill machine. Continues ECG and respiration rate monitoring using thermistor sensor.

A) Equipment:

Cycle ergometer: Working of cycle ergometer is applying variable resistance to the pedaling speed, it may be the manual or electrical mechanism. Individual who are fatigue will reduce the speed of pedaling as resistance increase. Instruments may be calibrated in watt or kilo pounds, which can be converted easily to oxygen uptake. Cycle ergometer is less expensive and the major advantage is a reduction in motion of the upper body, so it is convenient to collect body parameters of interest. Overall physiological stress apply to the body is less compared to the treadmill and that's why cycle ergometer based exercise produce a lower peak of VO_2. Sometimes arm ergometer may prefer for lower-limb disabilities patients [1].

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Treadmill: Treadmill exercise is more natural and reflects greater overall muscle use. If a patient is using the handrails then O_2 utilization will merely be lower compared with someone who does not. The work performed on a treadmill depends on two variable the speed and incline of the treadmill. The major problem with treadmill testing is motion artifacts in signal acquisition and also discomfort during the recording of ventilator parameters as shown in fig 1.

B) Protocol:
There are several protocols that can be used with either a cycle ergometer or a treadmill. The type of workload depend on the manner in which work is applied: 1) Continues ramp protocol 2) Multistage exercise protocol (increasing intensity every few minutes) or 3) constant work rate for given time period

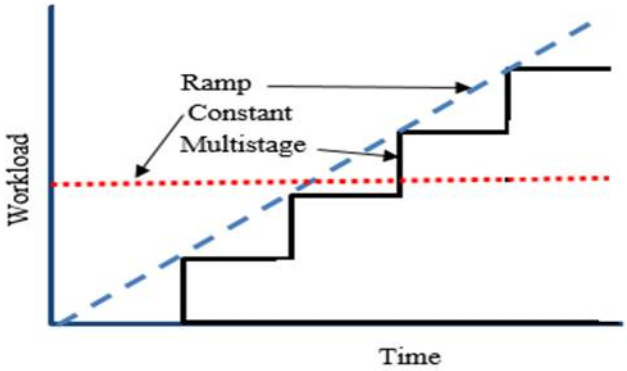

Fig. 2 Comparison of Ramp, Multistage and Constant workload protocol

As per figure 2, in continues, ramp protocol amount of workload applied to the individual is increased in a ramp fashion. In ramp protocol, the workload increases continuously, and steady states are not reached. In multistage exercise protocol amount of workload increase at regular interval and workload will remain steady for that interval. But there is no major variation between the ramp and incremental exercise for peak physiology responses [3]. While in constant workload protocol, the amount of workload is same for the whole test and that's why after initial few minute dynamic responses remains same.

Stage	Minutes	% grade	km/h	MPH	METS
1	3	10	2.7	1.7	5
2	6	12	4.0	2.5	7
3	9	14	5.4	3.4	10
4	12	16	6.7	4.2	13
5	15	18	8.0	5.0	15
6	18	20	8.8	5.5	18
7	21	22	9.6	6.0	20

Table 1 stages of BRUCE incremental protocol

In ramp protocol slope of exercise intensity and in multistage exercise step of workload increase at every periodic interval is important and it depends on the subject of interest and objective of the study. On that bases, many exercise protocol available or it is possible to manually design a protocol is available with many instruments. Like Bruce incremental exercise protocol is most commonly used protocol [4], for assessment of cardiopulmonary capacity of fire fighters, wellness fitness initiative (WFI) protocol is adopted in United States [5], Naughton protocol is recommended

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for treadmill exercise testing of heart patient [1] and many more available for different purpose. But equally, exercise total duration is also important if test duration is shorter than maybe possible that subject will not come across nearly peak condition. Conversely when the duration is greater than average then maybe possible that subjects may terminate exercise because of specific muscle fatigue. Longer test duration may cause an increase in core temperature, dehydration or discomfort. A key point is that exercise duration should be in between 8 to 12 minutes regardless of baseline fitness level. Sometime questionnaire related to their daily activity, energy consumptions and habits is used before exercise to select exercise protocol.
When test should be terminated before completion is also important, condition like chest pain, fall in systolic blood pressure from resting value, a sign of respiratory failures, muscle fatigues etc. Although exercised testing is considered as a safe and noninvasive way still it should be performed under observation of medical staff which has knowledge of exercise physiology, which can identify abnormal response during exercise and able to provide some prior treatment if necessary.

IV.EXISTING WORKS

Today various physiological parameters and their morphological changes during exercise play an important role in evaluating fitness/abnormalities related to the cardiopulmonary system. Available signal processing techniques and interpretation of statistical analysis are the core of the concept.

In last decay, work related to the prediction of maximum workload that anyone can sustain and maximum oxygen uptake have given much more importance, the reason behind it is as workload increase metabolic activity and oxygen uptake increase but each person has different capacity in term of cardiovascular and pulmonary function. For the prediction purpose, they have assumed a linear relationship between Heart rate, workload & oxygen uptake and as a predetermined endpoint for the test selected from age predicted heart rate (220-age) [6]. From the literature review, found that it also possible to predict maximum workload by ending test before completion [7, 8]. For that concept of artificial neural network (ANN) and K- nearest neighbor network (K-NN) used but in both modeling techniques, a reference knowledge base is compulsory to either to train network or to find the similarity between new test and reference database. The experimental evaluation shows that ANN (Artificial Neural Network) based classifiers always provide lower values of prediction error and a more accurate result than the K-Neural Network based classifier [8]. It is also true that neural network requires a long training time for prediction [9]. For direct measurement of VO_{2max} require expensive laboratory setup but it can be estimated indirectly from the measured HRmax to HRrest ratio [10]. In past [11], attempt to derive generalize equations for predicting maximal workload from factual data such as age and weight had done but it is not giving the fully satisfactory result for local populations.

Exercise level and their effect of improvement can be the judge from the morphological changes of ECG or Pulse waveform. A regular exercise for a few week can improve functional capacity of the cardiopulmonary system that can be noticed by observing increased R peak amplitude and decreased exercised HR compare to initial week response of same exercised [12]. It is also proven that Pulse wave transient time (PWTT) after regular exercised increased, which may affect by the improvement of cardiac reserve and vascular conditions. A lot of research work found on various clinical indexes that reflect exercise effect on cardiac system especially. That may cover QRS amplitudes, ST segment deviation, Athens QRS score, PR interval pattern and much more [13,14] but it is proved that QRS amplitude changes more clearly define heart response to exercise compared to ST deviation.

The Athen QRS score [13]

$$AthenQRS = QRS_{avF} + QRS_{v5}$$
$$= [R - Q - S]_{avF} - [R' - Q' - S']_{avF} + [R - Q - S]_{v5} - [R' - Q' - S']_{v5} \quad (1)$$

Not necessary to perform a complex experimental setup and modeling to evaluate a cardiopulmonary fitness. Measurement of time constant of Heart rate recovery can also help to measure fitness [15] this index is better than VO2max because VO2max depends on measurement methods like bicycle or tread mill. Photoplethysmogram(PPG) also reflect exercise induced stress, low-frequency spindle seen in PPG reflects hemodynamic stressors to the human vascular system[16]. Classification of hypertension patients from healthy persons also possible with the help of

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recovery time of BP and maximum systolic pressure [17]. Similarly, heart rate variability (HRV) provides information of the cardiovascular system, after the literature review, it is found that low frequency and the High frequency component of HRV are highly correlated with cardiovascular disease [18].

CPET is widely used medical technique but dataset of reference values are equally important in diagnosis or result interpretation. Reference values of CPET are varied with age, sex, body mass index and exercise protocol [19]. Deviation of actual response from reference values is helpful to diagnose cardiac and pulmonary function. The various standard has been defined by American Heart association for exercise based training or testing [20].
In today's era need of mobile health applications are far more increased because of its comfortless, compactness and ability of real-time processing. The high noise content and other system's interference during exercise is one of the major problems for further analysis. In reference [21] author has developed a system that provides a high accuracy as well as providing the safety for the person under evaluation through the use of PI fuzzy controller.

In past decay works related to finding hidden information of human body is depends upon capability of different algorithms/models or signal processing techniques. But my observation is that compare to linear, nonlinear systems perform better because human body is itself complex and interconnected nonlinear system.

While dealing with data collection, facing major problems like the high noise content in ECG, motion artifacts, baseline wander, respiration system interface, small amplitude and much more. It is also not easy to deal with morphological changes like at high heart rate T wave overlap with P wave. Diagnostic system/ model performance highly depends on a quality of collected database.

The role of artificial intelligence is increased in diagnostic or decision-making system, the role of cardiopulmonary exercise testing also include early diagnostic for safety purpose. An exercise test delivers a large number of measurements that are valuable in risk prediction, in detecting coronary artery disease, and in describing the functional exercise response of a patient. The Exercise Test Interpretation program [38] make the task easy for adviser just by comparing exercise measurements against established thresholds and provides statements and reasoning texts, as well as explanations of the statements when thresholds are exceeded.

V. CONCLUSION AND FUTURE WORK

- Despite growing technology in the Diagnostic field, exercised based evolution stays as a cheap and quick tool for beginning identification of cardiopulmonary potential.
- Evaluation of cardiopulmonary system based on exercise gives crucial information for evaluating individual characteristics, guidance for choosing appropriate exercise level and health maintenance planning.
- Statistical analysis of dynamic data recorded during test plays an important role in the noninvasive way of diagnosis.

Further work can be extended in the clinical domain to analyze pulmonary and cardiac patients, while exercised protocols are usually characterized by lower workload increments and shorter step durations. Further work can be extended by optimization in signals selection, modifying the algorithm to make it effective, extracting information for clinical diagnostic applications and selecting test protocol for diagnostic specifics. Work can be extended for comparison of individual performance and Fitness measurement for athletes. A common index of fitness can be implemented from dynamic response of individual and it can assist the practicing physician to either advise the patient to follow a regular drug or to provide a common guideline to set upon day-to-day routine for improvement of fitness. Further research related to the early prediction of cardiopulmonary response may reduce the patient's physical stress and time of the test.

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