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EDITORIAL

“This edition of the South African Journal of Sports Medicine, the first of 1998, has a number of changes. First and foremost, there has been a complete restructuring of the management of the Journal which now includes two Senior Associate Editors, who are Prof Maurice Mars and Dr Mike Lambert. I would like to take this opportunity of congratulating Prof Mars and Dr Lambert on their appointment and I look forward to working with them to improve all aspects of the Journal and make it a Journal that the South African Sports Medicine Association can be really proud of. Furthermore, Dr Peter Macfarlane from Cape Town has agreed to serve as a News Editor, a very much needed section within the Journal. I would like to encourage individual members of SASMA to be in contact with Dr Macfarlane to keep him up to date on events that are worthy of publication in this news section.

Finally, I would like to congratulate the new members of the Editorial Board of the South African Journal of Sports Medicine. These members represent Academic Institutions across the country and I look forward to serving the Journal and the Association with their input and expertise.

The contents of this Journal consists of a review article and three original research articles. This ratio of review to original research is what the Journal would strive for over the next 2 years. We recognise that review material is important, but we would first and foremost like to encourage a research culture in the South African Sports Medicine Association. I would therefore encourage researchers in all fields to consider submitting their material to the South African Journal of Sports Medicine, thereby supporting your local Journal. In addition, the Journal would also have ample opportunity for publishing Brief Reports, and Case Reports. Hopefully this will facilitate the busy practitioner who has little time for in-depth clinical research to still submit interesting work in the form of case reports or a brief report. I would like to encourage each of you to consider submitting material in this format for publication. The guidelines for authors wanting to submit either brief reports or case reports has recently been circulated through the SASMA Newsletter. These are also obtainable from the office in Cape Town.

I am indeed excited about the new format of the South African Journal of Sports Medicine, and would encourage you all to support it and our Association.

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EDITOR
South African Journal of Sports Medicine
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Exercise intolerance in patients with chronic heart failure: A Review

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ABSTRACT

Exercise intolerance in patients with heart failure is a common but complex phenomenon. Traditionally it has been thought that central cardiorespiratory factors were the important limiting factors of exercise performance in patients with heart failure. However, more recent research suggests that peripheral abnormalities within the skeletal muscle might play a role in the exercise intolerance experienced by these patients. This review encompasses research examining the effects of heart failure on some of the organ systems and physiological response to exercise. Studies of both central (cardiorespiratory) and peripheral (skeletal muscle) factors limiting exercise performance have been reviewed. It is probable that whilst both central and peripheral factors contribute to the exercise intolerance in these patients, patients may be limited more by disease of skeletal muscle than by dyspnoea or central fatigue.

HISTORICAL PERSPECTIVE OF EXERCISE INTOLERANCE IN HEART FAILURE

Braunwald and Grossman defined heart failure as "the condition in which abnormality of myocardial function is responsible for the ventricles' inability to deliver adequate quantities of blood to the metabolizing tissues at rest or during normal activity". The most common cause of heart failure is loss of cardiac muscle secondary to ischaemia on the basis of coronary artery disease. Viral and other cardiomyopathies are more common in younger patients. Heart failure can also occur in persons with poorly controlled blood pressure or with valvular heart disease.

Of the many symptoms experienced by patients with heart failure, dyspnoea, fatigue and exercise intolerance are amongst the most common. Indeed, the first indication of heart failure is a diminished tolerance to physical exercise. Of such importance are symptoms of dyspnoea that functional capacity in patients with chronic heart failure was, and still is, measured in terms of the four-tiered classification of breathlessness, which is subjective and only semi-quantitative. Only recently has exercise testing become more popular for the determination of functional capacity in patients with heart failure.

Historically it was believed that central cardiorespiratory factors determined submaximal and maximal exercise capacity in patients with chronic heart failure. As these patients had reduced cardiac output at rest and during exercise, it was thought that the heart was unable to deliver sufficient oxygen to the active skeletal muscles so that an oxygen deficiency in the active muscles caused fatigue. The focus of studies to determine mechanisms of fatigue at rest and during exercise in patients with heart failure was on pulmonary congestion, reduced lung compliance and dyspnoea. Even more recently, the majority of studies have continued to focus on the role of the heart and lungs in the limitation of exercise performance in patients with heart failure.

However, since 1960 there has been evidence that signs and symptoms of heart failure could be absent even in the presence of severe heart disease. This led researchers to believe that central cardiovascular function may not necessarily be related to exercise capacity and that chronic heart failure encompasses impairment of multiple organ systems including skeletal muscle.

PHYSIOLOGICAL FACTORS CONTRIBUTING TO EXERCISE INTOLERANCE IN PATIENTS WITH CHRONIC HEART FAILURE

Although exercise intolerance is the most frequent symptom in patients with heart failure, the exact cause of exercise intolerance has yet to be identified. Whilst heart failure is a complex and multisystemic disorder, and whilst the authors appreciate that central and peripheral physiological systems cannot be entirely separated, the limitation of exercise performance in heart failure will be discussed under central (cardiorespiratory) factors and peripheral (blood flow and skeletal muscular) abnormalities which could possibly alter exercise tolerance in patients with chronic heart failure.

1. Contribution of central cardiorespiratory abnormalities to exercise intolerance in patients with heart failure

(i) Left Ventricular Systolic Function

Left ventricular systolic function is compromised in chronic heart failure. It was thought that this would alter exercise tolerance in patients with heart failure.
However, the poor relationship between maximal exercise capacity and indices of left ventricular (LV) function in patients with heart failure is now an established finding. There is clearly no correlation between exercise capacity measured on a cycle ergometer or treadmill, and LV ejection fraction, nor any correlation between the degree of ventricular dysfunction and the clinical severity of chronic heart failure. A study by Benje et al. showed that 50% of patients with an ejection fraction of less than 30% had normal exercise capacity. Reading et al. also reported that there was no relationship between resting ejection fraction and peak aerobic power or resistance in the calf vasculature.

Furthermore, it was reported that patients with severe LV dysfunction increased their peak exercise performance after exercise training, whilst they did not show any change in LV ejection fraction or any reduction in wall motion abnormalities. These findings suggest that factors other than those relating to central cardiovascular function may have determined the beneficial adaptations to training. Regardless of these findings, the ejection fraction continues to be the most common measure of central cardiovascular function and predictor of future survival in these patients.

(ii) Cardiac Output

Cardiac output is reduced at rest and during exercise in patients with chronic heart failure. Furthermore, a lower proportion of total cardiac output is delivered to skeletal muscle during exercise in patients with heart failure. Bain et al. demonstrated that exercise time to exhaustion measured during incremental exercise in patients with heart failure, cannot be predicted from resting cardiac output. However, maximal cardiac output and the ability to increase cardiac output during exercise, do correlate with exercise capacity. Muller et al. showed that blood flow to the gut, kidneys, and limbs was reduced in patients with chronic heart failure. The lack of any correlation between limb blood flow and cardiac output helps to explain the lack of correlation between cardiac output and symptoms during exercise.

Further evidence that cardiovascular function does not determine exercise capacity in patients with heart failure is the observation that improvement of left ventricular function by acute ingestion of inotropic drugs, vasodilators, or repair of valvular stenosis does not result in an immediate normalization of exercise capacity or of their ventilatory response during exercise, despite marked improvements in cardiac output.

(iii) Blood Pressure

Regulation of blood pressure and temperature are major cardiovascular challenges which arise during muscular work and which may conflict with the need to perfuse the active muscles. Normal persons actively regulate mean arterial blood pressure during exercise by increasing skeletal muscle vascular tone when cardiac output decreases. In patients with heart failure, this reflex-mediated peripheral vasoconstriction is thought to maintain blood pressure during dynamic exercise when cardiac output has reached its maximum value. As a result, blood flow to the active muscles is restricted in order to maintain blood pressure when cardiac output is limited.

Heat rate and mean systemic arterial blood pressure increase less during dynamic exercise in patients with heart failure compared to control subjects and the increase in stroke volume in the patients is also minimal. Despite this abnormal response, mean systemic blood pressure does not relate directly to exercise capacity, suggesting that exercise intolerance in these patients is influenced by factors other than peak systolic blood pressure.

(iv) Pulmonary Haemodynamics

It was originally thought that increased pulmonary capillary wedge pressure during exercise caused by left ventricular failure caused dyspnoea, which in turn limited exercise performance. However, the elevated pulmonary capillary wedge pressures at rest in patients with heart failure increase to the same levels during submaximal and maximal exercise and these elevated levels appear to be well-tolerated. Massie et al. found pulmonary capillary pressures to be no higher in patients with heart failure whose exercise tolerance was limited by dyspnoea compared to patients limited by leg fatigue. These findings indicate that mechanisms other than pulmonary capillary wedge pressure appear to be important in limiting exercise performance in patients with chronic heart failure.

(v) Pulmonary Ventilation

Patients with chronic heart failure have altered ventilatory responses to graded exercise. Hyperventilation is commonly observed during exercise in patients with heart failure and has been attributed to decreased lung compliance, regional ventilation-perfusion mismatch in the lungs as a result of the reduced cardiac output and increased dead space volume. Despite this abnormal ventilatory response to exercise and decreased maximal ventilation, the normal control of ventilation by V̇CO₂ is present in patients with chronic heart failure.

Although it is unclear to what extent these ventilatory abnormalities influence exercise performance in patients with chronic heart failure, it has been suggested that leg fatigue causes termination of exercise before there is a substantial encroachment on ventilatory reserve in patients with severe heart failure.

It is possible that abnormal respiratory muscle function or skeletal muscle abnormalities may contribute to dyspnoea and ventilatory abnormalities in these patients. Nishimura et al. reported that inspiratory muscle strength was impaired in patients with severe congestive heart failure and may limit exercise in these patients. Furthermore, 'periodic breathing' has been described in patients with congestive heart failure at rest and during exercise. This has been attributed to unstable ventilatory control caused by poor circulation and to delayed transmission of humoral ventilatory stimuli to the chemoreceptors. However, the exact mechanism for the periodic breathing in patients with heart failure is still unknown, although a central (cardiovascular) mechanism is still favoured.
latory alterations. It is not known whether these alterations in pulmonary ventilation are the cause or effect of the exercise intolerance.

**(vi) Peak Oxygen Consumption (VO₂ peak)**

Reduced VO₂ peak in patients with heart failure has been repeatedly confirmed.¹²,¹³,¹⁰,¹²,¹³,¹⁴ However, the exact cause of this finding has not been identified. Decreased oxygen consumption in patients with chronic heart failure implies that either O₂ supply or O₂ utilization by the active skeletal muscle is altered. Alternatively, the muscle's capacity to perform exercise could be impaired even in the face of an adequate oxygen supply.

Wade and Bishop¹⁵ suggested that the primary limitation of VO₂ peak in patients with heart failure is a relatively reduced pulmonary blood flow. However, many investigators have since shown that arterial oxygen tension and systemic arterial O₂ saturation remains normal even at peak exercise in patients with chronic heart failure.¹⁴ This suggests that pulmonary function does not limit VO₂ peak in these patients, and that peripheral alterations may indeed influence peak oxygen consumption in these patients. These theories are supported by the following important findings:

(a) Weber et al.¹⁶ demonstrated that although peak cardiac output and peak VO₂ are linked, as the severity of heart failure worsens, the slope of the cardiac output response with increasing VO₂ decreases. This indicates that the normal relationship between cardiac output and oxygen consumption is altered in these patients, possibly due to increased oxygen extraction at the periphery from a reduced (muscle) blood flow.

(b) Thompson et al.¹⁷ and Sullivan et al.¹⁸,¹⁹ reported that femoral venous P₀₂ does not decrease below the critical level of 10mmHg during exercise in both normal subjects and in patients with chronic heart failure. These findings suggest that muscle fatigue may not be caused by an inadequate oxygen supply to the active muscle.

(c) Failure to observe an improvement in oxygen uptake by skeletal muscle during exercise even when oxygen availability is enhanced by pharmacological intervention in patients with chronic heart failure.¹⁹ indicates a change in the properties of skeletal muscle itself in these patients.

(d) Moore et al.²⁰ reported that maximal exercise performance on a cycle ergometer was acutely enhanced compared to exercise with room air, when patients with heart failure inspired oxygen at a concentration of 50% O₂. This was explained by an increased efficiency during exercise, so that there was a decreased ventilatory and circulatory demand at a given workload, while O₂ delivery to muscle was maintained (Moore et al. 1992). However, this does not prove that oxygen supply to the active muscle was limiting during exercise.

(e) Jondeau et al.²¹ measured VO₂ peak during maximal exercise with lower limbs and with lower limbs plus upper limbs in patients with heart failure. Patients were able to increase VO₂ peak when exercising with both lower and upper limbs. This finding was not observed in the control group of healthy subjects. This indicates that the exercise intolerance in cardiac patients during lower limb exercise was not due to a central limitation, as VO₂ peak increased when additional skeletal muscle was recruited in these patients.

(i) Recent reports indicate that VO₂ peak is predicted by muscle strength in patients with chronic disease. Isometric maximal voluntary contraction (MVC) of the quadriceps muscle correlates to peak VO₂ during exercise in patients with chronic heart failure.²² This finding indicates that skeletal muscle function can predict maximal exercise performance. Similarly, isokinetic quadriceps muscle strength correlates to peak VO₂ in patients with renal failure.²³ Therefore peak VO₂ is probably indicative of peripheral, skeletal muscular rather than central cardiovascular function in this group of patients.²⁴

In light of the above-mentioned findings, the search for mechanisms of exercise intolerance in patients with heart failure has shifted from the central cardiovascular system to the peripheral musculoskeletal system.

2. Contribution of peripheral abnormalities to exercise intolerance in patients with heart failure

(i) Physiological alterations in the periphery during exercise in patients with chronic heart failure are:

(a) Alteration of blood flow to skeletal muscle

Results of studies investigating blood flow to the skeletal muscle during exercise in patients with heart failure have produced conflicting results. It appears that many factors including the mass of skeletal muscle recruited, severity of cardiac failure, exercise protocol used, and the patients' medication contribute to alterations in blood flow during exercise in these patients.

Peripheral blood flow is lower during progressive dynamic and during sustained isometric exercise in patients with chronic heart failure compared to normal controls.²⁵,²⁶,²⁷,²⁸ A lower proportion of total cardiac output is delivered to exercising skeletal muscle in patients with heart failure. This occurs as a compensatory mechanism to prevent hypoperfusion of important non-exercising areas (brain, kidney) or to preserve arterial blood pressure.²⁹,³⁰ or as a result of increased skeletal muscle vascular resistance.³¹

It appears that blood flow to the working skeletal muscle is dependent on the volume of active skeletal muscle mass recruited during exercise.²² These researchers reported that patients with moderate heart failure can attain a peak skeletal muscle perfusion and leg oxygen consumption comparable to that of healthy control subjects when small amounts of skeletal muscle mass is recruited. However, during recruitment of larger volumes of skeletal muscle mass (>4kg), peak blood flow, muscle perfusion and oxygen uptake as well as blood flow to the non-working skeletal muscle is reduced compared to controls.²²

Recently Yamabe et al.²³ reported that blood flow to skeletal muscle during submaximal cycle exercise is higher in NYHA class III patients than to skeletal muscle of patients with less severe heart failure. These investigators suggest that the relatively increased skeletal muscle blood flow in patients with severe heart failure plays a role to compensate for the insufficient cardiac output response in these patients.
Impaired vasodilation during exercise is an important factor responsible for the reduced maximal limb blood flow in patients with heart failure. However, the pathophysiological cause of decreased muscle blood flow during exercise has not been clearly defined. Possible factors limiting blood flow to the skeletal muscle during exercise in patients with heart failure include increased vascular stiffness, alterations in neurohumoral activation, alteration in blood vessel vasodilator capacity, and alteration in flow-dependent dilation. These factors may play an important role in the natural history of the disease, but may not be critical to the impaired exercise capacity of these patients.

It is important to note that Wilson et al. examined the acute effects of the vasodilators dobutamine, dopamine, and phosphodiesterase on maximal exercise performance in patients with chronic heart failure and found no improvement in exercise performance even when blood flow to the legs was acutely increased by these agents. Nor did increased blood flow to exercising muscle induced by hydralazine appear to reduce femoral venous lactate concentrations or the degree of acidosis or fatigue in patients with heart failure. These results indicate that exercise performance was not dependent on muscle blood flow, as it failed to increase with an acute increase in muscle blood flow.

Drexler et al. reported that chronic administration of angiotensin-converting enzyme (ACE) inhibitors can partially reverse mitochondrial abnormalities in patients who have depressed oxidative capacity of skeletal muscle during exercise. Chronic ACE inhibition not only increases skeletal muscle blood flow at maximal exercise, but also improves functional capacity in these patients by acting primarily on the peripheral vasculature without changing intrinsic myocardial function. These results suggest that there is a gradual reduction in structural vascular abnormalities by the chronic effect of ACE inhibition, and that this improves exercise performance.

(b) Reduced blood flow causing altered skeletal muscle metabolism

It has been suggested that reduced muscle blood flow at rest and during exercise in patients with heart failure might be important in determining the metabolic response to exercise. Reduced muscle blood flow is characterized by increased glycolytic metabolism and decreased oxidative phosphorylation in the skeletal muscles of these patients. However, Weiner et al. reported that the reduced blood flow to exercising skeletal muscle was not a consistent finding in forearm muscles where metabolism was altered. Massic et al. established that metabolic abnormalities are unrelated to blood flow by comparing the effects ischaemic forearm exercise in patients with heart failure and in normal control subjects. While the brachial artery was temporally occluded during submaximal finger flexion, patients utilized phosphocreatine (PCr) at a faster rate compared to controls despite performing much less work, and pH levels fell substantially. As blood flow was not different, results suggest that a functional abnormality of the skeletal muscle exists in patients with congestive heart failure. Buller et al. measured fatigability of adductor pollicis muscle during supramaximal repetitive stimulation of the ulnar nerve during circulatory occlusion in patients with severe heart failure and in normal controls. The effect of ischaemia was greater in patients with severe (Class IV) heart failure than in patients with mild to moderate heart failure or in normals and the investigators attributed this to impaired skeletal muscle metabolism. Marie et al. confirmed this when they reported that the rate of PCr resynthesis in calf muscle of patients with congestive heart failure was similar following either aerobic or ischaemic exercise.

(c) Oxygen extraction and utilization

Despite decreased blood flow during submaximal exercise, it has been demonstrated that the skeletal muscles of patients with chronic heart failure can compensate by increasing oxygen extraction, hence increasing the arterio-venous oxygen (A-VO2) difference. However, Roubin et al. observed that although the A-VO2 difference across the leg during exercise was greater in patients with heart failure than in normal persons, VO2 peak was 40% lower, suggesting that the greater A-VO2 difference does not compensate completely for the reduction in skeletal muscle blood flow. Alternatively, skeletal muscle weakness may prevent patients with heart failure from reaching high levels of exercise at which higher VO2 values would be measured. Wilson et al. showed that maximal leg blood flow and maximal leg oxygen uptake in patients with chronic heart failure were markedly reduced in patients with the poorest exercise tolerance. These findings suggest that either the skeletal muscle cannot fully utilize the delivered oxygen or that oxygen availability or diffusion to the skeletal muscles is impaired in these patients. However, these studies do not exclude the possibility that muscle weakness limits exercise tolerance before an oxygen limitation develops.

(d) Blood lactate concentrations

It is usually argued that skeletal muscle hypoperfusion during exercise contributes to the early onset of skeletal muscle lactate production and that increasing exercise intolerance is associated with progressively earlier increases in mixed venous blood lactate concentrations in patients with chronic heart failure. Furthermore, it has been demonstrated that venous blood lactate accumulation patterns correlate with severity of circulatory failure at rest and with severity of heart failure during exercise. Increased lactate concentration is thought to be a contributing factor to fatigue and dyspnoea experienced during exercise in patients with chronic heart failure.

However, more recent studies suggest that blood lactate concentrations are indeed much lower at peak and submaximal exercise in patients with heart failure compared with controls and therefore increased blood lactate production does not contribute to the exercise intolerance experience by the patients with heart failure.

(ii) Skeletal muscle abnormalities

(a) Histological and biochemical abnormalities in skeletal muscle biopsies of patients with chronic heart failure

Recent studies report that patients with heart failure identify leg fatigue as the limiting factor during exer-
cise720 and that the stride length of walking is reduced in patients with chronic heart failure. The study of skeletal muscle as the possible cause of exercise intolerance in these patients has gained popular interest.

A review of histological and biochemical findings of previous studies of skeletal muscle samples from patients with chronic heart failure is presented in Table 1. Abnormalities of skeletal muscle fibre morphology, cellular organelles, capillary structure and biochemical alterations have been described in these patients (Figure a + b).

Recent work by Lipkin et al., Mancini et al. and Minotti et al. suggests that skeletal muscle atrophy occurs early in the course of congestive heart failure and might play a role in the reduction of functional capacity in patients with chronic heart failure. Compared to normal muscle, atrophied muscle is subjected to a greater workload per remaining fiber when faced with a given external load and therefore develops greater reductions in PCr and intracellular pH.

Mancini et al. recently tested this hypothesis by correlating calf muscle volume with the metabolic response of the calf muscle to exercise during supine plantar flexion against increasing force. They discovered that skeletal muscle atrophy contributed significantly to the abnormal metabolic response to exercise, but that the correlation was relatively weak, suggesting that increases in muscle mass would produce only modest improvements in exercise capacity, and that the primary factor causing reduced pH and PCr during exercise is not skeletal muscle atrophy.

A possible cause of skeletal muscle atrophy in patients with chronic heart failure is chronic malnutrition and deconditioning due to reduced levels of habitual activity. Carr et al. reported that 50% of 48 patients in severe heart failure were malnourished, defined by a decrease in percent body fat, a decreased weight to height index, or reduced serum albumin concentrations. However, they did not measure skeletal muscle volume. Mancini et al. showed that muscle atrophy was not usually associated with signs of severe malnutrition and that protein synthetic function was maintained in heart failure. They also reported that anorexia was not the sole aetiological factor for the muscle atrophy; other factors include inactivity, an increased catabolic state due to heightened sympathetic stimulation and increased serum concentrations of cortisol, ACTH, and tumor necrosis factor.

Diaphragmatic muscle atrophy has been described in patients who are chronically ill and in patients with chronic obstructive lung disease who have lost weight. Indeed, diaphragmatic muscle changes occur in patients with heart failure and could contribute to the generation of dyspnea during exercise and indeed to Cheyne-Stokes breathing. Other researchers have recently reported a shift of fast to slow myosin heavy chain isoforms with an increase in oxidative capacity and a decrease in glycolytic capacity in biopsies of the diaphragm muscle of patients with cardiac failure. These changes mirror those noted following endurance training in limb musculature of normal individuals and might be due to increased limb...
muscle ergoreflex activity from damaged peripheral skeletal muscle in patients with heart failure, which in turn leads to increased ventilation.\textsuperscript{106}

Gibson et al\textsuperscript{[11]} reported that immobility in patients with heart failure is associated with a 25% fall in protein synthesis in quadriceps muscle. However, as skeletal muscle regains normal protein synthesis after heart transplantation,\textsuperscript{102} even though patients remain relatively immobile after heart transplantation, immobility cannot be the sole cause of this skeletal muscle abnormality.

Although skeletal muscle atrophy may be caused by inactivity and bedrest, Poole-Wilson et al\textsuperscript{[11]} reported that histological abnormalities seen in patients with chronic heart failure are not typical of the changes seen as a result of either prolonged bedrest or of reversible ischemia caused by peripheral vascular disease.

Increased subsarcolemmal mitochondrial aggregates have been reported in children with cardiomyopathy and chronic heart failure.\textsuperscript{11} Conversely, cardiac conduction defects have been described in many patients with mitochondrial myopathy,\textsuperscript{87,109} suggesting that the myopathy is generalized.\textsuperscript{11}

(b) Capillary abnormalities

Longhurst et al\textsuperscript{[12]} studied biopsies from pronator teres muscle and found capillary basement membrane thickening in patients with heart failure compared to a control group. Wroblewski et al\textsuperscript{[13]} documented increased capillary basement membrane thickening in the skin in patients with chronic heart failure and suggested that increased venous pressure due to heart failure and abnormal baroreceptor-mediated arteriolar vasodilation\textsuperscript{14} raised capillary pressures in these patients. This enhanced stress could eventually lead to increased thickness of these basement membranes. Some studies suggest that basement membrane thickening is a result of repeated episodes of cell death and cell regeneration and may decrease diffusion across the capillary.\textsuperscript{142,143} However, Alpert et al\textsuperscript{[15]} studied increased basement membrane thickness in diabetes and suggested that the increased thickness facilitates rather than retards oxygen diffusion.

(c) Glycolytic and mitochondrial enzyme activities

Whilst the skeletal muscle glycolytic enzyme activities are not reduced in CHF\textsuperscript{[16,17]} reduced activities of the enzymes involved in aerobic metabolism (succinate dehydrogenase and cytochrome oxidase) is a common finding in these patients.\textsuperscript{14,16,31,96,103,125} Some researchers have found respiratory exchange ratios to be lower at maximal and at submaximal exercise in patients with chronic heart failure compared to controls.\textsuperscript{109,170,174} The decreased values in the patients could be explained by an increased reliance on fat, as opposed to carbohydrate metabolism in these patients in an effort to preserve skeletal muscle glycogen stores.

(d) Oxidative enzyme activity

Reduced oxidative capacity of skeletal muscle enzymes involved in aerobic metabolism, including succinate dehydrogenase and cytochrome oxidase, is a common finding in patients with heart failure.\textsuperscript{150,154,154,155,156} Drexler et al\textsuperscript{[16]} reported a close relationship between the oxidative capacity of skeletal muscle and VO\textsubscript{2} peak during exercise in patients with chronic heart failure, and suggested that the extent of alteration of skeletal muscle metabolism was related to exercise capacity in these patients. Furthermore, Stratton et al\textsuperscript{[17]} reported that training improved oxidative capacity of forearm skeletal muscle, indicating that the impaired oxidative capacity may be due to inactivity and responds to a period of training. However, Lipkin et al\textsuperscript{[18]} reported that skeletal muscle oxidative enzyme activity was within the normal range in patients with severe chronic heart failure. This finding is supported by Minotti et al\textsuperscript{[19]} who reported that since oxygen extraction by skeletal muscle is near complete in these patients, skeletal muscle metabolic disorders are not likely to substantially limit maximal exercise performance.

(c) Increased blood concentrations of tumor necrosis factor

Increased circulating concentrations of tumor necrosis factor (TNF) in skeletal muscle of patients with heart failure have been measured. However, this cytokine is not present in all patients with cardiac abnormalities.\textsuperscript{144,145} Furthermore, Drexler et al\textsuperscript{[15]} recently reported that circulating concentrations of tumor necrosis factor do not correlate with the extent of skeletal muscle damage.

In summary, few studies have examined skeletal muscle abnormalities and whilst some studies have documented gross ultrastructural changes in the skeletal muscles of patients with chronic heart failure,\textsuperscript{68,77} few studies have yet provided a detailed description of these changes or have provided adequate control groups to establish the specificity of these changes to heart failure.

**SKELETAL MUSCLE FUNCTION IN PATIENTS WITH CHRONIC HEART FAILURE**

(i) Isometric skeletal muscle function

Studies of isometric skeletal muscle function have produced conflicting results. This is possibly due to differences in exercise protocol used in various studies, size of the muscle group examined and correction for lean muscle mass or cross sectional area.

Several studies have reported that skeletal muscle function is impaired in patients with heart failure, even when the heart failure is mild.\textsuperscript{15,71,104} Lipkin et al\textsuperscript{[15]} documented that isometric maximal voluntary contraction of quadriceps muscles of heart failure patients was 85% of the predicted strength for an age-, mass- and sex-matched population even after taking into account the decrease in cross-sectional area of the muscle, but no control group was actually tested.

Muscle cross-sectional area in healthy subjects is directly related to force development\textsuperscript{15,105} and it has been assumed that decreased cross-sectional area of skeletal muscle causes decreased skeletal muscle strength in patients with heart failure.\textsuperscript{70}

Buller et al\textsuperscript{[17]} reported that supramaximal repetitive stimulation of a large muscle mass (quadriceps) caused rapid onset of fatigue and reduced isometric force production in patients with severe heart failure compared to patients with mild heart failure and controls, whereas force production and fatigue of adductor pollicis was not different between groups.
However, the maximal isometric force production per unit muscle cross-sectional area was within the normal range (according to norms of Chapman et al)\(^a\). This led to the conclusion that the reduction in force for the larger muscle mass was not due to impaired force production by the myofibril. Minotti et al\(^a\) reported that maximal voluntary contraction was not different in patients compared to control subjects even though maximal cross-sectional area of the knee extensors was significantly smaller in the patients. They also found a strong correlation between isometric strength and maximal cross-sectional area of the thigh muscles. In addition, Magnusson et al\(^a\) found that although the isometric strength of the quadriceps femoris muscle of these patients was 14% less than age-matched controls, the tension per unit of muscle cross-sectional area was similar between groups, which is in accordance with the report of Budoric et al.\(^a\)

More recently Harridge et al\(^a\) studied contractile characteristics and resistance to fatigue in male patients with chronic heart failure. These researchers found that maximal voluntary isometric contraction was similar for patients and controls, however, a faster isometric twitch time course was observed in the patients with heart failure compared with controls. The poor resistance to fatigue was confirmed in this study by using twitch interpolation. This was shown not to be due to poor skeletal muscle activation. These findings indicate that independent of muscle strength, patients with heart failure have impaired resistance to muscle fatigue. However, the increased fatigability seems not to be due to poor muscle activation.\(^a\)

(II) Isokinetic skeletal muscle function

Minotti et al\(^a\) measured peak torque and endurance during isokinetic knee extensions in these patients and found that dynamic muscle endurance was significantly lower in patients compared to controls. Furthermore there was only a weak correlation between dynamic endurance and knee extensor cross-sectional area in these patients.\(^a\) Also, Magnusson et al\(^a\) reported a markedly lower dynamic endurance capacity of the quadriceps femoris muscles in patients with chronic congestive heart failure compared to age-matched controls, but there was no difference in peak tension per unit of cross-sectional area of the skeletal muscle. Thus it appears that diminished skeletal muscle endurance capacity during repetitive exercise is the most consistent finding in these patients, and that a reduction in muscle strength is not always a consistent finding, especially when the cross sectional muscle area is taken into account.\(^a\)

(iii) Skeletal muscle recruitment

It has been suggested that central nervous system inhibition of skeletal muscle afferents may limit exercise during hypoxia or hyperperfusion in normal subjects.\(^a\) It is not known whether this is due to a feed-forward or feedback mechanism from damaged or hypoxic skeletal muscle, or whether this mechanism could affect exercise tolerance in patients with chronic heart failure.

Minotti et al\(^a\) measured amplitude and area of the M wave (compound muscle action potential) decline during progressive, fatiguing exercise in an attempt to determine whether the accelerated fatigue in these patients is due to impaired muscle activation as a result of inadequate central motor drive or neuromuscular transmission, or by a change in muscle itself. Their findings indicate that the more rapid onset of muscle fatigue in patients with congestive heart failure is not caused by impaired central motor drive or neuromuscular junction transmission. Rather, they suggest that this fatigue is caused by an abnormality in the muscle itself.

(iv) Additional factors and their possible effect on exercise performance in patients with chronic heart failure

It is possible that the medication ingested by patients with chronic heart failure, chronic deconditioning due to heart failure, or the age of the patient might also contribute to the impaired exercise performance of these patients.

(a) Effects of medication on exercise performance in patients with heart failure

Ingestion of medication plays a key role in the management of symptoms in patients with chronic heart failure and the effect of these agents on exercise performance requires consideration. A recent significant development in medical management of heart failure is the introduction of angiotensin converting enzyme (ACE) inhibitors. Chronic ingestion of either captopril and enalapril not only improves signs and symptoms of heart failure and increase exercise performance, but reduces mortality in patients with chronic heart failure.\(^a\)

The negative inotropic effect of beta blockers causes haemodynamic and clinical deterioration in patients with heart failure,\(^a\) and may also cause an increased rate of perceived exertion during submaximal exercise effecting either the central nervous system or skeletal muscle in these patients.\(^a\) Diuretics are effective in reducing total body sodium and water content, and thus relieving the symptoms due to fluid retention in patients with heart failure, but there are no data to suggest that they improve quality of life or exercise tolerance in these patients. Digitalis does appear to be effective in improving prognosis in patients with heart failure,\(^a\) but the benefits are confined to those patients who have markedly dilated left ventricles, with markedly impaired systolic function.

(b) Physical deconditioning

Patients with heart failure are less physically active than normal healthy controls. The pattern of skeletal muscle changes seen in patients with chronic heart failure is consistent with the effects of chronic exercise deconditioning, but the magnitude of these changes exceeds those which occur after exercise deconditioning in normal subjects.\(^a\) In both states there is exercise intolerance, sympathetic activation, increased resting heart rate, reduced heart rate variability, atrophied skeletal muscle and reduced activity of skeletal muscle oxidative enzymes.\(^a\) Deconditioning appears to be one factor involved in the development of these potentially reversible skeletal muscle alterations\(^a\) and for the impaired peripheral vasodilatation during exercise in patients with chronic heart failure.\(^a\)
As various physiological changes occur with increasing age, it is important that these changes are considered when the physiological response to exercise in patients with heart failure is gauged. Although it has been reported that oxygen consumption, cardiac output, stroke volume, ejection fraction, heart rate and Frank-Starling response at maximal exercise are significantly reduced in normal elderly subjects compared to younger subjects, the muscle strength of patients with chronic heart failure is significantly less than age-matched, sedentary controls. Hence, while cardiovascular function is attenuated in both healthy elderly persons and elderly persons with chronic heart failure, skeletal muscle strength appears to be affected to a greater extent in patients with chronic heart failure than in age-matched sedentary controls.

**SUMMARY**

Exercise performance is markedly reduced in patients with heart failure but the mechanism explaining the exercise intolerance has not been precisely defined. Previously, central cardiorespiratory factors were the main focus of researchers, who measured mainly central physiological variables during exercise to determine the limitation of exercise in these patients. The many inconsistencies discussed in this review indicate that other factors could be responsible for exercise intolerance in these patients. More recently, exercise intolerance in patients with heart failure has been explained by abnormalities in peripheral blood flow, skeletal muscle structure, and in skeletal muscle metabolism. It is probable that whilst both central and peripheral factors contribute to the exercise intolerance in these patients, patients may be limited more by disease of skeletal muscle than by dyspnoea or central fatigue.

**Table 1. Review of histological and biochemical findings in studies of skeletal muscle biopsies in patients with chronic heart failure.**

<table>
<thead>
<tr>
<th>Structure</th>
<th>Finding</th>
<th>Study</th>
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<tr>
<td><strong>Fibre Morphometry</strong></td>
<td></td>
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<tr>
<td>Type I CSA</td>
<td>increased</td>
<td>Sullivan et al. 1990.</td>
</tr>
<tr>
<td></td>
<td>decreased</td>
<td>Lipkin et al. 1988.</td>
</tr>
<tr>
<td>Type II CSA</td>
<td>decreased</td>
<td>Dunnigan et al. 1987.</td>
</tr>
<tr>
<td>Type I %</td>
<td>increased</td>
<td>Mancini et al. 1989.</td>
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<td></td>
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<td>Sullivan et al. 1990.</td>
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<td>Type II %</td>
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<td>Mancini et al. 1989.</td>
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<td></td>
<td></td>
<td>Sullivan et al. 1990.</td>
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<tr>
<td><strong>Capillaries</strong></td>
<td></td>
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</tr>
<tr>
<td>Basement membranes</td>
<td>thickened</td>
<td>Longhurst et al. 1975.</td>
</tr>
<tr>
<td><strong>Intracellular lipid content</strong></td>
<td>normal</td>
<td>Drexler et al. 1992.</td>
</tr>
<tr>
<td></td>
<td>increased</td>
<td>Dunnigan et al. 1987; Lipkin et al. 1988; Smith et al. 1976.</td>
</tr>
<tr>
<td><strong>Intracellular glycogen content</strong></td>
<td>normal</td>
<td>Drexler et al. 1992.</td>
</tr>
<tr>
<td></td>
<td>decreased</td>
<td>Sullivan et al. 1990.</td>
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<tr>
<td><strong>Oxidative enzyme activity</strong></td>
<td></td>
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<tr>
<td>Cytochrome oxidase</td>
<td>decreased</td>
<td>Drexler et al. 1992; Ralston et al. 1991; Lipkin et al. 1988.</td>
</tr>
<tr>
<td>Succinate dehydrogenase</td>
<td>decreased</td>
<td>Ralston et al. 1991; Mancini et al. 1989; Sullivan et al. 1990; Sullivan et al. 1990;</td>
</tr>
<tr>
<td>β-hydroxysteroyl CoA dehydrogenase</td>
<td>decreased</td>
<td>Bussieres et al. 1997</td>
</tr>
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</table>

Abbreviations: CSA, cross sectional area.


Performance indicators of elite beach volleyball players

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ABSTRACT

Objectives: This study analyzed heart rate, blood lactate and motion patterns of South African (SA) and Overseas (OS) professional beach volleyball players.

Methods: Thirty two subjects participating in the World Beach Series, Cape Town, 1995, volunteered with written informed consent (SA=20; OS=12). Anthropometric measures included stature, mass and percentage body fat. Physiological parameters included heart rate monitoring during match-play recorded by the Polar Heart Watch Sports Tester. Blood lactate was measured after match-play using the Acusport Blood Lactate Analyzer. Motion analysis was recorded during match-play and included; jump serve, serve, block, dig, volley, run and dive. This information was synchronised with the heart rate data.

Results: Results indicated that OS players were significantly (p<0.05) older, taller, heavier and lower in percentage body fat, compared to SA players. Mean heart rate (beats.min⁻¹) during match-play was not significantly different (SA=157.94 vs OS=155.66) neither was maximal heart rate (SA=182.20 vs OS=180.66). No significant difference was observed in post-match blood lactate concentrations (mmol⁻¹) for both groups (SA=3.83 vs OS=2.85). The frequency of motion technique utilization was similar for SA and OS players with the exception of service and volley technique. Connee et al. investigated glycogen depletion by muscle fibre staining as a result of volleyball match-play. They reported after examining pre- and post-match muscle staining of slow and fast twitch muscle fibres, the mean percentage depletion of glycogen in slow twitch fibres was 36% as compared to 6.5% in fast twitch fibres. This may suggest that the increased glycogen depletion of slow twitch fibres as compared to fast twitch fibres in this study illustrates a significant involvement of the aerobic energy pathways during volleyball match-play. Kunstlinger et al. reported elevated concentrations of free fatty acids after volleyball match-play, implying an increased contribution by the oxidative metabolism in well-trained players. Indications of energy production by the anaerobic pathways during the dynamic high intensity movements including spikes and blocks were shown by

INTRODUCTION

There appears to be a paucity of research regarding the sport of “2 Man” beach volleyball. This study sought to redress this shortcoming by examining heart rate, blood lactate and motion analysis of participants at the World Series Beach Volleyball Championships, Cape Town 1995.

Although beach volleyball may be construed to be an emerging sport in comparison to other sports, including “6 versus 6” indoor volleyball, it has however gained increased importance at both recreational and professional levels. This is perhaps best reflected by the inclusion of beach volleyball at the 1996 Olympic Games, and the ‘1996 World Series’ offering 4.5 million US Dollars in prize money.

Beach volleyball would appear to be a sport characterised by short periods of intense physical activity, followed by longer periods of less intense activity. Motion analysis of patterns of play for beach volleyball appear to be lacking, although this has been well researched for the indoor code, along with other sporting codes such as rugby, soccer, handball, waterpolo, and ice-hockey goal tending.

Physiological studies of the indoor code have identified the predominant energy requirements during match-play. Smith et al. consider the indoor game to be aerobic in nature, combined with a high anaerobic component. Connee et al. investigated glycogen depletion by muscle fibre staining as a result of volleyball match-play. They reported after examining pre- and post-match muscle staining of slow and fast twitch muscle fibres, the mean percentage depletion of glycogen in slow twitch fibres was 36% as compared to 6.5% in fast twitch fibres. This may suggest that the increased glycogen depletion of slow twitch fibres compared to fast twitch fibres in this study illustrates a significant involvement of the aerobic energy pathways during volleyball match-play. Kunstlinger et al. reported elevated concentrations of free fatty acids after volleyball match-play, implying an increased contribution by the oxidative metabolism in well-trained players. Indications of energy production by the anaerobic pathways during the dynamic high intensity movements including spikes and blocks were shown by

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changes in electrolyte and catecholamine levels.\textsuperscript{15}

Smith et al.\textsuperscript{16} considered that during international indoor volleyball matches, fitness, physical characteristics and skill are the key factors determining performance. This may also be the case for beach volleyball for there is little doubt that the underlying principles of match-play for the two volleyball codes are similar. However the two codes are distinct from each other with regard to the following factors. Beach volleyball is a 2-aside game, while indoor volleyball is 6-aside, but both are played on a court 9m by 18m. The playing surface of beach volleyball is sand, a placeable/compliant substrate, which raises the metabolic cost of motion by as much as 100\% compared to a hard surface.\textsuperscript{19}

Climatic and geographic factors are also likely to affect performance. This is because the major beach volleyball competitions in the world, including the World Beach Volleyball Series take place almost exclusively during the summer months. The combination of several strenuous games in a day with relatively high temperatures and humidity, in energy sapping sand is likely to raise the metabolic cost of playing, and increase the risk of dehydration.\textsuperscript{14,15} Murray makes the observation that when a competitive psyche from a cool, temperate climate meets a warm and humid environment without considering acclimatization, the results can be disastrous for both performance and health.\textsuperscript{16}

The World Series Beach Volleyball Tour was staged in Cape Town, 1995, attracting many of the best players from both South Africa and Overseas. Participants were studied to identify anthropometric characteristics and motion-patterns. Physiological demand on the players was assessed using continuous heart rate monitoring and postmatch blood lactate concentrations. The organisation of the World Series allows the host nation to enter significantly more teams (n=15) than would normally occur. This meant that subject numbers allowed for a comparison between South African (SA) and Overseas (OS) players. The aim of this study is to identify anthropometric and physiological characteristics of successful players, as well as their preferred patterns of play.

**METHODS**

20 South African (SA) and 12 Overseas (OS) professional beach volleyball players participated in this study with written informed consent.

Climatic parameters included dry and wet bulb temperature readings (°C) along with wind speed measures (m/sec). A sling psychrometer was rotated three minutes prior to each match in a shaded area for one minute whereupon dry and wet bulb temperature readings were recorded. Relative humidity was derived from a psychometric chart conversion of dry and wet bulb readings.\textsuperscript{17} Wind speed data was collected by a TurboMeter\textsuperscript{20} wind speed indicator, Davis Instruments, Hayward, California, USA, sampling wind speed (m/sec) every ten seconds for two minutes prior to the match with the mean value being recorded. Matches were played at either Camps Bay beach or on the man-made courts at the Waterfront in Cape Town, site of the World Series.

**Anthropometric measures** included stature and body mass as described by Tanner.\textsuperscript{19} Percentage body fat was calculated from skinfold measures of four sites, namely biceps, triceps, supra iliac and subscapular according to the method of Durnin and Womersley.\textsuperscript{10}

**Physiological measures** involved the recording of heart rate during competitive matchplay and blood lactate sampling immediately after the game. Heart rate was measured by the telemetric Polar Heart Watch ‘Sports Tester’, a portable heart-rate monitor set at 5 second record intervals. The transmitter and electrode strap was placed around the subject's chest at the level of the inferior border of the pectoralis muscles. The 'watch'/receiver was located on the back of the subject, attached to the electrode strap between the scapulae. The reason for not wearing the 'watch'/receiver on the wrist, was to avoid high impact with the ball during spiking, blocking, digging and diving actions. It was anticipated that this high impact might damage the ‘watch'/receiver itself and distort the telemetric transmission. After the game the heart rate data was downloaded onto a computer where it was analyzed via the Polar Heart Rate Analysis Software.\textsuperscript{20} An example of the graphic representation of heart rate response during a game can be observed in Figure 1.

Blood lactate was analyzed using the Acusport Blood Lactate Analyzer from Bohringer. Within 2 minutes of the conclusion of a match the finger was pricked with a lancet, the suspended globule of blood was allowed to drop onto the test strip, which was then inserted into the Acusport for analysis.\textsuperscript{21}

**Motion analysis** was recorded during actual play. A recorder observed one player during a game and noted down on a running spread sheet every major motion that the player performed. The different patterns of play were synchronised with heart rate data in order to study the physical strain associated with each major motion. Eight major motions were noted, namely: Jump Serve, a serve whereby the player jumps up in

\textbf{Figure 1: An example of a smoothed heart rate plot during match-play}
the air and hits the ball hard with heavy top spin; Serve, a regular tennis style action where the player stands and strikes the ball above his head; Block, a defensive action where a player jumps at the net and attempts to stop an offensive action (hit/spike) by presenting a barrier with both arms out stretched above the net band; Dig, a passing technique where the player plays the ball with clasped hands and straight arms off the forearms; Volley, where the ball is played above the head with the fingers of both hands in a clean manner; Hit/Spike, an attacking shot where the player jumps as high as possible at the net, enabling him to hit/spike the ball down into the opponent’s court; Run, when a player runs more than 3m to chase or retrieve a ball; Dive, when a player in order to play the ball is forced to throw himself or sprawl in the sand. Video recordings were taken of match-play as a back up to the in situ motion analysis recording.

Statistical analysis was performed by the Statgraphics software package, Version 5. Summary statistical analysis included means and standard deviations, along with One-Way Analysis of Variance (ANOVA) at \( p < 0.05 \).

RESULTS

Anthropometric data of both SA and OS players are shown in Table 1. It was noteworthy that the OS players were significantly \(( p < 0.05 )\) taller, heavier, lower in percentage body fat and older when compared to SA players.

Physiological parameters in Table II show the means and standard deviations of total, maximal and mean heart rates during match play. It was interesting to note that there is little difference between the maximal and mean heart rates of SA and OS players.

| TABLE I: Means and Standard Deviations anthropometric data of South African (SA) and Overseas (OS) players. |
|----------------------------------------------------------|----------------------------------------------------------|
| **SA** \(( n = 20 )\) | **OS** \(( n = 12 )\) |
| Stature (cm) | 184.94 (5.9) | 190.75 (5.49) |
| Mass (kg) | 77.67 (8.14) | 88.66 (3.47) |
| % Body Fat | 15.95 (3.09) | 12.38 (4.55) |

* indicates a statistical difference at \( p < 0.05 \)

There was a significant difference between the two groups with regard to total heart rate, and this was directly related to the difference in the mean length of the games of the two groups analyzed \( (SA=25.18 \text{ mins and OS}=37.45 \text{ mins}) \). Blood lactate concentrations 2 minutes after the game showed no significant difference between SA and OS players (Table II).

Climatic conditions were ascertained by measurement of wet and dry bulb temperature, wind speed and relative humidity (Table III). The climatic conditions experienced by both SA and OS players during match play were not significantly different.

Motion analysis data can be observed in Table IV which indicates the mean time lapse between specific motions. This is a way of presenting the frequency at which each motion technique was utilized. SA and OS players had similar frequency rates for the block, dig, hit/spike, run and dive. The two groups differed with regard to the type of serve used and to a lesser extent the volley technique. Table IV also shows the mean time lapse \( (\text{secs}) \) between all motion techniques \((SA=20.88 \text{ secs vs OS}=20.78 \text{ secs})\), as well as between high intensity motions \((SA=41.41 \text{ secs vs OS}=38.22 \text{ secs})\), which includes jump serve, block, hit/spike, run and dive. The time-lapse between all monitored motions and high intensity motions were comparable for SA and OS players.

| TABLE III: Means and Standard Deviations for wet bulb, dry bulb \((^\circ C)\) and wind speed \((\text{m.sec}^{-1})\), along with relative humidity \((\%)\) encountered by South African (SA) and Overseas (OS) players during match play. |
|----------------------------------------------------------|----------------------------------------------------------|
| **SA** \(( n = 20 )\) | **OS** \(( n = 12 )\) |
| W. Bulb | 20.21 (3.01) | 20.75 (3.81) |
| D. Bulb | 26.73 (6.15) | 27.50 (6.31) |
| W. Speed | 1.76 (1.01) | 1.41 (1.22) |
| Humidity | 50 | 50 |

* indicates a significant difference at \( p < 0.05 \)

| TABLE IV: Mean time-lapse between individual motion \((\text{mins})\) and combined motion frequency \((\text{secs})\) of South African (SA) and Overseas (OS) players during match play. |
|----------------------------------------------------------|----------------------------------------------------------|
| **SA** \(( n=20 )\) | **OS** \(( n=12 )\) |
| Jump serve \((\text{mins})\) | 4.24 | 2.51 |
| Serve \((\text{mins})\) | 3.08 | 5.19 |
| Block \((\text{mins})\) | 3.03 | 2.40 |
| Dig \((\text{mins})\) | 1.21 | 1.24 |
| Volley \((\text{mins})\) | 2.37 | 3.37 |
| Hit/spike \((\text{mins})\) | 1.42 | 1.44 |
| Run \((\text{mins})\) | 3.07 | 3.25 |
| Dive \((\text{mins})\) | 6.27 | 6.28 |
| All Motion \((\text{secs})\) | 20.97 | 20.76 |
| High intensity \((\text{secs})\) | 41.69 | 38.22 |

* indicates a significant difference at \( p < 0.05 \)
Table V: Temporal analyses of indoor volleyball (1979 - 1987) and beach volleyball (present study) with regard to mean rally length, rest duration (secs) and rally-rest ratio.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Mean duration of rally</td>
<td>Mean duration of rest</td>
</tr>
<tr>
<td>9.7 9.0 7.0 6.6 5.29</td>
<td>11.7 12.0 13.3 14.2 19.08</td>
</tr>
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</table>

DISCUSSION

It has been observed in previous studies that temperature and relative humidity can have a significant effect on selected physiological responses including heart rate and levels of blood lactate during exercise. It was clear that temperature and relative humidity experienced by the two groups namely SA and OS beach volleyball players was very similar, and therefore did not confound or skew the data (Table III).

SA and OS players were significantly (p<0.05) different in terms of stature, body mass and percentage body fat, with the OS players being taller, heavier and leaner. Previous studies of the indoor code suggest that elite players have greater stature, higher body mass and lower percentage body fat, when compared to lower standard performers. In order to hit/spike and block effectively it is necessary to be able to play the ball above the net, therefore greater stature is advantageous. Jumping ability also plays an important part when attempting to hit/spike or block the ball.

The OS players were in most cases experienced members of the World Series Tour and were more likely to be full-time professionals, while the SA players were in most cases semi-professional, whose experience of pro-beach volleyball was largely restricted to domestic competitions. Greater frequency of high level tournaments at international level of the OS players has probably resulted in greater concern about dietary intake and training preparation with regard to optimising performance, and could account for the lower percentage body fat of these players when compared to SA players.

The maximal heart rate (beats.min⁻¹) for the two groups was highly comparable (SA=182.2 vs OS=180.66) along with mean heart rate (SA=157.9 vs OS=155.6). This would appear to imply that SA and OS players have similar peak and mean levels of exertion during match-play, as indicated by heart rate response. Previous studies of heart rate during indoor volleyball match play show it to be less strenuous than the findings in this study, with the following average heart rates (beats. min⁻¹) reported: 110-125.15, 155,16 139,17 144,18 and 127.19

The only major divergence in heart rate analysis concerned total heart rate per game, and this is linked unquestionably to game length. The OS players spent a significantly (p<0.05) longer period on court than their SA counterparts, thus their greater total heart rate (SA=4135.47 beats.match⁻¹ vs OS=6139.17 beats. match⁻¹).

The post match concentrations of blood lactate for SA and OS players (8.83 and 2.85 mmol.l⁻¹, respectively) were relatively low and concurred with similar findings for indoor volleyball of 2.57 mmol.l⁻¹ and 0.85 mmol.l⁻¹. These observations indicate that during the rally-phases of both beach and indoor volleyball, energy is predominantly supplied by phosphagen breakdown (ATP/CP) for the first few (2-3) seconds of work, coupled by an increasing contribution by glycolysis as the exercise duration lengthens. Thus, there is an interplay between all three energy systems (ATP/CP, glycolysis and oxidative metabolism) to provide energy for work. During less intense phases of play, namely non-rally phases the oxidative metabolism replenishes depleted ATP/CP stores. This contention appears to be supported by the findings of Essen and Kajser who reported that during intermittent exercise of 15 seconds work and 15 seconds rest, the ATP/CP concentrations were largely replenished during the recovery phase. This oscillating demand made upon the energy systems of the body is a reflection of the intermittent nature of beach volleyball. The work to rest ratios in this study were 1:3.5, comprising on average a rally-phase of 5.39 seconds and a non-rally-phase (recovery/partial recovery) of 19.08 seconds. The non-rally phases would also appear to facilitate the removal of lactate which may have accumulated during prolonged rally-phases whereas one would assume that an increased demand had been made upon glycolysis.

Motion analysis (Table IV) focused on the mean frequency at which each motion was performed by identifying mean time-lapse (minutes/seconds) between each defined motion. The time-lapse between all of the identified motions by SA and OS players was relatively comparable with the exception of the service and volley technique. Thus, SA players performed a jump serve on average every 4.24 minutes, while OS players performed the same motion significantly (p<0.05) more often every 2.51 minutes. Conversely SA players performed the standing serve more frequently, once every 3.08 minutes, while OS players did so every 5.19 minutes. The SA players used the volley technique every 2.37 minutes, whereas the OS did so only every 3.08 minutes, this was significantly different (p<0.05). The average frequency at which all motions were performed in relation to game length was once every 20.97 seconds for SA players and once every 20.78 seconds for OS players (Table IV). High intensity motion techniques such as the jump serve, block, hit/spike, run and dive occurred on average less frequently. SA players, performed one every 41.69 seconds and OS players once every 38.92 seconds. This would indicate that the pace at which elite beach volleyball was played, was similar for both SA and OS players and provides an explanation for the parity of mean and maximal...
heart rate values exhibited by both groups.

The average length of a rally was 5.39 seconds (SA and OS players) (Table V). This appears to be considerably shorter than reported mean rally length for the indoor code, characterised by average rally lengths of 9.7 secs1, 9.0 secs2, 7.0 secs3 and 6.6 secs4. Conversely, the average duration of the non-rally phase was longer for beach volleyball at 19.08 seconds, when compared to the indoor code, where rest times of 11.7 secs, 12.0 secs5, 13.8 secs6 and 14.2 secs7 have been reported (Table V). This indicates that beach volleyball has shorter rallies and longer rest periods (work to rest ratio = 1:3.5), as opposed to the indoor game, where (work to rest ratio varied between = 1:1.2, 1:1.3, 1:1.2 and 1:2.2) even though the general physiological exertion as indicated by heart rate was higher. An explanation of the substantially longer non-rally periods can be attributed to more permissible time outs (4 vs 2 per team compared to the indoor code) and end changes after every 5 points, which is not a feature of indoor volleyball and involves both teams having to walk and occupy ‘opposing’ ends. An explanation for the higher mean heart rate levels was probably due to the fact that only 2 players form a beach volleyball team as opposed to 6 players for the indoor code on a court the same size. Also the sand would appear to slow down the players around the court, as well as inducing increased energy cost.13 These factors probably diminish the likelihood of repeated exchanges (rallies) between teams, and result in shorter rallies than those reported for indoor volleyball. Another factor concerns the increased difficulty involved when defending against a typical power offence (hit/spike) in beach volleyball when compared to the indoor code. It is clear that a team must position their players defending against one person hitting/spiking, typified by a two man block and four other players covering the rest of the court, are more likely to be successful than two players attempting the same task. Thus the numerical advantage that a 6-aside team has over a 2-aside beach volleyball team, improves their defensive capabilities and contributes to longer rallies.

CONCLUSION

The data from this study indicate that beach volleyball is made up of short intense sequences of motion (rally-phases) that are on average 5.39 seconds in duration indicative of a predominant provision of energy by the ATP/CP systems for the initial phase of high intensity activity (2-3 seconds), along with glycolysis and the oxidative metabolism. These ‘rally-phases’ alternated with recovery ‘non-rally-phases’ which were on average 19.08 seconds in duration, and allowed for the replenishment of ATP/CP by the aerobic metabolism. Relatively low concentrations of blood lactate (3.84 mmol/l) found after match-play are probably due to the intermittent nature of beach volleyball. Thus, non-rally-phases which were on average 19.08 seconds provided sufficient time for the removal of any lactate that may have accumulated during rally phases. The aerobic energy system was utilised extensively, especially during non-rally-phases, when the players performed low and medium intensity motion on sand such as standing, walking and jogging. The aerobic energy system concomitantly replenished ATP/CP stores depleted during intense phases of match-play. The overall increased energy cost of beach volleyball was reflected in higher mean (159.5 beats.min-1) and maximal (181.43 beats.min-1) heart rate values relative to those found for the indoor code.

Motion analysis of the major techniques utilised in beach volleyball indicated that both SA and OS utilised similar motion techniques at comparable frequencies, with the notable exception of service and volley technique. The difference in the use of the volley pass, which is usually employed to set the ball up for an attack may be explained by the fact that some of the OS players were previously specialist international indoor volleyball players, whose roles rarely required them to volley. The beach volleyball rules on volleying are strict, and it is likely that the OS players in this study used the volley only when they had to, so as to avoid being penalized for handling errors. Apart from the type of service employed and the volley technique the patterns and frequency of play of the SA and OS players were highly comparable. This resulted in similar exertional profiles as indicated by heart rate response and blood lactate levels.

The results of this study should provide coaches and players of beach volleyball with scientifically derived information which can assist in preparation and match-play. Motion analysis highlighted desirable motion patterns of elite professional beach volleyball players, along with an insight into the exertional demands of the game. These factors should serve to improve the standard of performance, particularly for those players who are involved at competitive levels.

REFERENCES

The heart rate response of cricket umpires to on-field events

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INTRODUCTION

Due to the increased speed of bowlers and the complexity of cricket, the integral role of umpires within the game has necessitated a rise in standards with a high degree of accuracy and consistency. The introduction of the third or “TV” umpire has relieved the on-field umpires of making certain “line decisions” in internationals and Test matches. This has assisted in making the task of the umpire easier with regard to stumpings and run-out decisions, as well as in cases where doubt may exist as to whether the ball had crossed the boundary or not. This has, however, necessitated an increase in the number of TV cameras and slow motion replays available to the third umpire, as well as to the commentators and viewers who are able to view the incidence a number of times before making their “decision”. However, the on-field umpires have to make split-second decisions without the luxury of these slow motion television replays from a variety of different angles with any mistakes highlighted by “trial by television” re-plays. As the pressure increases on the umpire, the more likely he is to make the wrong decision with inaccuracy and inconsistency bringing the umpire under tremendous pressure and criticism.

Besides having to implement the laws of the game, the umpire is also required to arbitrate on issues of gamesmanship, “sledging” and personality differences. Umpires are expected to maintain alertness throughout the duration of the match, which may last up to six hours a day for five consecutive days in a Test match. An umpire who performs well goes largely unnoticed, while an umpire who is deemed to have erred is accused of incompetence and even bias. This constitutes immense psychological pressure.

Umpires, due to the fact that they need to gain experience before becoming eligible to umpire at provincial and international level, tend to belong to an age range that is older than the cricket players themselves. Umpires further differ from the players in that they are not professionals, generally holding full-time employment outside of the game of cricket.

Heart rate monitors have primary being used to evaluate the movement patterns and intensity of playing a variety of sports,1-5,8,9 with researchers having focused very little attention on the match official. Two Australian football field umpires recorded mean heart rates (HR) of 159 beats min\(^{-1}\) and 148 beats min\(^{-1}\), increasing to 175 beats min\(^{-1}\) when having to intervene in a scuffle between players.8 The resting HR of soccer referees were high (100 beats min\(^{-1}\)) before a match, averaging 165 beats min\(^{-1}\) (95% of the estimated maximal HR) for the duration of the match.8 In both studies the mean HR was similar for both halves of the match.8,9

ABSTRACT

Objectives: This study assessed the heart rate (HR) responses recorded every 15 seconds, of ten umpires (six provincial and four international umpires) to on-field events during limited-overs’ cricket matches.

Methods: Specific on-field events, including appeals, the umpires resulting decisions and any other tasks the umpire had to make such as calling a no-ball or a wide-ball, were recorded.

Results: The results showed that the umpires’ ratings of the on-field decisions varied from “below average” to “stressful” with regard to the amount of perceived stress they felt. The international umpires’ ratings indicated less perceived stress than the provincial umpires, who showed a far greater variance with regard to LBW, catch, run-out and wide-ball decisions. The mean HR rate before the commencement of the match (90±11.8 beats min\(^{-1}\)) and during the first (100±12.4 beats min\(^{-1}\)) and second innings (100±8.6 beats min\(^{-1}\)) of the match corresponds to approximately 60% of the umpires’ estimated maximal HR. The recorded HR varied from 68 beats min\(^{-1}\) to 127 beats min\(^{-1}\) at the time of the event, with the highest HR (139 beats min\(^{-1}\)) recorded 18s post event. Non-significant variations in the HR occurred during the various periods of the match for the whole group. The differences (D=0.7 beats min\(^{-1}\)) between the heart rates of the international umpires prior to the match and the first session of the first innings was significantly less (p<0.05) than the corresponding difference (D=7.5 beats min\(^{-1}\)) during the same period of the second innings, as well as between the second and the third sessions of the second innings, illustrating greater variation for the inexperienced umpires. Heart rate data of an umpire during a hat-trick (three wickets in three balls) during an international, showed anticipatory increase in HR for each delivery.

Conclusions: It can be concluded that the heart rate response of the umpires to on-field events indicate that they are under psychological pressure, with international umpires, although umpiring at a higher level, better able to handle these pressures.
The task of cricket umpiring was rated as "psychologically demanding" and in order to achieve and maintain high standards, umpires need to be introduced to the educative and performance enhancing applicability of psychological techniques. These include the setting of realistic performance goals, improving communication skills and the development of techniques to improve attention, concentration and confidence.

Therefore, the main aim of this study was to assess the HR response of cricket umpires to on-field events during provincial and international limited-overs matches. These findings would provide a better understanding of the psychological and physiological demands of umpiring, which in turn could improve the mental and physical preparation of the umpires in order to meet specific on-field demands, thereby raising the standard of umpiring.

METHODS

The subjects consisted of ten umpires who were on the South African Cricket Umpires Association provincial panel. Four of these umpires had umpired at international level, with the other six umpires having umpired at provincial level. Consent was obtained from the South African Cricket Umpires Association and all subjects following an explanation of the investigation.

The data collection took place during three official 50-over day-night provincial fixtures of the United Cricket Board of South Africa and two official 50-over day-night international fixtures during the quadrangular series between South Africa, New Zealand, Sri Lanka and Pakistan. All these matches were played at Buffalo Park, East London.

Heart rate monitoring

The HR was recorded for the full duration of each match by means of short-range telemetry using the Polar Sport Tester (Vantage XL, Polar USA, Stanford, Connecticut, USA). Rubber electrodes made contact with the skin and were held in position just beneath the pectoral muscles by an elastic strap. The HR signal was transmitted to a microcomputer receiver worn on the wrist. The receivers were programmed to measure and store the HR readings every 15 seconds. At the end of the match these data were downloaded into an IBM PC using an interface and software purchased from the manufacturers (Polar Computer Interface, Polar USA) for later analysis.

The HR monitor was placed on the subject 20 minutes before the start of the match, with the collection of the HR commencing 15 minutes before the start of play. This allowed the subject time to become familiar with the equipment. The collection of HR continued until 5 minutes after the end of the match. The commencement of the collection of the HR data was synchronised with a stop watch in order to relate the HR to specific on-field events which were recorded. These included appeals and resulting decisions made by the umpire, and any other tasks or decisions that the umpire had to make such as calling a no-ball or a wide-ball. However, due to the fact that a number of these categories did not contain enough data it was decided to consider only the catch - out, catch - not out, Leg before wicket (LBW)- out; LBW - not out; run-out; no-ball; and wide-ball. Therefore, the main aim of this study was to assess the HR response of cricket umpires to on-field events during provincial and international limited-overs matches. These findings would provide a better understanding of the psychological and physiological demands of umpiring, which in turn could improve the mental and physical preparation of the umpires in order to meet specific on-field demands, thereby raising the standard of umpiring.

In order to assess the differences between the on-field responses of the umpires the HR at the time of the occurrence of the umpire's decision, 15s after the occurrence and 30s after the occurrence were analysed. To gain further insight into the umpire's responses, differences between the HR at the time of the event and 15s post event (D1), as well as the differences 15s and 30s post event (D2) were investigated. It was felt that such differences could be assumed to be normally distributed. The responses of the umpires to select on-field events were divided into the following categories: catch - out, catch - not out, Leg before wicket (LBW)- out; LBW - not out; run-out; no-ball; and wide-ball. However, due to the fact that a number of these categories did not contain enough data it was decided to consider only the catch - out, catch - not out, LBW - out and LBW - not out.

As the HR was collected during the actual match situation it was not possible to control for or take into account factors such as the time of the day of the HR measurements, food or liquid ingested, tobacco or medication used before or during the match, and the posture or change in posture during the recording of the HR, which all have a significant effect on the HR response.

The umpires were required to complete a questionnaire on their perceived rating of how stressful they found making certain on-field decisions. These included the following decisions: LBW, catch close to and behind the wicket, run-out and deciding on a "wide-ball" and a "no-ball".

Statistical Analysis

Single variable statistics were computed using the SAS Package with the results expressed as means and standard deviation (± SD). A Student's t test was used to determine differences between the provincial and international umpires, with statistical significance accepted for P values <0.05.

<table>
<thead>
<tr>
<th>TABLE I: Biographic data and umpiring experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Umpires</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Umpiring Experience (years)</td>
</tr>
<tr>
<td>Club</td>
</tr>
<tr>
<td>Provincial</td>
</tr>
<tr>
<td>International</td>
</tr>
<tr>
<td>Limited-overs matches umpired(#)</td>
</tr>
<tr>
<td>Provincial</td>
</tr>
<tr>
<td>International</td>
</tr>
<tr>
<td>First-class matches umpired(#)</td>
</tr>
<tr>
<td>Provincial</td>
</tr>
<tr>
<td>Test matches</td>
</tr>
</tbody>
</table>
RESULTS

The biographical data (Table I) shows a mean age of 46.3 ± 8.4 years for all the umpires, with similar average ages for those having umpired at international (46.8 ± 8.3 years) and provincial (46.0 ± 8.5 years) level. On average the umpires had experience umpiring at club level for 12.1 ± 4.5 years, at provincial level for 7.2 ± 4.5 years and at international level for 2.5 ± 3.2 years. At provincial level on average the umpires had umpired 22.9 ± 22.0 limited-overs and 25.3 ± 17.3 first class (3 or 4 days) matches, while at international level they had umpired 5.2 ± 9.3 limited-overs and 1.7 ± 3.3 Test (5 days) matches. All the international umpires, with the exception of one, had umpired at Test match level at the time of the study. This umpire has subsequently umpired in a number of Test matches.

The umpires generally rated the on-field decisions from "below average" to "stressful" with regard to the amount of stress they felt (Table II). The umpires who had umpired at international level tended to rate the on-field decisions as "below average" to "average", with the ratings of the umpires who had only umpired at provincial level showing a far greater variance in their ratings. They rated the LBW, catch, run-out and wide decisions as "stressful". One of the provincial umpires rated the catch and run-out decision as "very stressful". All the umpires rated umpiring in first-class and Test matches as more stressful than the limited-overs matches as they had to maintain concentration for a longer period of time and, due to the field placing, there was a greater likelihood of them having to make decisions with regard to catches behind and close to the wicket.

The number of decisions that the umpires had to make in response to appeals are shown in Table III. From this it is evident that the "LBW - not out" decisions was the most common decision made by the umpires. In the international matches, the third umpire made the decision with regard to run-out and stumpng appeals with the use of slow motion TV replays, while during provincial matches the on-field umpire had to make these decisions.

The results showed a mean HR rate for the umpires before and during the match (Table IV) which corresponds to approximately 60% of the umpires' estimated maximal HR. The HR rate of the

<table>
<thead>
<tr>
<th>TABLE III: Number of decisions made by the umpires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch</td>
</tr>
<tr>
<td>Out*</td>
</tr>
<tr>
<td>Not Out</td>
</tr>
<tr>
<td>LBW</td>
</tr>
<tr>
<td>Out*</td>
</tr>
<tr>
<td>Not Out</td>
</tr>
<tr>
<td>Run-out</td>
</tr>
<tr>
<td>Out*</td>
</tr>
<tr>
<td>Not Out</td>
</tr>
<tr>
<td>Stumping</td>
</tr>
<tr>
<td>Out*</td>
</tr>
<tr>
<td>Not Out</td>
</tr>
<tr>
<td>Wide-ball</td>
</tr>
<tr>
<td>No-ball</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
</tbody>
</table>

* These were all the dismissals where the batsman was out caught. In some cases the umpire was not called on to give a decision as the batsman "walked", other decisions were fairly straight forward decisions, while in some cases it was difficult to determine whether the umpire was called on to give a decision or not.

<table>
<thead>
<tr>
<th>TABLE IV: Mean heart rates (beats min−1) during the first and second innings of the match</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>All Umpires</th>
<th>International</th>
<th>Provincial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD Diff</td>
<td>Mean</td>
</tr>
<tr>
<td>1st Innings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session 1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Innings</td>
<td>99 11.8</td>
<td>102 13.9</td>
</tr>
<tr>
<td>2nd Innings</td>
<td>94 9.6</td>
<td>95 10.7</td>
</tr>
<tr>
<td>1st to 2nd break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session 2:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Innings</td>
<td>101 8.1</td>
<td>7 6.7</td>
</tr>
<tr>
<td>2nd Innings</td>
<td>100 15.8</td>
<td>2.5</td>
</tr>
<tr>
<td>2nd break to end</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session 3:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Innings</td>
<td>99 12.3</td>
<td>1 12.8</td>
</tr>
<tr>
<td>2nd Innings</td>
<td>96 8.7</td>
<td>97 7.2</td>
</tr>
<tr>
<td>End plus 5 min:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Innings</td>
<td>100 12.5</td>
<td>7 98 13.5</td>
</tr>
<tr>
<td>2nd Innings</td>
<td>97 11.4</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Mean for innings:

1st Innings 100 12.4 0.3 125 2.5 100 13.5 1.1
2nd Innings 100 11.1 0.0 100 11.1 0.0

* Data from one umpire was excluded because the HR monitor malfunctioned during this part of the match

Diff The difference between the mean HR for a period and the preceding period, with a - indicating that the second session HR was the greater of the two

** Significant difference (p<0.05)
umpires did not differ significantly during various periods of the match. The slight, non-significant decreases in heart rates during the second innings may be as a result in decrease in environmental temperature during the evening.\(^1\) However, significant differences (p<0.05) were found for the difference between the HR of the international umpires during the 15 minutes before the start of the match and the first session of the first innings and the corresponding time during the second innings, as well as when the differences between the HR of the second and third sessions of the second innings, were compared. Although these differences are significant this could be as a result of differences in environmental conditions.

The HR response of the umpires at the time of the event, 15s post event and 30s post event are shown in Figure 1 and Figure 2. The HR of the umpires varied from as low as 68 beats min\(^{-1}\) at the time of the event to 139 beats min\(^{-1}\) at 15s post event. The differences in the heart rate response between the time of the event and 15s post event (D\(_{1}\)) and 15s and 30s post event (D\(_{2}\)) were both positive and negative (Fig 3 and Fig 4). In order to obtain more information from the data the positive and negative differences were separated for D\(_{1}\) and D\(_{2}\). However, the small sample size did not reflect any statistical significant differences, but for the “LBW - not out” decision it is clear that the provincial umpires manifested greater negative differences for both D\(_{1}\) and D\(_{2}\).

DISCUSSION

The principal finding of this study was that the heart rates of the umpires was high before and during the match, with variations in the HR of the umpires occurring as a result of on-field decisions. Cricket umpires do not engage in light physical warm-up activities before going onto the field and the elevated HR could be attributed to the emotional state of the umpires prior to the commencement of the match. This anticipatory increase in HR was evident in all the umpires before the game and concurs with the findings of the study on soccer referees.\(^9\) The elevated HR during the match was similar, although with lower recorded mean HR than those found in Australian football field umpires,\(^8\) association football referees\(^8\) and netball umpires.\(^1\) In these sports the bodies physiological responses to the task of umpiring and refereeing would be greater due to the nature of the task which is more physically demanding than that of cricket umpiring.

The second important finding is the large variations in the umpires’ HR at and after the event (Fig 1 and Fig 2) with the HR varying from as low as 68 beats min\(^{-1}\) to 139 beats min\(^{-1}\). These variations in HR response could be as a result of the psychological or physiological response to the appeal. At the time of the event, an appeal for a catch, the measured HR varied from of 68 beats min\(^{-1}\) (Umpire 2) to 127 beats min\(^{-1}\) (Umpire 9) - a difference of 59 beats min\(^{-1}\). The greatest change in HR occurred when Umpire 9 showed an increase in HR from 121 beats min\(^{-1}\) at the time of the event to 189 beats min\(^{-1}\) 15s after an appeal for a catch that he gave “not-out”. This umpire, an international umpire, who admitted to going through a “relatively bad patch” in his umpiring, also showed the greatest variation in heart rate from 15s to 30s after an appeal. The opposition players obviously attempted to exploit this by pressurising him with a large number of LBW appeals as recorded.

Figure 1 and Figure 2 also show that the provincial umpires (Umpires 1 to 6) generally showed greater differences in HR response than the international umpires (Umpires 7 to 10), with the exception of Umpire 9 who by his own admission had a very poor match. This could be an indication that the international umpires, although umpiring at a higher level with more spectators in attendance, greater media coverage, particularly television coverage, and more at stake for the players, through a combination of their psychological characteristics and years of conditioning as an umpire, are better able to control their emotions on the field of play and not feel pressurised by the players and the importance of the occasion.

The variation in HR response was further evident in the increased HR occurring in the case of one of the umpires (Umpire 4) where the differences (D\(_{1}\)) between the event and 15s post-event (Fig 3) were smaller than the differences (D\(_{2}\)) between 15s and 30s post-event (Fig 4). However, in all cases the change in the HR of the umpires after an appeal could not be attributed solely to anxiety. The umpire would often have to make a decision and then move into position in order to prepare for the next decision, such as an appeal for LBW followed by a attempted
run-out. This physical activity, as well as environmental factors have had an effect on the heart rate.

During one of the internationals Waquar Younis, the Pakistani fast bowler, took a hat-trick (three wickets in consecutive deliveries). Although the umpire was not required to make a decision in any of these dismissals as all three batsmen were bowled, an increase in the heart rate of the umpire occurred at the time of each dismissal (Table V). This could again illustrate the psychological component of HR being so closely involved in an event that occurred very seldom in international cricket.

It is recommended that further studies should focus on the HR response of cricket umpires during the first-class and Test matches which last for between three and five days and that, although it may

<table>
<thead>
<tr>
<th>Dismissal</th>
<th>15s post Dismissal</th>
<th>30s post Dismissal</th>
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<tbody>
<tr>
<td>1st Dismissal</td>
<td>89</td>
<td>92</td>
</tr>
<tr>
<td>2nd Dismissal</td>
<td>93</td>
<td>88</td>
</tr>
<tr>
<td>3rd Dismissal</td>
<td>98</td>
<td>103</td>
</tr>
</tbody>
</table>

Figure 3: Differences (D1) between the HR (bpm) at the time of the event and 15s post-event for the umpires

Figure 4: Differences (D2) between the HR (bpm) from 15s to 30s post-event for the umpires
be extremely difficult in the match situation, attempts should be made to control for other factors such as the ingestion of food, postural changes, temperature, etc.

In conclusion, it seems that the major finding of this study is that the HR response of the umpires to on-field events indicate that they are under psychological pressure. Stressful perceptions were related to the development of dissatisfaction, burn-out and withdrawal in soccer referees and before a similar situation arises in cricket training clinics, which include stress management, should be introduced for cricket umpires at all levels. Good umpires, like good cricketers, are both born and made through their experiences and some umpires are better able to handle the situation due to their psychological characteristics which may be a product of years of conditioning. Accurate and consistent decision-making, though desirable from officials at all times, is in reality difficult to achieve. However, together with regular practice and competition and the correct mental and physical preparation, errors and variability in the performance of the umpires should be reduced.

REFERENCES


Anterior cruciate ligament surgery - A survey of surgical technique and rehabilitation practice in Southern Africa

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ABSTRACT

Objectives: To assess the choice of surgical repair procedures and post-operative management of the ruptured Anterior Cruciate Ligament (ACL) in the South African Orthopaedic community.

Methods: A census questionnaire study was conducted on all 475 Orthopaedic surgeons registered with the Orthopaedic Association of South Africa during 1993/1994. The Chi-square test was used to determine statistical significance between different groups of respondents.

Results: Seventy seven percent of the questionnaires were returned. Of the respondents, 77% performed ACL reconstructions. The surgeons who described themselves as "general" Orthopaedic surgeons were more likely to perform less than 1 operation per month (p<0.001), to use arthrotomy incisions (p<0.001), to be in hospital practice (p<0.001) and not to use accelerated rehabilitation protocols (p<0.001). The majority of registrar respondents (85%) use arthrotomy procedures for ACL repairs.

Conclusions: Procedures used by Orthopaedic surgeons who perform ACL reconstructions infrequently (one or less than one operation per month), particularly those of arthroscopic procedures and post-operative rehabilitation, need to be reviewed. A cause for concern is that the registrar population is using techniques of ACL repair which have been succeeded by more modern methods, which are used more frequently in the private sector. This concern can perhaps be resolved by involving the private Orthopaedic surgeons in Orthopaedic registrar training where deficiencies exist.

INTRODUCTION

Since 1919, when Hey Groves described a reconstruction procedure for the ruptured Anterior Cruciate Ligament (ACL) using tensor fascia lata as a replacement material,1 there has been continued interest in ACL repair and rehabilitation.2,3 In 1963, Jones used part of the patellar tendon as a replacement graft.4 A modified version of his method, popularised by Clancy - the bone-patellar tendon-bone graft - has become the replacement material of choice.6,8 However, post-surgical problems with the knee extensor mechanism have prompted continued interest in the use of the semitendinosus, gracilis, iliotibial band or vastus lateralis tendons as replacement grafts.7

Research in the last decade has also focused on the use of artificial grafts, the efficacy of primary repair of the damaged ACL,6 and non-surgical management.8 All these techniques have shown to be less successful than the bone-patellar tendon-bone graft described above.6,8,9,10 The advent of arthroscopic procedures reduced intra-operative damage to the knee joint capsule, removed the need for long term casting, and allowed a shorter period of rehabilitation with reduced post-operative knee extensor mechanism weakness.1,3,11 Although the greater portion of the literature shows arthroscopic procedures produce fewer complications than the arthrotomy type ACL procedures,11,12,13,14,15 studies have reported complications, including tension pnuemoarthrosis and fistula formation, which may be directly caused by the arthroscopy procedure itself.16,17

Rehabilitation of patients after surgical repair of the ACL ligament has also evolved, with studies showing the potentially deleterious effects of immobilisation, both on the graft itself and surrounding musculature.13 Later studies showed that early mobilisation protocols decreased the side effects of immobilisation,16 and Shelbourne and Nitz's landmark study on accelerated rehabilitation,17 though still provoking some controversy,18 heralded the way for almost immediate mobilisation and full weight bearing after an ACL reconstruction. Their protocol, with some amendment, has become accepted practice for post-surgical rehabilitation of patients undergoing ACL surgery in most developed countries.19,20

In 1981, Paulos et al14 questioned fifty American Orthopaedic surgeons, and discovered that these surgeons were rehabilitating their patients to full activity faster than was considered appropriate at that time. The surgical and rehabilitation practices used by South African Orthopaedic surgeons in repairing the ruptured ACL have not been quantified. Therefore, the aim of this study was to determine, through a questionnaire study, the current ACL reconstruction technique and post-operative rehabilitation protocols used by the majority of Orthopaedic surgeons in South Africa.

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METHODS

A census-type questionnaire study was undertaken of the Orthopaedic community of Southern Africa during 1993/1994. A draft copy of the questionnaire was sent to an Orthopaedic surgeon, physiotherapist and statistician for their comments. In addition, a small sample \( n=8 \) of hospital Orthopaedic surgeons completed the questionnaire in a pilot study. Problematical questions were identified and adjusted. The corrected questionnaire was translated into Afrikaans and checked by an Afrikaans-speaking Orthopaedic surgeon.

A questionnaire was sent to each Orthopaedic surgeon listed with the South African Orthopaedic Association. A second questionnaire was sent to those Orthopaedic surgeons who did not respond to the first mailing, and a third questionnaire to those that did not respond to either the first or second mailings. This was followed by a short questionnaire which was sent to those that did not respond to any of the three earlier questionnaires, seeking the reasons for their lack of response.

The questionnaire sought answers to the following questions: i) personal data, including the type of practice and sub-speciality interest of the Orthopaedic surgeon, ii) operative details and surgical techniques used by the Orthopaedic surgeon for ACL reconstructions, including the number of operations performed per month, choice of graft, and whether augmentation procedures were used, iii) protocols used for post-operative rehabilitation, including time of post-operative limb immobilisation, whether continuous passive motion and accelerated rehabilitation regimens were prescribed, and when the patients were referred post-operatively to physiotherapists or biokineticians, and iv) the Orthopaedic surgeons perceptions of the use of physiotherapists in the ACL rehabilitation process.

The Chi-square test was used to determine statistical significance between different groups of respondents. Statistical significance was accepted when \( p<0.05 \).

RESULTS

Respondent Characteristics

Four hundred and seventy five questionnaires were distributed using the methods described. Three hundred and sixty eight Orthopaedic surgeons responded to either of the three questionnaires, or the non-response questionnaire, giving a \( 77\% \) return. Sixty questionnaires (18\%) were excluded from analysis due to missing or incorrect data. Of the respondents who answered the questionnaire correctly, 176 answered the first sendout, 88 the second, 42 the third, and 52 the non-return questionnaire. A large portion of non-responders (44\%) felt the questionnaire was not relevant to their field of interest. Other reasons given by the non-responders were that they were retired (17\%), personal reasons precluded response (8\%), or that incorrect grammar (2\%) or incorrect use of language (2\%) in the questionnaire prevented their response. Fifteen percent of the non-responders indicated that they did not receive any of the three questionnaire mailings.

Of the \( 256 \) respondents whose answers were used in the analysis, \( 40\% \) were in private practice only, \( 20\% \) in hospital practice only, and \( 40\% \) in both private and hospital practices. The highest proportion of the respondents practiced in Southern Gauteng (Transvaal) (31\%), followed by the Northern Gauteng (Northern Transvaal) (21\%), Western Cape (20\%), KwaZulu-Natal (14\%), Eastern Cape (7\%) and Orange Free State (7\%). The largest proportion of the respondents classified themselves as “general” Orthopaedic surgeons (41\%). The most common sub-specialties in which the other Orthopaedic surgeons concentrated were the knee (14\%), spine (8\%), hip (8\%) and shoulder (7\%). Of the respondents, 14\% were registrar members of the Orthopaedic Association of South Africa.

Surgical Procedures

Seventy seven percent of the 256 respondents performed ACL repairs. Of these, 61\% performed one, or less than one, operation per month, 34\% performed two to five operations per month, and 5\% more than five operations per month. Table I shows the surgical preferences for ACL repair of all respondents. Seventy three percent of respondents used either the Clancy or modified transpatellar arthrotomy incisions, compared to 27\% using arthroscopic procedures. The large majority of surgeons used autografts (88\%) to reconstruct the ruptured ACL, with the bone-patellar tendon-bone graft being the most popular replacement material used (79\%). Primary repair of the ACL was performed by 81\% of surgeons. Ninety two per-

| TABLE I: Number of Orthopaedic surgeons \( n=256 \) reporting surgical techniques for ACL repair |
|-----------------------------------------------|-----------------------------------------------|
| Incision                                      | Percentage                                  |
| Athrotomy - Standard Clancy                   | 37                                           |
| Athrotomy - Modified Transpatellar            | 36                                           |
| Arthroscopy                                   | 27                                           |
| Primary Repair                                |                                              |
| Yes                                           | 31                                           |
| No                                            | 69                                           |
| Primary Repair Augmentation                   |                                              |
| Yes                                           | 12                                           |
| No                                            | 19                                           |
| Do Not Perform Primary Repairs                | 69                                           |
| Reconstruction Graft Used                     |                                              |
| Autograft                                     | 88                                           |
| Allograft                                     | 1                                            |
| Artificial Graft                              | 0                                            |
| Perform Primary Repair Only                   | 11                                           |
| Reconstruction Material Used                  |                                              |
| Bone-patellar Tendon-Bone Graft               | 79                                           |
| Semitendinosus Tendon                         | 5                                            |
| Gracilis Tendon                               | 1                                            |
| Iliotibial Band                               | 3                                            |
| Other                                         | 1                                            |
| Perform Primary Repair Only                   | 11                                           |
| Extra-Articular Graft Augmentation             |                                              |
| Yes                                           | 39                                           |
| No                                            | 61                                           |
percent of surgeons would manage a ruptured ACL nonsurgically in certain situations. The main reasons given for this option were that the age of the patient (70%) or the patient's level of activity (77%) precluded surgery. Twenty percent of these surgeons felt that non-surgical management was the best option routinely, and 6% felt that the patient's gender was important in deciding whether to manage an ACL injury non-surgically.

The respondents who performed one or less than one ACL repair per month performed a significantly higher proportion of arthrotomies than those performing 2 or more ACL repairs per month ($p<0.001$) (Figure 1). Respondents in hospital practice performed a significantly higher proportion of arthrotomies than those in private practice ($p<0.001$) (Figure 2). Similarly, a significantly higher proportion of respondents who performed one, or less than one operation per month were in hospital practice compared to those in private practice ($p<0.001$).

A highly significant proportion of "knee specialists" use arthroscopic procedures for ACL repair ($p<0.001$) (Figure 3). Similarly, "knee specialists" were more often in private practice, and a significant proportion performed two or more ACL procedures a month compared to "general" Orthopaedic surgeons ($p<0.001$). Conversely, a significantly higher proportion of "general" Orthopaedic surgeons performed one or less than one ACL repair per month, were in hospital practice and used arthrotomy type procedures for ACL repairs ($p<0.001$). A significant proportion of Orthopaedic surgeons who performed Clancy arthroscopy incisions also performed the insubstance primary repair procedure ($p<0.001$).

A higher proportion of registrar respondents performed less than one operation per month ($p<0.05$) when compared to qualified Orthopaedic surgeons in private and hospital practice. Eighty five percent of these registrars used arthroscopy procedures for ACL repairs.

**Figure 1.** The relationship between the type of surgical procedures used for ACL repair (Arthroscopy vs Arthrotomy) and the number of ACL operations performed by Orthopaedic surgeons per month (PM). ($** \cdot p<0.001$)

**Figure 2.** The relationship between the type of surgical procedures used for ACL repair (Arthroscopy vs Arthrotomy) and the type of practice in which the Orthopaedic Surgeon is involved (hospital vs private). ($** \cdot p<0.001$)

**Figure 3.** The relationship between the type of surgical procedure used ACL repair (Arthroscopy vs Arthrotomy) and whether the Orthopaedic Surgeons were "general" Orthopaedic Surgeons or "knee specialists" (see text for definitions). ($** \cdot p<0.001$)
Post-operative ACL Rehabilitation

The majority of respondents (68%) referred their patients to a physiotherapist or biokineticist in the first post-operative week. Sixty five percent of all respondents believed that the lower limb should be immobilised after an ACL repair (Table II). Of these, 29% believe that the limb should be immobilised for 6 weeks or longer.

<table>
<thead>
<tr>
<th>Immobilise 65%</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration:</td>
<td></td>
</tr>
<tr>
<td>1 week</td>
<td>10</td>
</tr>
<tr>
<td>2 weeks</td>
<td>10</td>
</tr>
<tr>
<td>3 weeks</td>
<td>5</td>
</tr>
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<td>4 weeks</td>
<td>10</td>
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<td>5 weeks</td>
<td>1</td>
</tr>
<tr>
<td>6 weeks</td>
<td>27</td>
</tr>
<tr>
<td>6 weeks-8 months</td>
<td>2</td>
</tr>
<tr>
<td>&gt;3 months</td>
<td>0</td>
</tr>
</tbody>
</table>

Mobilise 35%

Forty nine percent of the respondents allowed their patients to use an accelerated rehabilitation protocol, although only 23% of them allowed full weightbearing on the injured limb in the first week post-operatively. Of the 49% of respondents who used the accelerated rehabilitation protocols, 35% immobilised the limb for 6 weeks or longer. Of the same surgeons who use accelerated rehabilitation, 92% allowed weightbearing on the damaged limb 4 weeks or longer post-operatively.

Approximately half of the respondents (51%) used continuous passive motion post-operatively. The large majority of respondents thought that muscular atrophy (83%) and decreased range of motion (66%) were the most common post-operative complications caused by immobilization.

The surgeons who performed more than five ACL repairs per month used accelerated rehabilitation more frequently than those who performed one or less than one operation per month (p<0.05). Similarly, respondents who performed arthroscopic ACL procedures used accelerated rehabilitation protocols with greater frequency compared to those who performed the Clancy arthroscopy procedure (p<0.05).

Finally, although 90% of surgeons used physiotherapists or biokineticists for post-operative ACL rehabilitation, 13% of all respondents, including the 4% who did not use physiotherapists, did not believe that physiotherapy treatment speeds up recovery. In addition, 45% of all surgeons were not sure, or did not believe, there was adequate communication between Orthopaedic surgeons and physiotherapists during the period of rehabilitation.

DISCUSSION

The first important finding of this study was that a high proportion of South African hospital Orthopaedic Surgeons used Clancy or modified transpatellar arthroscopy procedures rather than arthroscopic procedures. This is surprising given that arthroscopic procedures have been shown to have fewer complications than arthroscopy ACL procedures.4,13,10-12 This can perhaps be explained either by the financial constraints in the hospital sector, or because these operative techniques are the first choice procedures of the respondents for reasons not elucidated by the study.

Whichever of these two is the cause, it is clear that the large majority of registrar respondents who replied to the questionnaire are using arthroscopy procedures rather than arthroscopic techniques. It has been suggested by Mackenzie22 that, as in the New Zealand system, registrars spend six months rotation in accredited private Orthopaedic practices as part of their Orthopaedic training. In this period they would learn more sophisticated surgical techniques such as arthroscopic procedures. Given the findings of this study, his idea would appear to have merit.

When the questionnaires were analyzed according to different sub-groups, some tendencies developed. Firstly, those surgeons who perform one, or less than one, ACL operation per month performed the arthroscopy type procedure with significantly higher frequency than those surgeons who performed the operation more frequently and who were more likely to perform the surgery arthroscopically (Figure 1). Typically, surgeons performing arthrotomies worked in a hospital practice (Figure 2), and defined themselves as "general" Orthopaedic surgeons (Figure 3). They also used accelerated rehabilitation less frequently than did surgeons that performed two or more ACL operations a month.

In contrast, those Orthopaedic surgeons who performed two or more ACL operations per month, and particularly those who performed five or more procedures a month, used arthroscopic procedures significantly more often, and were more often in private practice.

This group also defined themselves as "knee specialists", and prescribed accelerated rehabilitation protocols with greater frequency. This perhaps may indicate that specialization in a certain sub-speciality of Orthopaedic surgery, which allows more frequent use of specific operations by an Orthopaedic surgeon, may be beneficial in maintaining surgical progress.

The majority of Orthopaedic surgeons in this survey still believe that it is beneficial to immobilise the limb for a period post-operatively. A portion (29%) of the respondents in the study immobilise the limb for 6 weeks or longer, which is contrary to the concepts quoted in the literature of the last two decades.15,16,17,18 A wide variety of accelerated rehabilitation protocols were described by the respondents. Some protocols were far less aggressive than the prescribed regimen with some respondents immobilising the limb for up to six weeks. These findings indicate that the interpretation of accelerated rehabilitation among the respondents. This perhaps explains the finding that 13% of respondents do not believe physiotherapy is of benefit post-operatively. In addition, 45% of respondents were not sure, or did not believe, there was adequate communication between Orthopaedic surgeons and physiotherapists. A possible reason for this lack of communication may be that the requests made to physiotherapists by Orthopaedic surgeons for certain rehabilitation protocols are based on incorrect assumptions, and varied interpretation of terminology.

The strengths of this study were that, firstly, a cen-
sus study design was used. This is probably the most representative research design available, because it canvasses an entire population, and thus no selection bias ensues, although a non-response bias is possible because persons self-select as respondents in the census. Secondly, the response rate of the questionnaire was high. Therefore we can accept with a high degree of probability the findings of the study as being representative of South African Orthopaedic surgeons as a whole.

In conclusion, it appears that South African Orthopaedic surgeons use the majority of surgical practices of ACL repair as described in the recent literature. However, the procedures used by Orthopaedic surgeons who perform ACL reconstructions infrequently (one or less than one per month), particularly those of arthroscopic procedures and post-operative rehabilitation, need to be reviewed. A cause for concern is that the registrar population who replied to the questionnaire are using techniques of ACL repair which have been superseded by more modern methods, and which are used more frequently in the private sector. This concern can perhaps be resolved by involving the private Orthopaedic surgeons in Orthopaedic registrar training where deficiencies exist.

REFERENCES


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Everyone feels pain at some time . . .

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- Significant analgesic, anti-inflammatory and antipyretic action.
- Rapid therapeutic response ensured.
- Action Pack containing 15 tablets.
- Pack of 12 suppositories.
TransAct™ patches for NSAID power that goes to work immediately and continues to work for up to 12 hours.

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- well tolerated.
- convenient non-sticky, non-greasy formulation with no residue.
- cooling sensation on skin, with a pleasant menthol aroma.