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Pilot Study-Estimated VO2max via Modified Harvard Step Test (MHST) in Anterior Cruciate Ligament Injury Patients Undergoing Pre-Op Rehabilitation

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ABSTRACT

Introduction: Anterior Cruciate Ligament (ACL) injury ranging from partial to full thickness tear causes much dysfunction physically and psychologically. It affects both daily & sporting activities with potential of creating long term complications such as post-traumatic osteoarthritis of knee, functional limitations, increase in body mass index (BMI) and loss of cardiorespiratory fitness. Cardiorespiratory fitness is an important indicator for functional and fitness capacity and VO2max is used to measure cardiorespiratory fitness. VO2max is the maximum rate of oxygen consumption during a vigorous exercise. Cardiopulmonary exercise testing is usually done on a treadmill with gaseous exchange system, a process that is time consuming, expensive and difficult to assess and not available in our public health setting. Modified Harvard step test is easy to do, cost friendly and allows mass testing to measure cardiorespiratory fitness (VO2max) however there are inadequate data on ACL injury and its influence on cardiorespiratory fitness using modified Harvard step test.

Method: A prospective study was done using patients attending Sports Medicine Gym Hospital Tuanku Ja'afar 2023 and data from 20 patients who were undergoing pre-ACL reconstruction rehabilitation were evaluated. Patients were divided into two groups according to post trauma duration; (<6 months of injury and rehabilitation and >6 months injury and rehabilitation). Patients were required to do modified Harvard step test and translated into VO2max scores. Anthropometric data were also taken from patients.

Results: The mean age for our study is 21.9±4.3 years. The mean VO2max for the entire participant was 43.2ml/kg/min. Mean VO2max for groups <6 months injury rehabilitation and >6 months injury rehabilitation was at 35.4±1.8 ml/kg/min and 49.0± 5.8ml/kg/min respectively. We report difference in both groups VO2max

Conclusion: Cardiorespiratory fitness is often reduced during earlier phase of injury due to inability to perform aerobic exercises. Progressive rehabilitation can improve cardiorespiratory fitness, aid in patients return to sports and reduces morbidity post operatively. Modified Harvard step test is a reliable and cost-effective method to test VO2max. It is also important to increase cardiorespiratory fitness to maintain healthy BMI.

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Introduction

Anterior cruciate ligament (ACL) injury stands out as a common, moderate to severe injury in patients. Anterior Cruciate Ligament (ACL) injury ranging from partial to full thickness tear causes much dysfunction in the active population as it affects both daily & sporting activities with potential of creating long term complications such as post-traumatic osteoarthritis of knee, functional limitations, sedentary behaviours, psychological and mood changes which ultimately affect quality of life [1]. These injuries reduce the cardiorespiratory fitness/aerobic capacity in patients due to the inability to do physical activity and sports specific games. Management of this ailment can be either conservative via physical therapy or surgical intervention through ligament reconstruction. Both methods of treatment will precede with a period of reduced level of physical activity thus the affected population in-evidently will experience reduced cardiorespiratory fitness during this phase. Those patients who intends to return to sports post ACL injury usually undergo a series of test or rehabilitation miles stone. These criteria include knee stability, isokinetic strength test, time of ACL reconstruction (ACLR), knee stability, hop tests and self-reported questionnaires Most study state that the time allowed to return to sports is usually around six months however most of these athletes does not meet these criteria and about 45% of patient does not return to sports or return to their pre-injury levels [2-5]. According to a study done by Hughes et al the effects of exercise training increases oxygen delivery to muscles and increase endurance capacity whereas those who train against heavy load will get muscle hypertrophy and increase strength. Exercises and proper pre-rehabilitation also reduce post operative morbidity and increases rehabilitation milestone so that one is able to return to sports faster. Another study by Clodagh et al on 100 adults with knee injury states that higher fat mass is associated in athletes who had history of knee

injury with reduction of cardiorespiratory fitness. These adults also report increase in body mass index as compared to their uninjured control. Therefore, there is a need for rehabilitative measures to address these concerns and to find an easily accessible method to assess and monitor fitness levels.

Cardiorespiratory fitness is measured by VO2max. It is the maximum rate of oxygen consumption during a vigorous exercise. It has long been approved by World Health Organization as the most appropriate indicator to measure cardiorespiratory fitness. It is usually measured in mililiters/kg/min and can be measured via direct or indirect methods. In addition, it is usually done on a treadmill with gaseous exchange system, a process that is time consuming, expensive and difficult to assess. Cardiopulmonary exercise testing (CPET) is an excellent tool to measure fitness and functional capacity. It projects integrated functions of muscle metabolic systems, respiratory systems, cardiac and circulatory markers under physiological stress thus identify causes of exercise intolerance Moreover these (CPET) are used in preoperative assessment and are centred on functional impact of comorbidities and evaluation of functional capacity overall However, this method of testing is expensive and is not readily available in most of our public health settings [6, 7].

Modified Harvard Step Test is a simple method to evaluate estimated VO2max and is readily available in the public health setting. It is easy to perform, minimal resources needed, easy to direct and available for mass testing It is used to test cardiorespiratory system and reflects on the capacity of the body to cope with increased physical stress.

Currently there is inadequate data on cardiorespiratory fitness among local population of ACL injury cases during pre op and post op rehabilitation phase, most of the data available are on post op ACL reconstruction using cardiopulmonary exercise testing (CPET). Thus, there is a need for more studies on Modified Harvard Step Test as a tool to predict cardiorespiratory fitness (VO2max) in patients and to find out if these is an alternative to the expensive (CPET) in terms of VO2max results and to find the correlation between endurance and resistance training on cardiorespiratory fitness among patients with deficient ACL.

Materials and Methods

This is a cross-sectional study using data of patients undergoing pre-habilitation program for Anterior Cruciate Ligament injury in Sports Medicine Gymnasium Hospital Tuanku Ja'afar Seremban. A total of 20 patients were recruited for this study. Patients were explained regarding the objective of the study and consent was taken prior to the start of the study. Patients were then divided into 2 groups. Group of rehabilitation <6 months and groups that have > 6 months. All these patients were scheduled to be seen in the sports gymnasium every 2 weeks for their ACL rehabilitation. These patients followed the rehabilitation guidelines of University Malaya Medical Centre Sports Medicine ACL Rehabilitation.

For patients in group <6months rehabilitations goals were divided in 4 phases. 1st phase (0-2weeks) consists of swelling management and pain control, minimize arthrogenic muscle inhibition, re-establish quad control, restore full extension, gradually improve flexion, restore patellar mobility and weightbearing and proprioception training. Patients were then progressed to phase 2 (3-5weeks) which consist of range of motion to maintain full extension and restore full flexion, increase quadriceps and hamstring strength, lumbopelvic strengthening, hip strengthening, balance/ proprioception and gait retraining such as single leg standing, balance and inclusion of cardiovascular fitness such as stationary cycling. Phase 3 (6-12weeks) consist of maintaining full range of motion, progressive strengthening with closed kinetic chain exercises with eccentric focus such as squat variation, lunge variations and hip hinges: Romanian deadlift, open kinetic exercises, balance and proprioception such step and hold, single leg squat and Y balance test. Patient subsequently progressed to phase 4 (12-20 weeks) which includes closed and open kinetic exercises, multiplane resisted hip exercise, initiation of running program, progressive plyometrics such as vertical and power jumps. Progressive balance training includes perturbation training and single leg stand with eyes closed on non-compliant surface.

Patients in group >6 months were prescribed phase 5 rehabilitation module which include return to running, progressive plyometric such as anterior-box hop both double leg and single leg, lateral-lateral jump over cone, multiplanar box hop, agility training such as anterior forward run, backward run, lateral side shuffle, carioca and multiplanar box drill. Patients were also introduced to sports specific drill. Phase 6 consist of continues strengthening and proprioceptive exercises such as multi-plane sport specific plyometrics programs, multi-plane sport specific agility program, hard cutting and pivoting movements, non-contact sports specific drills, full practice and full play.

Both group of patients were then subsequently required to the modified Harvard Step Test during their follow up at 4months interval for the group < 6months and 7 months interval for group > 6 months. Anthropometric markers such as age, height, weight, body mass index and heart rate pre and post Harvard test is taken. Patients body mass index (BMI) were determined by dividing the patient's weight (in Kg) with square of height (in m). Patient's BMI were classified based on The Malaysian Clinical Practice Guidelines on Obesity (Clinical Practice Guidelines on Obesity (2023). Subsequently VO2max is calculated for the respective patients (VO2max= 15 x (HR max÷ HR rest). The data records of the 20 patients are recorded and kept by the principle investigator in a laptop protected by password and physical documents kept in cupboard locked and keys kept safe by the principle investigator.

A descriptive analysis was performed using the Statistical Package for Social Sciences (SPSS) and a p value of <0.05 was considered statistically significant difference.

Shapiro-Wilk Test was used to assess the data distribution, variables were expressed as mean and standard deviation or median and interquartile range depending on normality of data distribution. Categorical data will be presented as frequency (n) and %.

Student t-test or Mann-Whitney test was used to compare between independent groups based on data distribution.

Results

A total of 20 patients with anterior cruciate ligament injury due to various sporting background were included in this study. All of them vary in terms of level of play, some being recreational and some being professional players in sports such as rugby and football. 10 patients were under 21 years old while the remanding 10 were above 21 years old [8].

Majority (n=11,55%) of the patients were Malay ethnicity while the remaining were Chinese (n=2, 10%) and Malaysian Indian ethnicity (n=7, 35%) Table 1 shows the demographic data of the patients. The mean age of the patients was 21.9 ± 4.3 years. Majority of the patients in our study had overweight and obese BMI (n=11,55%), the remaining patients were normal (n=9,45%).

Table 1: Baseline Overall Demographic Data

Variables	MEAN	SD
Age(years)	21.9	4.3
Body mass index (BMI)	23.7	3.4
VO2	43.2	8.5
Maximum Heart Rate (MHR)	197.3	4.8
Resting Heart Rate (RHR)	75.0	8.5

Table 2: Comparison between Patients who underwent Rehabilitation 3-6 Months and more than 6 Months

Variable (Median±IQR)	Rehabilitation Interval		P value
	<6 months(n=10)	> 6months (n=10)	
Age(years)	19.0±2.2	25.0±4.2	0.085
Body mass index (BMI)	26.9±2.9	20.9±2.3	0.015
VO2	35.4±1.8	49.0±5.8	0.001
Maximum Heart Rate	201±2.8	194±4.8	0.823
Resting heart rate	84±6.7	68.5±5.8	0.035

According to the data extracted and analyzed above. We found that in our study there is a difference between patients who had undergone rehabilitation for > 6months compared with those who have underwent rehabilitation <6months namely in parameters of VO2, body mass index, and resting heart rate.

Body mass index (BMI) was 20.9±2.3 standard deviation in patients who had rehabilitation >6months with mann whitney test P<0.05 significant as compared to BMI of the later which recorded 26.9±2.9. When taking into VO2 parameters, the mean VO2max for the entire participant was 43.2ml/kg/min. The groups >6months of rehabilitation recorded 49.0±5.8 with P<0.05 significance as compared to the patients in <6months group which only recorded 35.4±1.8

P value was also significant when comparing resting heart rate among the two groups. Those >6 months rehabilitation group recorded 68.5±5.8, P<0.05while the later recorded 84±6.7

Discussion

Suffering from ACL tears can be a serious setback to patient's physical fitness, potentially affecting the career if one is a professional athlete [9]. Following initial phase of injury, there is a phase of reduced activity and physical deconditioning [10]. However, there is limited research on the topic of aerobic fitness in patients after ACL injury. VO2max stands as one of the most crucial indicators of endurance performance and has undergone extensive testing among players who have undergone ACL rehabilitation with or without reconstruction involved, though its assessment after an acute ACL injury and during the period of rehabilitation pre operatively is still new [11]. VO2max has been shown to be an independent predictor of injuries in soccer players [12].

This study demonstrates that the VO2max in patients who have experienced ACL injuries is significantly reduced during the initial period of injury while there is improvement six months after ACL rehabilitation. This is likely due to the fact that these patients who initially present with acute ACL injury undergo treatment for acute phase which decreases physical activity and directly affect their physical fitness. During this acute phase of injury, many of these athletes would be recommended the principles of Peace & Love treatment which includes protect, elevate, avoid anti-inflammatory modalities, compress, educate, load, optimism, vascularisation and exercise. During the period of protect, there would be elements of immobilization causing deconditioning to set in. According to a study done by H J Appell muscle atrophy happened after the onset of immobilization and up to 35% of muscle fibre diameter was reduced during the first 7 days of immobilization. It is further denoted that after 18 days of immobilization muscle fibres were 35% thinner than mobilized muscle in control group. Muscle morphological alterations happened within the 4th day of immobilization. This is due to reduction in protein synthesis. Strength is severely reduced during the 1st week. Most muscle do recover from immobilization but recovery period is much longer than immobilization period. Thus, to prevent losses in strength, a basic maintenance program must be established, which is exercise in lower intensity and frequency. When comparing VO2max parameters, a study by Marques et al found out that preoperative VO2max among ACL injured group was at 45.2±4.3 while the postoperative VO2max was 48.9±3.8. This study was done using CPET devices. The findings of these study are almost similar to our findings in group <6 months identical to pre operative VO2max and groups >6 months of rehabilitation showing almost identical results to post operative VO2max. These shows that VO2max results are reproducible using modified Harvard step test which is more cost effective and easier for patients to follow as compared to the more expensive CPET testing.

Furthermore, our research revealed a significant distinction between the resting heart rates of patients of rehab group <6months versus those patients >6 months of rehabilitation, Notably, the resting heart rate of patients >6 months of rehabilitation was lower than that of their other counterparts. We also found that the VO2max in the group of rehabilitation >6months is higher than the other group with body mass index (BMI) lower in these group as compared to the group <6months of rehabilitation due to the increase in cardiovascular fitness. These findings are supported by a study done by Shah et al which states that VO2max is inversely proportional to BMI and heart rate. The higher the VO2max the lower the BMI and heart rate. One plausible explanation for this difference in heart rate lies in the varying impact of endurance training on the re-modeling of the parasympathetic system. This training could enhance vagal tone, resulting in a reduction in resting heart rate. It's conceivable that more extensive re-modeling occurs with longer exposure to endurance training. This re-modeling is essential for accommodating increased demand by allowing greater end-diastolic volume, leading to more forceful cardiac contractility due to the Starling law effect [13].

According to a study done by Frank W Booth et al regular endurance exercises was shown to improve the capacity of skeletal muscle to oxidize substrate to produce ATP for muscle work. A single bout of exercise can cause alteration to skeletal muscle mRNA. Effects of exercises increases new capillary blood formation (angiogenesis) and increases the number of mitochondria as well as size of the mitochondria. Moreover, introduction of resistance training has early gains in strength and neural adaptations. It increases neural drive which increases muscle recruitment and motor unit. The increase in motor unit indirectly increases the amount of muscle mass activation. Combination of both aerobic and resistance training causes one to have greater presynaptic nerve terminal area which directly translates to an increase in number of nerve terminal branches, increase in perimeter of nerve terminal, increase in length of individual nerve terminal and

increase in presynaptic and postsynaptic receptor All these factors combined is directly proportional to the increase in VO2max in the group with rehabilitation >6 months [14].

Furthermore, exercise also causes muscle fibre type alteration, conversion is possible with these cross innervations, where type 2 motor unit is cross innervated by type 1 motor neuron. Alteration within a type of fibre is possible with training Both type 1 and type 2 muscle increase with resistance training but type 2 muscle fibres increase more [15]. Long term gains in strength (muscle hypertrophy) usually happened due to increase in muscle size with actual structural changes, greater size = greater force. Resistance exercise increases myofibrils, actin and myosin filaments and increases sarcoplasm. These is due to increase muscle protein synthesis. Eccentric training is shown to have greater muscle hypertrophy, increased blood flow and muscle metabolism This could explain our findings with patient more than 6 months of rehabilitation exhibiting lower body mass index (BMI) and increase VO2max as these patients underwent training regime which causes muscle fibre type alteration and conversion which increases muscle mass and reduces fat free mass and increased muscle blood flow and reduced fatigability [16]. Our study is comparable to another study done by Clodagh et al which consisted 100 adults with knee injury who performed 20m shuttle test to test cardiorespiratory fitness. Those with knee injury had a decrease in cardiorespiratory fitness and increase fat mass.

However, this study is not without limitation, in this study we were unable to provide detailed analysis on the compliance level of our patients at home. Therefore, we were unable to comment on the basic physical activity levels of these patients. Patients with higher physical activity will show better cardiorespiratory fitness (VO2max). Patients were also from different socioeconomic background i.e.: sub-elite athlete to desk job personnel and basic functional capacity may vary among them. Moreover, we did not perform a detailed analysis on the body mass index (BMI) on whether the increase of BMI is more centred on increase of muscle mass or increase in fat percentage.

Conclusion

Anterior Cruciate Ligament injury is a common injury in our field of practice. Although it is related to musculoskeletal system, it often affects the cardiorespiratory fitness and causes changes in body anthropometric reading due to the nature of the injury. It is important to have proper rehabilitation regime so that patients are able to reduce the negative effects of prolonged immobilization, and muscle wastage which impacts their cardiorespiratory fitness (VO2max) and causes morbidity in their recovery. It is proven that early introduction of mobilization, resistance and progressive endurance training can increase cardiorespiratory fitness as well as increase muscle mass and further improve operative morbidity to patients. Cardiorespiratory fitness can be measured using the simple modified Harvard step test which could reproduce results identical to its more expensive CPET devices.

Conflict of Interest

The authors declare no conflict of interest.

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Authors Contribution

Authors Lavinen Kumar Sugumar, Rozaiman Ebrahim and Au Yong Puisan, were involved in designing and conception of these work, involved in analysis and data interpretation, drafting the work and revising it for critical important intellectual content, reading the final approval of the version to be published and agreed to be accountable for all aspects of work ensuring that questions related to the accuracy or integrity of any parts of work are appropriately investigated and resolved. All authors read and approved the final version of the manuscript.

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