CHAPTER 2. REVIEW OF LITERATURE

An exhaustive literature search was undertaken in Google Scholar and Pubmed database on Nutritional status, Fitness, Supplement use, Morbidity-Injury profile and Muscle Recovery from delayed onset muscle soreness in athletes and specifically in Cricketers. In this chapter, an attempt has been made to identify, evaluate and synthesize the published work. The review of literature has been done under the following heads:

Cricket- The Sport

- Introduction and Formats
- History of Cricket

Energy Metabolism during Physical Activity/Exercise

- Energy Systems involved during exercise
- Energy production from the three Substrates: Carbohydrates, Fats and Proteins
- Integrated functioning of Energy systems

Energy Expenditure in Athletes

- Energy expenditure- Background
- Methods to track energy expenditure
- Energy expenditure in cricketers

Sports Nutrition

- Introduction to Sports Nutrition
- Nutritional Requirements of Athletes
  - Energy and Macronutrient requirements
  - Micronutrient requirements
    - Role of Vitamins
    - Role of Minerals
    - Sports anaemia
- Hydration
- Commonly Encountered Problems by Athletes
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Assessment of Nutritional Status of Athletes

- Anthropometry of athletes
- Dietary intake of athletes
- Body composition

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- Components of fitness
- Physical fitness tests

Morbidity- Injury in Athletes

Muscle Damage and Recovery

- Muscle damage
  - Exercise induced muscle damage (EIMD)
  - Delayed onset muscle soreness (DOMS)
  - Mechanism of muscle damage
  - Biomarkers to assess muscle damage and recovery post Exercise induced muscle damage(EIMD)

- Muscle recovery
  - Nutritional Strategies to recover from EIMD and DOMS
  - Cocoa Flavanols and Muscle Recovery from EIMD and DOMS

Ergogenic Aids

- Ergogenic aids- Background
- Nutritional ergogenic aids
- Commercial Nutritional Supplements commonly used by Cricketers
  - Protein supplements
  - Sports drinks

Nutrition Awareness

- Nutrition awareness amongst athletes and their Support staff (Coaches, Trainers, Physiotherapists)

Cricket- The Sport

There are numerous sports being played across the world. They belong to categories like Endurance sports, Strength, Power and Speed Sports, Team sports, racket sports and Weight Class sports. (Bhide and Mandalika, 2018) Cricket belongs to the team sport category.

- Introduction and Formats

Cricket is the second most popular international sport and the most popular on the domestic front (https://sportsshow.net/top-10-most-popular-sports-in-the-world/, https://sportzwiki.com/cricket/10-reasons-why-cricket-is-the-most-famous-sport-in-india, Mandrekar, 2017). Cricket is a team sport played between two teams consisting of 11 players each and is played by both men and women. Each team comprises players with specialized skills including batsmen, bowlers, all-rounders and a wicket-keeper. Cricket is played in three popular formats; test cricket (5 days), One day competition (50 overs cricket) and Twenty-twenty fixture (Twenty over match). It often involves playing in challenging hot conditions for extended periods. In cricket, all players are involved in fielding and may bat, however, only the specialist bowlers and all-rounders may be called on to bowl. (https://www.ais.gov.au)

Cricket is an intermittent sport which is dominantly endurance based, and also requires speed, flexibility, agility, strength, coordination and occasional bouts of power depending on the player's specialty. (Bhide and Mandalika, 2018) The physical requirements of cricket vary with the format of the match and the player's specialty or discipline. For example, a batsman may bat in the heat all day or may get out on the first ball and sit in the pavilion for the day's play. A bowler could bowl as many as 30 overs in a day's play or could sit around for 2 days while the teammates bat. Test cricket can involve long hours of low-intensity activity interspersed with very high-intensity activities (running between wickets, running to field a ball, bowling) while Twenty-twenty fixture (T 20) cricket is mainly a sport of strength, skill and speed, dominated by short bursts of running. (https://www.ais.gov.au)

- History of Cricket

Cricket is believed to have been invented during Saxon or Norman times by children living in Weald, South-East England. The first reference to cricket being played as an adult sport was in 1611. (https://www.icc-cricket.com/about/cricket/history-of-cricket/early-cricket)

Figure 2.1: Cricket on the Artillery Ground (https://www.icccricket.com/about/cricket/history-of-cricket/early-cricket)

Village cricket had developed by the middle of the 17^{th} century and the first English county teams were formed in the second half of the century. (https://www.icc-cricket.com/about/cricket/history-of-cricket/early-cricket)

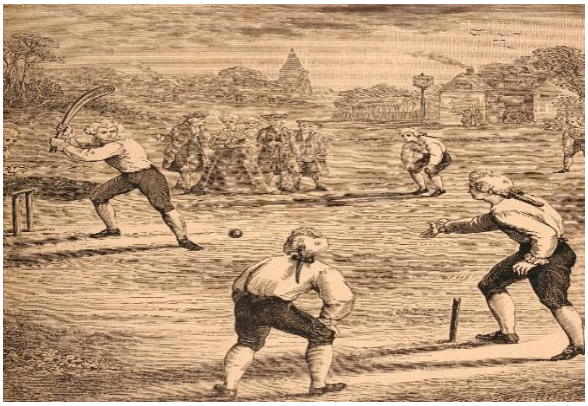


Figure 2.2: Early village cricket (https://www.icc-cricket.com/about/cricket/history-of cricket/early-cricket)

In the first half of the 18^{th} Century, cricket established itself as a leading sport in London and the south-eastern counties of England. Women's Cricket dates back to 1745 when the first known match was played in Surrey. (https://www.icc-cricket.com/about/cricket/history-of-cricket/early-cricket)

Figure 2.3: The first instances of cricket (https://www.icc-cricket.com/about/cricket/history-of-cricket/early-cricket)

Cricket was introduced to North America via the English colonies as early as the 17^{th} century, and in the 18^{th} century, it arrived in other parts of the globe. (https://www.icc-cricket.com/about/cricket/history-of-cricket/early-cricket)

Energy Metabolism during Physical Activity/Exercise

Energy is primarily obtained from food. Macronutrients- carbohydrates, fat and protein in food are transformed into a usable form of energy through a series of biochemical reactions. Adenosine triphosphate (ATP) is the form in which energy is stored in the body and energy is produced by breaking the high energy phosphate bond.

- Energy Systems involved during exercise

The body's store of Adenosine triphosphate (ATP) is limited and needs to be continually synthesized to fuel metabolism as well as physical activity. ATP is generated through the 3 energy systems namely, Phosphocreatine system (ATP-PC), anaerobic pathway and aerobic pathway. (Hargreaves & Spriet, 2020)The three pathways are discussed herewith.

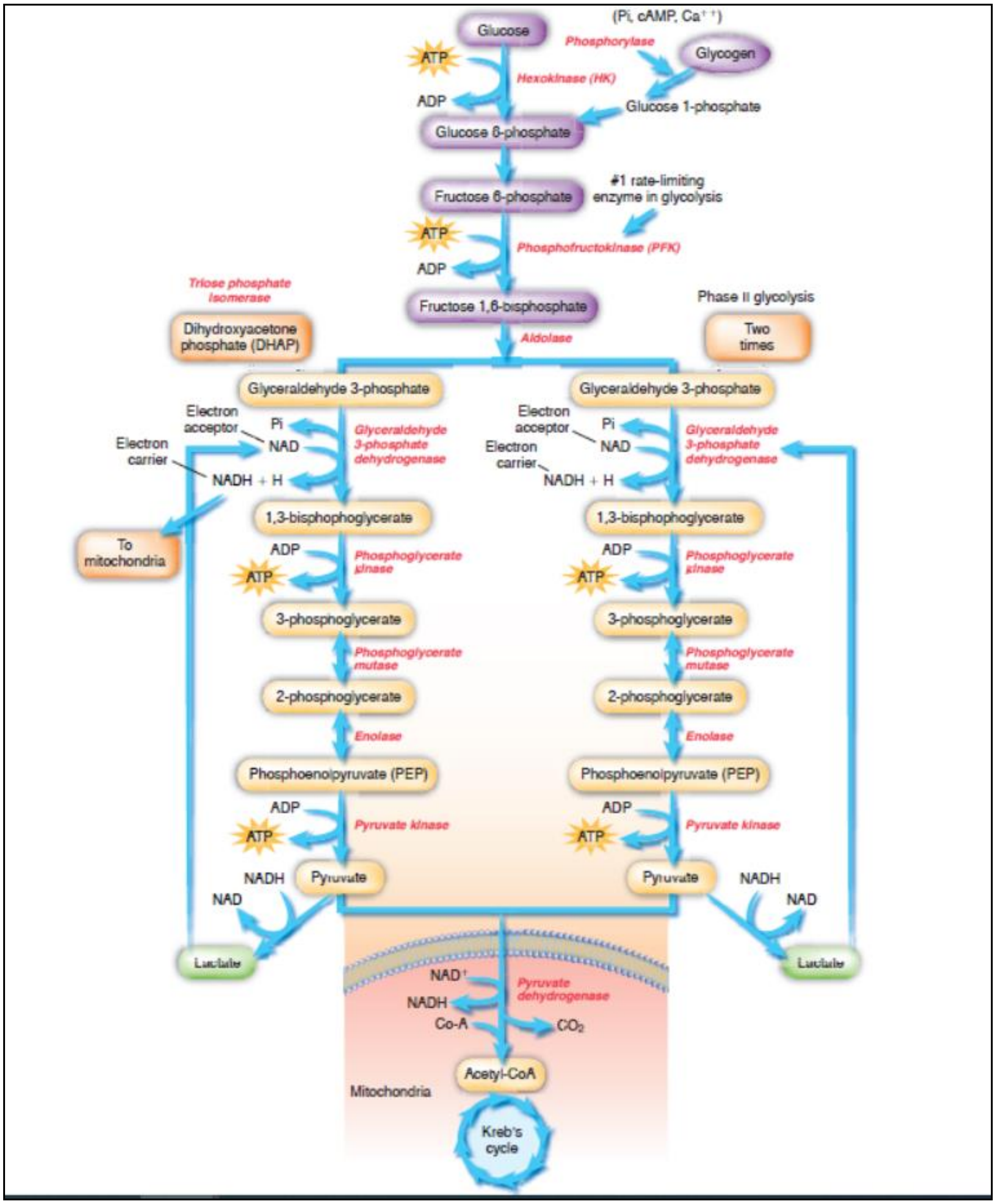
❖ Phosphocreatine system (ATP-PC)

The limited store of ATP can fuel activity only for a few seconds that is sufficient only for short-duration intense activities like a 100-metre sprint, throws, jumps, kicking a football or tennis serve. The cells also store another high-energy molecule creatine phosphate or phosphocreatine (PCr). Phosphocreatine is broken down to creatine and phosphate in the presence of an enzyme creatine kinase. The phosphate group is picked up by low-energy ADP to be converted to high-energy ATP. The process of ATP generation is rapid and does not require oxygen. ATP and phosphocreatine together help to sustain the energy needs of the muscle for about 3 to 15 seconds. Beyond this time, muscles have to generate ATP from other metabolic processes i.e. aerobic and anerobic glycolysis. (Hargreaves & Spriet, 2020;Porcari et al, 2015)

❖ Anerobic Glycolysis

Anerobic Glycolysis involves breakdown of glucose or muscle glycogen into two pyruvate or two lactate molecules. The series of reactions are depicted in figure 2.4. Pyruvate which is the end product of Glycolysis is further converted to lactate in the absence of ample oxygen or is transported into the mitochondria for aerobic respiration. The net ATP production of glycolysis is two ATP when the initial substrate is glucose and three ATP when the initial substrate is glycogen.(Hargreaves & Spriet, 2020)

Figure 2.4: Anerobic glycolysis



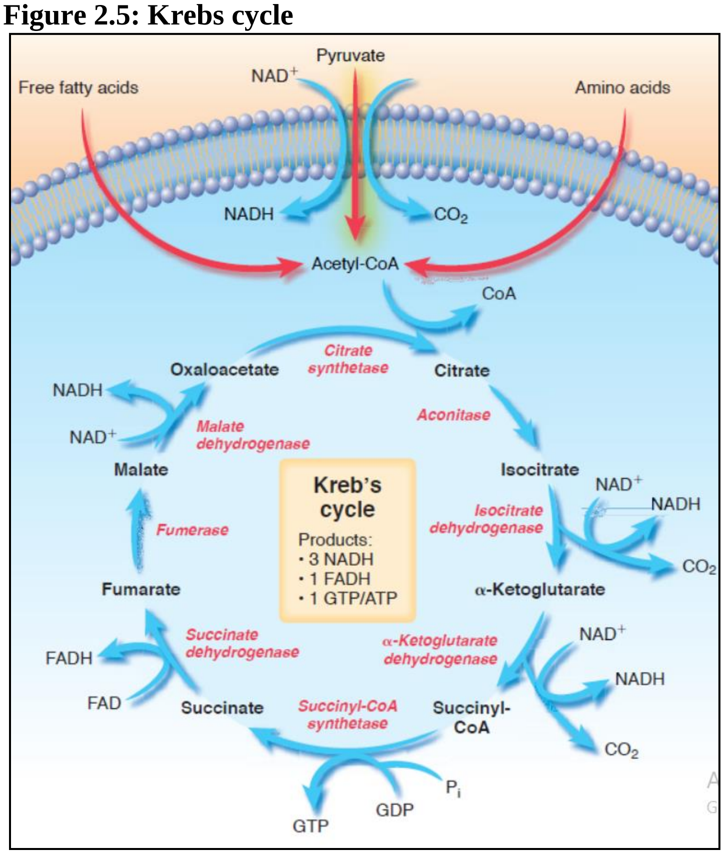
(Porcari et al, 2015)

During exercise, lactate produced in the skeletal muscle is transported out of the muscle cell and transported by the blood to the liver. Within the liver, lactate contributes to glucose production through gluconeogenesis. This manufactured glucose can then be released back into the blood and transported back to the exercising skeletal muscle and used as fuel. This lactate-to-glucose cycle between skeletal muscle and the liver is called the Cori cycle.(Porcari et al, 2015)

❖ Aerobic pathway

The production of ATP molecules in this pathway is greatest, but the rate of ATP production is considerably slower than from either the phosphagen system or anerobic glycolysis. In this pathway, all the three macronutrients serve as substrate for energy production. Carbohydrates in the form of glucose or glycogen pass through glycolysis to form pyruvate molecules. Pyruvate is either converted to lactate or to acetyl-coenzyme A (CoA) (irreversible) that enters mitochondrial respiration. Triglycerides are composed of free fatty acids (FFAs) and glycerol, and enter the aerobic pathway via: 1. beta-oxidation, a process of cleaving longer fatty acids into two-carbon structures to form acetyl-CoA or 2. glycolysis, the pathway followed by glycerol, a three-carbon structure that resembles pyruvate. Proteins contain nitrogen atoms in addition to carbon, hydrogen, and oxygen; therefore they first undergo deamination to remove nitrogen group from the amino acid. (Hargreaves & Spriet, 2020;Porcari et al, 2015)The remaining amino acid skeleton will either enter the aerobic pathway as acetyl-CoA or other intermediate products of the Krebs cycle (discussed in upcoming sections), or be converted to pyruvate. The figure 2.5 depicts the Krebs cycle.

Figure 2.5: Krebs cycle

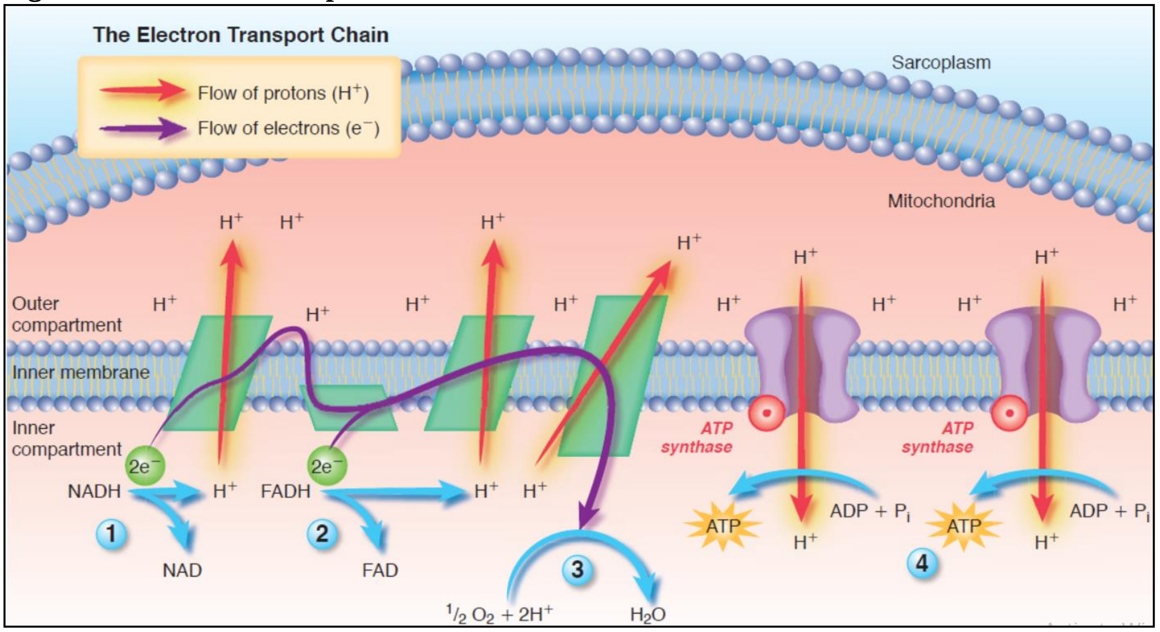


(Porcari et al, 2015)

Electron transport chain

The $FADH_2$ and NADH + H^+ molecules produced from glycolysis and the Krebs cycle donate protons and electrons (from hydrogen) to the electron transport chain (ETC). At the end of this chain, electrons are passed along to molecular oxygen, and it is only here that oxygen consumption in aerobic respiration takes place, forming water, an end product of respiration. The ETC is depicted in figure 2.6.

Figure 2.6: Electron transport chain



(Porcari et al, 2015)

- Energy production from the three Substrates: Carbohydrates, Fats and Proteins

The energy produced from carbohydrates is depicted in table 2.1

Table 2.1: Total ATP production from carbohydrates

Source	**No of ATP**
Directly from glycolysis	2-3 ATP
2 NADH + H^+ produced during glycolysis	4-6 ATP
2 NADH + H^+ produced during the conversion of 2 pyruvate molecules to acetyl-CoA Molecules	6 ATP
6 NADH + H^+ produced during the Krebs cycle (two turns, each producing three molecules)	18 ATP
2 $FADH_2$ produced during the Krebs cycle (two turns, each producing two molecules)	4 ATP
Substrate phosphorylation, manufactured directly in the Krebs cycle (two turns, each producing one molecule)	2 ATP
Total	36-39 ATP

(Porcari et al, 2015)

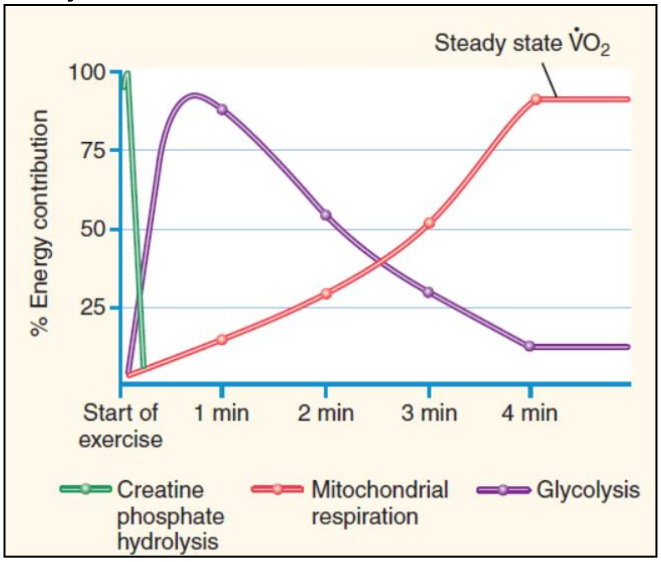
Body fat is an abundant source of energy which can provide 60,000 to 100,000 kcal of energy. Fat is stored in the body as triglycerides, phospholipids, and cholesterol. Triglycerides stored in adipose cells and within skeletal muscle fibres are the major source of energy. As the FFAs vary in length, the net ATP yield will vary from structure to structure. E.g. the complete oxidation of palmitate through beta-oxidation yields eight acetyl- CoA, seven NADH + H^+, and seven $FADH_2$ molecules. Each acetyl-CoA enters the Krebs cycle and produces three NADH + H^+, one $FADH_2$ molecule, and one ATP molecule via substrate phosphorylation. Considering that each NADH + H^+ yields three ATP molecules, and each $FADH_2$ yields two ATP molecules, the net ATP production from the electron carriers produced during beta-oxidation is 35 ATP (7 × 3 NADH + H+ plus 7 × 2 ATP from $FADH_2$). If we now combine fatty acids into a triglyceride (e.g., three palmitate + one glycerol), it increases the ATP total significantly, producing a grand total of approximately 406 ATP (129 × 3 – 3 palmitate + 19 ATP – glycerol). Thus lipids can yield much more energy in comparison with glucose, but the rate is very slow and efficiency is also low (i.e., yield less ATP per molecule of oxygen) than glucose. Therefore lipids are best used when oxygen is readily available and the demand for energy is low i.e., lower-to-moderate levels of exercise. (Hargreaves & Spriet, 2020;Porcari et al, 2015)

Carbohydrates and fats are the preferred source of energy during exercise. Protein is used as an energy source in endurance activities and intense training. Amino acid oxidation during short-term, low intensity exercise is negligible, whereas contributions during short-duration, high-intensity or sustained exercise in which glycogen depletion becomes a concern may be more substantial. Due to the short-term nature of high-intensity exercise, the overall ATP production from amino acid breakdown remains relatively small, but prolonged exercise with glycogen depletion will elicit a greater stimulus for protein catabolism and increased amino acid oxidation. The maximal contribution of amino acid oxidation to total ATP production during exercise ranges from 5% to 10%.(Hargreaves & Spriet, 2020;Porcari et al, 2015)

- Integrated functioning of Energy systems

The energy system used by the body varies with the type of exercise or sports activity. The 3 systems work in unison and at a time only one system usually predominates. The percent energy contribution by the energy systems in this steady state exercise is depicted in figure 2.7.

Figure 2.7: Overlap of all three energy systems during moderate intensity exercise from the onset to steady state

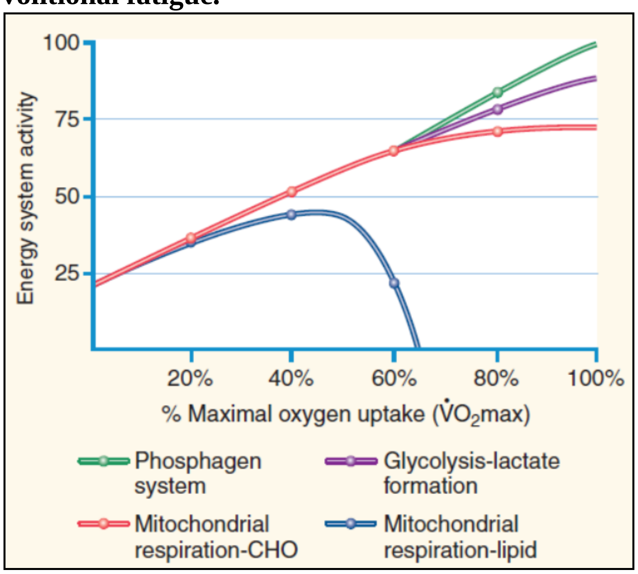


(Porcari et al, 2015)

Steady-state exercise refers to metabolic conditions where ATP demand is supplied exclusively with ATP generated from mitochondrial respiration. This is often takes between 45 and 90 seconds, or up to 4 minutes, to achieve.

The contributions from each energy system during maximal-intensity exercise from the onset to volitional fatigue is presented in figure 2.8.

Figure 2.8: Overlap of all three energy systems during maximal-intensity exercise from the onset to volitional fatigue.



(Porcari et al, 2015)

Throughout the range of low-intensity exercise (i.e., between 20% and 60% of VO_2max), ATP demand is supplied primarily from mitochondrial respiration. In particular, lipid catabolism makes a substantial contribution to ATP synthesis during this intensity range. However, as the intensity of exercise approaches approximately 60% VO_2max, a decline in lipid catabolism is evident. (Romijn et al, 1993) Gradually, the body begins to favor mitochondrial respiration from carbohydrates, a more efficient fuel that yields more ATP per molecule of oxygen and generates ATP more rapidly. As intensities continue to increase, glycolysis, resulting in lactate formation, begins to increase mitochondrial respiration. The contribution from glycolysis steadily increases until maximal exercise intensity is achieved. At near maximal exercise, the phosphagen system joins glycolysis and mitochondrial respiration in the ATP production. (Porcari et al, 2015)

Energy Expenditure in Athletes

- Energy expenditure- Background

Energy expended varies across various sports and from player to player as well. It is important to assess the energy expenditure of a player to accurately formulate the nutrition plan according to the required energy and nutrient needs and the body composition goal.

- Methods to track energy expenditure

There are several methods for measuring energy expenditure and these are discussed below.

❖ Doubly labelled water

The doubly labelled water (DLW) method is considered the gold standard for measuring energy expenditure. (Hills et al., 2014) However, it is not always the chosen method, due to its high cost and requirement for specialised technicians. DLW is often used to validate other methods like physical activity questionnaire and accelerometers. DLW has been used to measure energy expenditure within athletic populations. (Mcdonald, 2018)

❖ Calorimetry

Calorimetry; direct or indirect involves obtaining physiological measures of heat loss from the body or of gas exchange, oxygen consumption and or carbon dioxide production respectively. (Hills et al., 2014) Direct calorimetry has a major limitation in the sense the participants are confined to the metabolic chamber. Indirect calorimetry (IC) also has a practical limitation that the participants have to wear a mask, hood or a mouthpiece which might restrict the usual intensity of activity and movements. Scientific studies have used IC to estimate energy expenditure in athletes. (Mcdonald, 2018)

- Heart rate

Measuring heart rate through a portable device is relatively inexpensive, non-invasive and easy for the wearer. (Hills et al., 2014) However, consideration is required due to inter individual variance and various variables known to influence heart rate like hydration, fitness levels, posture, genetics, gender, age, anxiety, environmental temperature and altitude. Measurements are also reported to be inaccurate in case of extreme levels of activity and thus may suggest that it is a less reliable method for estimation of energy expenditure during intermittent exercise. In sports, heart rate monitors are used more frequently for determining exercise intensity rather than assessing energy expenditure. (Mcdonald, 2018)

- Accelerometers

Accelerometers are motion sensors that detect accelerations of the body. (Hills et al., 2014) They are small electronic devices, usually worn at waist level, that measure movement across 1 to 3 planes, vertical, anti-posterior and medio-lateral. Data from these can be entered in regression equations to estimate energy expenditure (EE). Large scale epidemiological studies investigating physical activity and health outcomes utilise accelerometers in determining activity patterns and intensity. Similar to heart rate monitoring, accelerometers are reported to be better predictors of EE at the group level and less suitable to determine individual activity EE across varied intensity sporting activities. (Mcdonald, 2018)

- Time-motion analysis

Time-motion analysis (TMA) is an investigation of athlete demands and movement patterns that occur over time during specific activities and is used to define activities over games and matches. TMA analysis can be conducted via the use of on-body motion tracking sensors and EE can be estimated from TMA output data. Global position system (GPS) technology is used worldwide by professional sporting teams, in training and in competition for providing TMA. (Mcdonald, 2018)

- Direct observation and recording

Observations of movement in athletes have been historically recorded via direct observation, film or computerised time motion analysis. Once the observation data is collected, individual EE can be calculated using the individual IC test values. If the individual IC energy expenditure values are not available, EE can be calculated from activity energy cost reference tables from a compendium physical activity list. This is a simple and useful method but the limitation is that it is not always possible to find data sets from a matched population. (Mcdonald, 2018)

- Activity questionnaires

Validated questionnaires, diaries and recalls are also used to estimate activity energy expenditure. (Hills et al., 2014) These are to be recorded by the participants themselves and can provide a retrospective or current recall of activity. Activity questionnaires are often used for large scale epidemiological health studies. The strength of activity questionnaires is that they can give detail on activity type and setting. Limitations with this method include participant recall bias, partial completion and/or inability to record accurately. Also, validity is dependent on matching EE reference tables that are specific to the particular activity and population in question. (Mcdonald, 2018)

- Energy expenditure in cricketers

It is challenging to accurately estimate the energy cost during a sporting event. Regardless of the format played, how a cricket game turns out in terms of time and activity is almost always uncertain. It is not surprising therefore that very few studies investigate Energy Expenditure (EE) as a research outcome in the scientific cricket literature. (Mcdonald, 2018) The earliest study investigating EE of cricketers during a test match was carried out in 1955. Oxygen consumption and EE of four players in the nets was assessed using a portable calorimeter. The study concluded that the overall match EE was as low as that of walking. The authors also calculated the 'average' EE of a 'hypothetical' player during an international test series. Observed recorded TMA of different types of activity across fielders, batters and bowlers was collected over 100 hours of international test data and converted into kcals per sq. m. per hour and the mean taken. The average EE of a test cricketer was calculated and reported to be as low as 279 Kcal/h (155 kcal·m·h-^{1} assuming a body surface area of 1.8 m^{2}). (Fletcher, 1955 as cited in McDonald, 2018)

Since 1955, two other studies have investigated energy expenditure in cricketers. These were conducted in simulated experimental conditions investigating the energy expenditure of batting using gas technology and reported higher energy expenditure than the work of Fletcher. These studies were similarly designed except for the running and rest protocol; participants ran 14 more shuttle runs in the second study but with 5 and 15 second longer rest periods between balls and overs respectively. In the first study (n=10) conducted outdoors, an average EE of 606 kcal/h was reported. (Christie et al, 2007) The second experiment (n=12), was conducted indoors and the energy cost estimated was just slightly higher, 663 kcal/h, compared to the experiment of Christie even though fewer shuttle runs took place in this protocol. Pote et al (2014) suggested that the higher EE in the earlier study may have been a result of the running protocol differences between studies. (Christie and Pote, 2014) In the first study double shuttle runs required turning action and may have consumed more energy. In both studies the EE results were higher than the batting EE that was reported by Fletcher et al (1955) 155 $kcal.m^2.h^{-1}$, (279 Kcal/h). However, study design differences, do not allow direct comparisons to be made. (McDonald, 2018)

From the computerized TMA of 27 fielders during 10 overs in a first class test cricket match, it was inferred that high intensity activity accounted for only 1.6% of the fielding time. The authors reported that long distances were covered by the fielders but described the fielding component of test cricket as overall undemanding. (Rudkin and Donoghue, 2008) An Australian research group compared high performance cricketers' movement patterns and differences in workload via GPS technology. This research looked across all playing positions and the three formats of cricket; Test, One day and Twenty-twenty. The study concluded that the physiological demands between different playing positions varied immensely, with the shorter format of play being higher intensity and multi-day demanding a greater physical load. The authors also concluded that cricket is a low intensity game that includes intermittent short sprint movements. (Petersen et al, 2010)

Thus as cited above, there is limited literature on Energy expenditure in cricketers. Calorimetry has been used to assess Energy expenditure and the Energy expenditure reported ranged from as low as 279 to 663kcal/hour in cricket players.

Sports Nutrition

- Introduction to Sports Nutrition

The nutritional requirements of athletes are different from the non-athletic population. In athletes, in addition to fulfilling the daily requirements for health, bodily functions and growth, the diet must also support the demands of training, competition, and recovery and in some cases meet the pre-requisite sport specific body composition goals. (Thomas et al, 2016) Sports nutrition is a constantly evolving field with hundreds of research papers published annually. In the year 2017 alone, 2082 articles were published under the keywords' Sport Nutrition'.(Kerksick et al., 2018)

A study conducted on non elite runners revealed that a planned scientific nutritional strategy helped them complete a marathon run faster. (Beck et al, 2015) Also, Research on trained cyclists demonstrated that a scientific nutritional strategy improved time trial performance by equivalent to 6 % when compared to self-chosen nutrition approach. (Hottenrott et al, 2012) As the dietary strategies vary based on the type of sports, athlete's goals, food preferences etc, individualized dietary advice in sports is becoming increasingly recognized. (Beck et al., 2015)

- Nutritional Requirements of Athletes

Nutrition requirements and goals are not static. Athletes undertake a periodized program in which preparation for peak performance in targeted events is achieved by integrating different types of workouts in the various cycles of the training calendar. The nutrition programme also needs to be periodized, taking into account the needs of daily training sessions (which can range from minor in the case of easy workouts to substantial in the case of strenuous sessions) and overall nutritional goals. (Thomas et al, 2016)

❖ Energy Requirements

An appropriate energy intake is the foundation of an athlete's diet as it supports optimal body function, determines the capacity for the intake of macronutrients and micronutrients and assists in meeting the target body composition. An athlete's energy requirements depend on periodized training and competition cycle and vary throughout the year depending on the training volume and intensity. (Thomas et al, 2016)

The ISSN recommends that energy requirements are calculated based on the level of physical activity and body weight as depicted in table 2.2. (Kreider et al., 2010)

Table 2.2: Energy requirements for physical activity

Physical activity level	**Kcal/kg/day**
General physical activity 30-40 minutes/day, 3 times a week	Normal diet, 25-35
Moderate levels of intense training 2-3 hours/day, 5-6 times a week	50-80
High- volume intense training 3-6 hours/day, 1-2 sessions/day, 5-6 times a week	50-80
Elite athletes	150-200
Large athletes	60-80

(Kreider et al., 2010)

The 2003 and 2010 IOC consensus recommend determining estimated energy availability ($_{est}$EA) in addition to calculating total energy requirements. Energy balance cannot provide reliable information about energy requirements and is not considered to be useful when calculating an athlete's requirements. $_{est}$EA is defined as dietary energy intake minus energy expended in exercise (EA= EI-EEE) and is expressed in kcal/kg fat-free mass (FFM)/day. The rationale behind calculating $_{est}$EA is that some physiological functions are adversely affected by drastically low energy availability (LEA). Loucks et al; 2011 as cited in (Potgieter, 2013) Energy availability > 45 kcal/kg FFM/day is necessary to achieve and maintain optimal energy status to support the cost of all body functions vital to health and performance. Energy availability of ≤45 kcal/kg FFM/day is considered as Low Energy availability (LEA) and both men and women are susceptible to its health risks. (Popp et al, 2022; Mountjoy et al., 2018)

LEA in adolescence and early adulthood is linked to compromised reproductive and skeletal health in both men and women. (Hutson et al, 2021; Popp et al., 2022; Villa et al, 2021) Disruption of a female athlete's menstrual cycle and compromised bone health have been observed when $_{est}$EA is less than 30 kcal/kg FFM. Moreover, LEA has adverse effects on recovery, muscle mass, neuromuscular function, and increases the risk of injuries and illness that may ultimately adversely affect performance. (Melin et al, 2019) EA of <30 kcal/kg FFM/day even for a short period (5 days) in eumenorrheic athletes causes severe endocrine and metabolic alterations. Prevalence of LEA is reported as up to 58% in various sports with the highest being in road cyclists and elite distance athletes. LEA is reported in elite female gymnasts(Silva & Paiva, 2015), elite distance athletes (Heikura et al., 2018), male endurance athletes, (Lane et al., 2019), collegiate women soccer players (Magee et al., 2020) and elite pre-teen and teen gymnasts (Villa et al., 2021). However, there is a lack of data on the prevalence of LEA in cricketers. Preventive educational programs and screening to identify athletes with LEA are important for timely intervention to prevent long-term secondary health effects. Treatment for athletes with LEA is primarily to increase energy availability. (Melin et al, 2019)

The ACSM recommends that energy requirements are calculated using either the dietary reference intakes (DRIs) or prediction equations, such as Cunningham or Harris- Benedict equations, where the resting metabolic rate is calculated using a physical activity factor (1.8-2.3) based on the type, duration and intensity of the exercise. (Rodriguez et al, 2009)

❖ Macronutrient requirements

o Carbohydrate

Carbohydrate provides key fuel for the brain and central nervous system and can support exercise over a large range of intensities due to its use by both anerobic and oxidative pathways. When working at the highest intensities that can be supported by oxidative phosphorylation, carbohydrate offers advantages over fat as a substrate because it provides a greater yield of ATP per volume of oxygen that can be delivered to the mitochondria. (Spriet, 2014) Prolonged sustained or high intensity intermittent exercise is enhanced by strategies that maintain high carbohydrate availability, while depletion of carbohydrate stores is associated with fatigue in the form of reduced work rates, impaired skill and concentration and increased perception of effort. (Thomas et al, 2016)

- Habitual or daily carbohydrate intake

The field of sports nutrition has shifted from calculating carbohydrate requirements as a percentage of the total energy requirement to grams per kilogram (g/kg) body weight (BW). The g/kg BW requirement ensures that adequate macronutrients are provided in respect of total energy intake and that there is some flexibility when it is required to individualize nutrition plans according to specific training regimes. (Burke et al, 2011) Athletes require more energy and macronutrients in proportion to their body weight, compared to sedentary individuals. Therefore, according to the ACSM and ADA, expressing energy and macronutrient needs in terms of grams per kilogram body weight is a practical method to document these needs. (Thomas et al., 2016)

In physically active individuals, habitual or daily carbohydrate intake should be timed according to training sessions to ensure optimal pre-workout nutrition, as well as to encourage recovery post-workout. (Burke et al, 2011) An optimal carbohydrate intake is essential for recovery and optimizing glycogen stores for the next training session. The daily dietary requirement for carbohydrates differs according to the amount and intensity of training and should focus on including more complex carbohydrates of low to moderate glycemic index. (Kreider et al., 2010) Meeting the daily carbohydrate requirement and ensuring gastrointestinal comfort are very important as attaining the high carbohydrate intake that is required for endurance exercise can lead to abdominal bloating, cramping and diarrhoea. (Burke et al, 2011)

Recommendations for the daily carbohydrate requirements differ between the three bodies namely the International Olympics Committee (IOC), the International Society of Sports Nutrition (ISSN) and the American College of Sports Medicine (ACSM). The ACSM provides a very broad guideline, while the ISSN and IOC suggest carbohydrate requirements based on the duration and intensity of the exercise programmes. (Kerksick et al., 2017,Kerksick et al., 2018, Burke et al, 2011) The IOC provides the most detailed breakdown in terms of recommended daily carbohydrate requirements. This is important as these requirements can be used to individualise training programmes to a greater extent than the ACSM's broad guidelines. The IOC recommendations also distinguish between strength and endurance training, which further facilitates a more individualised approach. (Burke et al, 2011) Table 2.3 provides guidelines for carbohydrate intake for athletes as recommended by the Joint position stand of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine, 2016.

Table: 2.3 Summary of guidelines for daily or habitual carbohydrate intake in athletes

Situation	**Carbohydrate targets**	**Comments on type and timing of carbohydrate intake**
Daily needs for fuel and recovery		
Light-Low intensity or skill-based activities	3-5 g/kg of athlete's body weight/d	• Timing of intake of carbohydrates over the day may be manipulated to promote high carbohydrate availability for a specific session by consuming carbohydrate before or during the session, or during recovery from a previous session • Otherwise, as long as total fuel needs are provided, the pattern of intake may simply be guided by convenience and individual choice. • Athletes should choose nutrient-rich carbohydrate sources to allow overall nutrient needs to be met
Moderate- Moderate exercise program (e.g., ~1 h/d)	5-7 g/kg/d	
High Endurance program (e.g., 1-3 h/d moderate to high-intensity exercise)	6-10 g/kg/d	
Very high- Extreme commitment (e.g., >4-5 h/d moderate to high-intensity exercise)	8-12 g/kg/d	

(Thomas et al., 2016)

- Carbohydrate intake before exercise/event

The limited glycogen stores in the body only last for approximately 90 minutes to three hours during moderate to high-intensity exercise. (Kerksick et al, 2008) Therefore, maximizing the glycogen stores before competitive events is practiced. Table 2.4 provides guidelines for carbohydrate intake before an event for athletes as recommended by the Joint position stand of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine, 2016.

Table: 2.4 Summary of guidelines for carbohydrate intake before an event

<table>
<tr><th>Situation</th><th>Carbohydrate targets</th><th>Comments on type and timing of carbohydrate intake</th></tr>
<tr><td colspan="3">Acute fueling strategies- These guidelines promote high carbohydrate availability to promote optimal performance during competition or key training sessions</td></tr>
<tr><td>General fueling up
Preparation for events <90 min exercise</td><td>7-12 g/kg/24 h as for
daily fuel needs</td><td rowspan="3">• Athletes may choose carbohydrate-rich sources that are low in fibre and easily consumed to ensure that fuel targets are met, and to meet goals for gut comfort or lighter “racing weight”
• There may be benefits in consuming small, regular snacks
• Carbohydrate-rich foods and drinks may help to ensure that fuel targets are met
• Timing, amount and type of carbohydrate foods and drinks should be chosen to suit the practical needs of the event and individual preferences
• Choices high in fat/protein/fiber may need to be avoided to reduce the risk of gastrointestinal issues during the event
• Low glycemic index choices may provide a more sustained source of fuel for situations where carbohydrates cannot be consumed during exercise</td></tr>
<tr><td>Carbohydrate Loading- Preparation for events >90 min of sustained/ intermittent exercise</td><td>36-48 h of 10-12 g/kg
body weight/24 h</td></tr>
<tr><td>Pre-event Fueling
Before exercise >60 min
1-4 g/kg consumed</td><td>1-4 h before Exercise</td></tr>
</table>

(Thomas et al., 2016)

- Carbohydrate loading

Carbohydrate loading is a strategy that involves consuming carbohydrate rich foods to maximize muscle glycogen stores prior to endurance exercise lasting longer than 90 minutes. This strategy has been found to increase endurance and exercise performance. (Burke et al, 2011) It has been shown to delay the onset of muscle fatigue by about 20% and improve performance by 2-3%. Initial protocols of carbohydrate loading consisted of a depletion phase (3 days of intense training and low carbohydrate intake) followed by a loading phase (3 days of reduced training and high carbohydrate intake) Further research suggested that muscle glycogen stores should be increased without the glycogen depletion phase. For exercise shorter than 90 minutes, 7-12 g of carbohydrate per kg of body mass is suggested during the 24 hours preceding. (Beck et al., 2015)

Carbohydrate-loading recommendations are provided by the ISSN and the IOC. The ISSN suggests a lower range i.e. 8-10 g/kg BW of carbohydrate ingested for 1-3 days prior to an endurance event while the IOC recommends 7-12 g/kg BW of carbohydrate for 24 hours, or 10-12 g/kg BW for 36-48 hours, prior to the endurance event (Kerksick et al., 2017, Kerksick et al., 2018, Burke et al, 2011). The traditional approach of carbohydrate loading for three days prior to an event was based on physically active, rather than well trained athletes. (Burke et al, 2011) The IOC recommendations are founded on more recent evidence that suggests that super-compensation of glycogen stores in well-trained individuals can be achieved by increasing carbohydrate intake 24-36 hours prior to an event, combined with training tapering and rest. This is an important practical application as increasing carbohydrate intake for days leading up to an event can cause gastrointestinal discomfort. Also, because of the nature of carbohydrate loading, not all athletes, mainly females, will be able to ingest such a large amount of carbohydrates for three days leading up to an event. Therefore, the most suited strategy to the individual should be administered. (Potgieter, 2013)

- Carbohydrate intake during exercise/event

During endurance events, muscle fatigue and hypoglycemia often occur due to low muscle glycogen stores. An increase in liver and muscle glycogen stores is therefore required for peak performance. Sub optimal carbohydrate intake usually causes low energy levels, heavy legs, fatigue or 'hitting the wall', slow recovery rate, loss of concentration, dizziness, irritability and fainting. (Potgieter, 2013) Ingestion of carbohydrate is recommended during exercise as it allows oxidation of exogenous carbohydrates and is likely to spare liver glycogen which can be used later, the onset of fatigue is delayed and the ability to sustain exercise is improved. (Potgieter, 2013 and Bhide and Mandalika, 2018)

Table: 2.5 Summary of guidelines for carbohydrate intake during an event or exercise

Situation	**CHO Targets**	**Comments on type and timing of carbohydrate intake**
During brief exercise- <45 min	Not needed	• A range of drinks and sports products can provide easy to consume carbohydrate • The frequent contact of carbohydrate with the mouth and oral cavity can stimulate parts of the brain and central nervous system to enhance perceptions of well-being and increase self-chosen work outputs • Carbohydrate intake provides a source of fuel for the muscles to supplement endogenous stores • Opportunities to consume foods and drinks vary according to the rules and nature of each sport • A range of everyday dietary choices and specialized sports products ranging from liquid to solid form may be useful • The athlete should practice finding a refuelling plan that suits his or her individual goals, including hydration needs and gut comfort • Higher intakes of carbohydrate are associated with better performance • Products providing multiple transportable carbohydrates achieve high rates of oxidation of carbohydrate consumed during exercise
During sustained high intensity exercise- 45-75 min	Small amounts, including mouth rinse	
During endurance exercise, including "stop and start" sports- 1-2.5 h	30-60 g/h	
During ultra-endurance Exercise- >2.5-3 h	up to 90 g/h	

(Thomas et al., 2016)

The type, amount and timing of carbohydrate intake are also very important. (Potgieter, 2013) A study by Burke and Maughan showed the beneficial effects of a carbohydrate mouth rinse during a competitive event on performance. In events lasting for a longer duration, carbohydrate intake improves performance mainly by preventing hypoglycemia and maintaining high levels of carbohydrate oxidation. (Beck et al., 2015) Table 2.5 provides guidelines for carbohydrate intake before an event for athletes as recommended by the Joint position stand of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine, 2016.

- Carbohydrate after exercise/event

Glycogen stores can be normalized with 24 hours of reduced training and adequate fuel intake unless there is severe muscle damage. (Burke et al, 2004) Glycogen restoration is one of the goals of post-exercise recovery, particularly between bouts of carbohydrate-dependent exercise where there is a priority on performance in the subsequent session. Refueling requires adequate carbohydrate intake and time. The rate of glycogen re-synthesis is only equivalent to 5% per hour and therefore early intake of carbohydrate in the recovery period (equivalent to 1 to 1.2 g/kg/h during the first 4 to 6 hours) is useful in maximizing the effective refueling time.

Ideal levels of carbohydrate intake optimize muscle glycogen re-synthesis. Speedy recovery becomes all the more important when there is less than 8 hours of recovery time between the subsequent training sessions or events. (Burke et al, 2011) During this time 1-1.2 g/kg/h of carbohydrate for the first 4 hours and the daily fuel needs after that is recommended. (Joint position stand of Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine, 2016)

- Protein

The dietary protein interacts with exercise and provides a trigger as well as a substrate for the synthesis of contractile and metabolic proteins as well as enhancing structural changes in tendons and bones. (Phillips, 2012; Phillips and Loon, 2011, Miller et al., 2005, Babraj et al., 2002) Adaptations are thought to occur by stimulation of the activity of the protein synthetic machinery in response to a rise in leucine concentrations and the provision of an exogenous source of amino acids for incorporation into new proteins.(Churchward-Venne et al., 2012)

Dietary protein requirements are elevated with strength, speed or endurance training. Energy intake, exercise intensity and duration, ambient temperature, gender and age also influence protein requirements. (Kreider et al., 2010 and Phillips and Loon, 2011) There are increased requirements in the individuals engaged in strength or resistance training because dietary protein supports muscle protein synthesis, reduces muscle protein breakdown and repairs muscle damage. Also, endurance exercise causes an increase in leucine oxidation. Therefore, endurance athletes may have slightly higher protein requirements than their sedentary counterparts. (Kreider et al., 2010)

- Daily protein requirements

The daily protein requirements for physical activity, as recommended by the ISSN, are summarised in Table 2.6.

Table: 2.6 Daily protein requirements for physical activity

Physical activity level	**g/kg BW/day**	**Comments**
General fitness	0.8-1.0 g/kg BW	Focus on protein quality, amino-acid content and whole foods. Safe, convenient supplements where needed.
Older individuals	1.0-1.2 g/kg BW	
A moderate amount of intense training	1.0-1.5 g/kg BW	
High volume of intense training	1.5-2.0 g/kg BW	

(Potgieter, 2013)

IOC general protein guidelines for athletes are 1.3-1.8 g/kg BW/day and 1.6-1.7 g/kg BW/day for strength-training athletes. Because of the high energy intake of these athletes, these requirements may be met easily. According to the IOC, protein intake above these cut offs does not have any additional benefit instead can promote amino-acid catabolism and protein oxidation. (Slater and Phillips, 2011) The IOC recommends optimizing body composition (by losing fat and gaining muscle mass) by decreasing daily carbohydrate intake (3-4 g/kg BW/day) and increasing daily protein intake (1.8-2.7 g/kg BW/day) while following a hypo-energetic diet and customised training programme. (Phillips and Loon, 2011)

While traditional protein intake guidelines focused on total protein intake over the day (grams per kilogram), studies now highlight that muscle adaptation to training can be maximized by ingesting these targets as 0.3 g/kg BW after key exercise sessions and every 3 to 5 hours over multiple meals. (Moore et al., 2009; Phillips, 2014) Milk-based protein consumption after resistance exercise is effective in increasing muscle strength and favourable changes in body composition in a few chronic training studies. (Hartman et al., 2007; Josse et al 2011; Josse et al., 2009)

- Protein before exercise

The ISSN recommends that, depending on the individual's exercise duration and fitness level, protein should be included with carbohydrates in the pre-event meal before resistance exercise or when a change in body composition is required. This can be achieved by including 0.15-0.25 g/kg BW protein with the recommended 1-2 g/kg BW carbohydrates in the pre-event meal 3-4 hours before training or competitive event. (Kerksick et al., 2008)

IOC has a contrasting stand on this matter. The IOC states that although preliminary evidence appears to support increased muscle protein synthesis in response to resistance training when protein is given before exercise, follow-up studies have failed to confirm this finding. Therefore, the current opinion of the IOC is that protein should be ingested after exercise. (Slater and Phillips, 2011)

- Protein during exercise

According to the ISSN, protein to carbohydrates (carbohydrates to protein ratio of 3-4:1) during exercise has shown beneficial effects. It has been demonstrated to be favourable in terms of improving endurance performance, increasing muscle glycogen stores, reducing muscle damage and promoting better training adaptations after resistance training.(Kerksick et al., 2008)

The IOC refers to recent evidence that suggests that co-ingestion of carbohydrates and essential amino acids is beneficial before and during resistance exercise as it increases substrate availability and exercise performance, improves the anabolic hormonal environment, stimulates muscle protein synthesis and decreases muscle damage or tenderness. However, the IOC concludes that current guidelines promote the ingestion of protein at a time that is associated with maximal stimulation of muscle protein synthesis (after exercise), and do not provide any recommendations for protein intake before or during a workout. (Slater and Phillips, 2011)

- Protein after exercise

Longitudinal training studies suggest that increases in strength and muscle mass are greatest with an immediate post-exercise intake of protein. (Josse et al, 2009) The ISSN recommendation for recovery is to add protein to carbohydrates at a carbohydrate to protein ratio of 3-4:1, or by supplementing with 0.2-0.5 g/kg BW protein. This results in increased glycogen re-synthesis and ultimately improved performance. The consensus also recommends that intake of amino acids, especially essential amino acids (EAA), stimulates muscle protein synthesis. This can be achieved by adding 6-20 g EAA to at least 30-40 g high glycaemic index carbohydrates and ingesting this immediately or within three hours post-exercise. The addition of protein to carbohydrates also results in increased strength and enhanced body composition during chronic resistance training. ISSN also recommends adding a small amount of creatine (0.1 g/kg BW) to the carbohydrate and protein mixture post-exercise to optimise the adaptations of resistance training. (Kerksick et al., 2008)

Current IOC guidelines also advocate the ingestion of protein after exercise, as this is when maximal stimulation of muscle protein synthesis is required. (Slater and Phillips, 2011) The IOC recommends that 20-25 g of high quality or high biological value protein is included after resistance exercise. (Phillips and Loon, 2011) The combination of carbohydrates and protein post-exercise is important to restore muscle glycogen and promote protein synthesis. Whereas protein intake that exceeds this recommended amount is not linked with the promotion of muscle protein synthesis, rather can cause protein oxidation. (Slater and Phillips, 2011)

- Fat

The fat requirements of athletes are slightly higher than those of non-athletes. Adequate intake of fat is necessary for health, maintenance of energy balance, optimal intake of essential fatty acids and fat-soluble vitamins, as well as to replenish intramuscular triacylglycerol stores. The amount of required fat depends mainly on the training status and body composition goals of the athletes. (Kreider et al., 2010)

The ISSN suggests a moderate fat intake of 30% of total energy for athletes. This can increase to 50% of total energy for high-volume training, i.e. elite competitor training of 40 hours/week (like the Ironman). (Kreider et al., 2010) Whereas, the ACSM recommends that daily fat intake for athletes should be 20-35% of total energy intake and should not be less than 20%.(Rodriguez et al, 2009) To reduce body fat or lose body weight, a fat intake of 0.5-1.0 g/kg BW/day is suggested. The type of dietary fatty acids is important, the focus should be on increasing dietary sources of unsaturated fats and essential fatty acids. (Kreider et al., 2010) The IOC recommends a daily fat intake of 15 to 20% of the total energy. (Sundgot-borgen and Garthe, 2011)

The position statement of the German Nutrition Society represents the current state of scientific knowledge regarding the recommended fat intake in ambitious recreational and high-level sports. It also addresses dietary strategies (fat-loading methods) and food supplements that are designed to influence fat metabolism during physical activity. So far, no recommendation has been established for sports-specific fat intake in absolute numbers (g/kg body weight/day), similar to the international practices regarding carbohydrates and proteins. However, there is consensus among scientific sports medicine associations that fat consumption should not exceed 30% of the energy intake, nor fall below 20%, particularly in endurance sports. (Schek et al., 2019)

Before competitions, some endurance athletes practice fat-loading strategies which include a ketogenic diet. This procedure is not advisable, as there is no scientific evidence of performance improvement. (Schek et al., 2019) Although in certain specific scenarios high-fat diets may offer some benefits or at least the absence of disadvantages for performance, in general, they appear to reduce rather than enhance metabolic flexibility by reducing carbohydrate availability and capacity to use carbohydrate effectively as an exercise substrate. Therefore, competitive athletes would be compromising their ability to perform high intensity physical activity by indulging in high fat diets.(Burke 2015) Attempts to increase fatty acid availability employing acute or chronic fat loading strategies (with or without subsequent replenishing of glycogen stores) have failed to show improvements in endurance performance, although fatty acid oxidation was enhanced. In the worst case, fat loading may even result in performance impairment in intermediate or final sprints, which is why low-carb, high-fat diets are not recommended. The current use of dietary supplements which are supposed to improve the availability/oxidation of fatty acids is also generally discouraged. (Schek et al., 2019)

- Micronutrients

The ACSM recommends that no additional vitamin and mineral supplementation is needed if an athlete obtains sufficient energy from a wide variety of foods. However, the ACSM allows for micronutrient supplementation such as folic acid supplementation during pregnancy. Supplementation may be individually prescribed if required by the healthcare professional for certain athletes, such as those restricting energy intake, vegetarians, athletes who are unwell, recovering from injury or with specific medical conditions. (Rodriguez et al, 2009) Vegetarians may require vitamin B_{12}, iron, calcium, vitamin D, riboflavin and zinc supplementation. (Potgieter, 2013)

ISSN also has a similar stand on micronutrient supplementation. The ISSN recommends that a normal nutrient-rich diet that contains a variety of food groups should provide sufficient amounts of micronutrients in most cases. Athletes who are susceptible to low energy intake, or who purposefully restrict energy intake to lose or maintain body weight, might be at risk of developing micronutrient deficiencies. Low doses of multivitamin and mineral combinations may be prescribed or vitamin and mineral enriched liquid meal replacements taken in such cases. However, this should be carried out in consultation with the dietitian and in combination with altered eating habits. (Kreider et al., 2010)

The IOC evaluated two micronutrients namely Antioxidants and Vitamin D in its latest consensus statement. Arguments in favour of antioxidant supplementation propose that they can decrease the reactive oxygen species formed during exhaustive exercise. These arguments in support of antioxidant supplementation, also suggest that some athletes do not consume a diet containing the required amounts of antioxidants. Moreover, antioxidant supplementation is not harmful to human health. Whereas, it is believed that although exercise promotes oxidative stress, there is no evidence to support the theory that it is harmful to human health or performance. Moreover, regular exercise increases the body's ability to produce endogenous antioxidants. Considering the above arguments, the IOC recommends that athletes should not consume antioxidant supplements and cautions against the use of single-nutrient, high-dose antioxidant supplements. (Powers et al, 2011 as cited in Potgieter, 2013)

Currently, there are no clear guidelines on micronutrient supplementation in athletes and which suggest that athletes should be monitored on an individual basis. (Kreider et al., 2010; Rodriguez et al, 2009)

- Role of Vitamins

Vitamins are essential organic compounds that serve to regulate metabolic and neurological processes, energy synthesis and prevent cellular destruction. (Kerksick et al., 2018) According to the ISSN, vitamin E, niacin, folic acid and vitamin C may exhibit some health benefits. Particularly, vitamins C and E may decrease oxidative damage caused by vigorous training schedules and may also aid to build a healthy immune system. (Kreider et al., 2010) Inadequate folate consumption has been associated with an increased risk of muscle soreness and fatigue, muscle breakdown, and muscle strength. Vitamin B_6 has also been found vital for the expression of genes useful for the repair and health of skeletal muscle. (Beckett et al, 2014)

- Vitamin C

Vitamin C is a scavenger of free oxygen radicals. It acts as an electron donor to minimize damage from free radicals, maintains the activity of glutathione (an endogenous antioxidant), and recycles oxidised vitamin E for reuse by cells. The other roles of vitamin C that may influence performance or which influence an athlete's capacity to undertake exercise are in immune function and the synthesis of essential cell compounds like carnitine, and the catabolic hormones noradrenaline and adrenaline. Its role in wound healing, bone repair and in reducing the severity of the common cold could also have implications for athletes. (The Nutrition Society, 2011)

Reported data on vitamin C status in athletes are scarce. (The Nutrition Society, 2011) In a placebo-controlled crossover design study, 100 males were screened for vitamin C baseline values in the blood. Subsequently, the 10 individuals with the lowest and the 10 with the highest vitamin C values were assigned to two groups. The 20 selected participants performed aerobic exercise to exhaustion before and after vitamin C supplementation for 30 days. The antioxidant group received orally three vitamin C tablets (each tablet contained 333 mg of vitamin C; Lamberts Health Care Ltd, Kent, United Kingdom) and the placebo group daily received orally three lactose tablets. All participants were instructed to consume the capsules every 8 h to achieve a high concentration of vitamin C throughout the 24 h. Vitamin C supplementation for 30 days improved VO_2 max and oxidative stress in the low vitamin C group. (Paschalis et al., 2014)

- Vitamin D

Vitamin D regulates calcium and phosphorus absorption and metabolism and plays a key role in maintaining bone health. (Thomas et al., 2016) Athletes who live at latitudes >35th parallel or those who train and compete indoors are likely at higher risk of Vitamin D deficiency. Other factors like dark complexion, high body fat content, training during early morning or evening when ultraviolet B levels (UVB) are low, and aggressive blocking of UVB exposure (via clothing, equipment and blocking lotions), increase the risk of deficiency. (Larson-Meyer and Willis, 2010) Vitamin D blood levels from 32 ng/ml to 50 ng/ml have been recognized as important for optimal training induced adaptation. (Larson-Meyer and Willis, 2010,Cannell et al, 2009)

A study was carried out on elite ballet dancers (n=24) who were intervened with 2000IU/day of oral vitamin D_3 for 4 months. A significant increase was noted in the intervention group in muscular function (measured by isometric strength and vertical jump) and the intervention group also sustained significantly fewer injuries compared to the controls. (Wyon et al, 2013) A study was carried out on 30 odd club-level athletes who were randomized (using baseline 25[OH] D concentrations) into one of three groups receiving either a placebo (PLB), 20,000 or 40 000 IU/week oral vitamin D_3 for 12 weeks. Serum 25 [OH] D and muscle function (1-RM bench press, leg press and vertical jump height) were measured pre-supplementation and 6 and 12 weeks post-supplementation. Both 20,000 and 40,000 IU vitamin D_3 supplementation over 6 weeks elevated serum 25 [OH]D concentrations above 50 nmol/l, but neither does given for 12 weeks improved the measures of physical performance. Thus in this study, vitamin D supplementation failed to have any impact on physical performance in athletes. (Close et al., 2013)

Current research does not support vitamin D as an ergogenic aid for sports, despite the fact that accurate assessment and correction of deficiency are probably crucial for athletes' health and increased athletic performance. (Thomas et al., 2016)

- Role of Minerals

Athletes have higher than normal requirements for minerals and inadequacy directly affects athletic performance. (Sorrenti et al., 2019) Calcium and Iron are discussed at length subsequently. Sodium phosphate has been shown to increase maximal oxygen uptake, anaerobic threshold and endurance capacity while sodium chloride helps to maintain fluid and electrolyte balance. Zinc is associated with a decrease in exercise-induced changes in immune functioning. However, there is little evidence to link improved sporting performance to boron, chromium, magnesium or vanadium. (Kreider et al., 2010)

- Calcium

Calcium is the most abundant mineral in our diets. About 1% of the calcium in our bodies is used to support metabolic functions including muscle contraction. The other 99% is found in our bones and teeth where it provides both a structural and functional role. (Australian Institute of Sports, 2014) Calcium reduces the risk of developing premature osteoporosis and helps maintain optimum body composition.

Along with calcium deficiency, energy, protein and vitamin D deficiency are also seen and in combination, they can negatively affect bone health. Exercise in itself does not lead to an increase in body needs for dietary calcium but electrolytes are often lost in high amounts through sweat and dietary calcium may be needed to compensate for those losses and to prevent deficits. High dietary protein intake especially from animal sources is associated with increased urinary calcium losses and is especially detrimental to bone health when in combination with inadequate dietary calcium intake. Sodium also affects calcium excretion in urine as both sodium and calcium compete for resorption in the renal tubules.

For about every 2300 mg of calcium excreted by the kidney nearly 40 to 60 mg of calcium is lost. (Kunstel, 2005)

- Iron

Iron is an essential mineral necessary for delivering oxygen to tissues throughout the body as well as has an important role in metabolism, respiration and immune function. (Rubeor et al, 2018) Severe iron deficiency with anemia is uncommon, but low ferritin concentrations with normal hemoglobin levels are frequent, particularly in female distance athletes. Routine screening is indicated for certain high-risk groups, such as elite female athletes, those with performance declines, vegetarians and athletes having a history of iron deficiency. Unmonitored supplementation with oral iron by athletes is not recommended. (Rowland, 2011)

Athletes involved in intense training may have increased iron losses in sweat, urine, feces and from intravascular hemolysis. (Thomas et al., 2016) Acute iron losses during exercise may be minimal but the accumulation of iron losses throughout extended training programme may affect the iron status of athletes. (Sim et al, 2014) Physical training may increase the estimated average requirement of iron in female athletes by 30 to 70%. (DellaValle, 2013; Sim et al., 2014)

A systematic review was conducted to determine the impact of iron supplementation in iron deficient non-anemic athletes on performance in which 12 studies were reviewed with a total of 283 participants. Iron supplementation in Iron deficient non-anemic (IDNA) athletes showed improved performance in 6 studies (146 participants) and did not show improvement in the performance in the remaining6 studies (137 participants) The studies that demonstrated performance benefits with iron supplementation in IDNA athletes, all used a ferritin supplementation threshold at or below 20 µg/L. Whereas, there is no evidence showing improvement in performance in IDNA athletes with Ferritin levels greater than 20 µg/L.(Rubeor et al, 2018)

A study was conducted on 85 athletes (handball, volleyball, soccer and judo players) and 67 non-athletes. A significantly greater number (p=0.05) of athletes (27%) demonstrated iron deficient erythropoiesis compared with non-athletes. (Ponorac et al, 2019) Another cross sectional study was conducted on 70 female athletes aged 12-21 years in which iron deficiency was determined by serum ferritin levels and bone density by bone densitometer quantitative ultrasound. The study revealed a significant relationship between iron deficiency based on serum ferritin (p=0.044) with bone density in young female athletes (Pradita et al, 2020)

A meta-analysis targeted to determine the beneficial effects of iron treatment in iron deficient non-anemic endurance athletes concluded that iron treatment via both oral supplementation and parentral injection are effective at improving iron status in these athletes. The findings also suggested that the effect of iron treatment on serum ferritin appears to reduce if the treatment period continues beyond 80 days. Also, the improved iron status following the treatment may enhance aerobic capacity (VO_2 max). (Burden et al, 2014)

A study was carried out to investigate the relationship between iron intake and anemia in college athletes in various sports. A total of 97 odd athletes engaged in sprinting, throwing, jumping, middle and long distance running, judo, gymnastics and American football were evaluated. Only 4% of male athletes whereas as high as 83% of female athletes consumed less Iron than the estimated average requirement. However, the hemoglobin concentration was normal in all participants irrespective of iron intake and thus none were anemic. (Fujii et al, 2015)

To sum up, there are no precise criteria for Energy and nutrient requirements in cricket players, unlike other sports. Therefore, much effort is required in this field to formulate the same. Literature reveals that a substantial amount of research is conducted on the Iron status of athletes participating in various sports. However, there is no relevant literature on the iron status of cricket players, which must be addressed. Moreover, there is paucity of literature regarding Calcium intake in athletes in general.

- **Sports Anaemia**

Sports anemia also known as dilutional pseudo-anemia is not genuine iron depletion or deficiency, but the result of a dilution effect on hematological markers. (Burke and Deakin, 2010) Intense training is often accompanied by an increase in plasma volume which is a normal adaptive response to training and a corresponding reduction in iron status measures. (Schumacher et al, 2001) Training increases plasma volume at a greater rate than the increase in the red cell mass. (Chatard et al, 1999) Hence the red cell mass appears diluted. Up to a 20% increase in plasma volume has been reported in the 48 hours after a race in marathon runners and can persist for as long as a week. (Schmidt et al, 1989)

There are usually no symptoms and performance is unlikely to be affected, as iron is not limiting red blood cell production. (Burke and Deakin, 2010) Dilutional pseudo-anemia does not respond to iron supplements. (Hegenauer et al., 1983) In clinical practice, differentiating between dilutional pseudo-anemia and true iron depletion using the usual hematological indicators becomes difficult. (Burke and Deakin, 2010)

- **Hydration**

Water is critical for the proper functioning of the body. Therefore, it is important that the loss of water through sweat and urine is compensated by adequate consumption of water and other fluids containing water. (Panandiker, 2007)

Optimal hydration during exercise refers to avoiding fluid losses greater than 2-3% of body mass while also avoiding over-hydration. During exercise, it is common for athletes to involuntarily dehydrate. (Mcdermott et al., 2017) Research demonstrates that exercise in hot adverse conditions can cause dehydration in as little as 15 minutes. (Panandiker, 2007) Dehydration is known to impair endurance performance, especially in hot environmental conditions. (Cheuvront et al, 2003) Excessive fluid intake is also an issue as hypo-natremia develops in severe cases of over-hydration. (Mcdermott et al., 2017) The inability to manage fluid intake resulting in hypo or hyper hydration can be detrimental to performance and in some cases increase health risk. (Belval et al., 2019)

The metabolic heat generated by muscle contractions during exercise can eventually lead to hypo-volemia (decreased plasma/blood volume) and thus, cardiovascular strain, increased glycogen use, altered metabolic and central nervous system function and a greater rise in body temperature. (Kenefick and Cheuvront, 2012; Shirreffs and Sawka, 2011) Although it is possible to be hypo-hydrated but not hyper-thermic (defined as core body temperature exceeding 40 ºC, in certain cases, the extra thermal strain associated with hypo-hydration can result in an increased risk of life-threatening exertional heat illness like heatstroke. (Armstrong et al, 2007)

Current consensus recommends that good hydration practices include: beginning exercise in a state of eu-hydration, preventing excessive hypo-hydration during exercise and replacing remaining losses following exercise prior to the next exercise bout. (Bergeron et al, 2012; Mcdermott et al., 2017; Racinais et al., 2015) However, fluid needs are individualistic and depend on factors like personal sweat rate, environmental conditions, exercise mode, intensity and duration. (Covertino et al, 1996) Exercise performance during intense or long duration events may be improved by the addition of carbohydrates and electrolytes to rehydration beverages. (Mcdermott et al., 2017)

Everyday hydration assessment in athletes is recommended using the WUT (Weight, Urine and thirst) symptoms. A daily loss of body weight (W) greater than 0.5 to 1.0 kg, a small volume of dark colored urine (U; apple juice or darker), and the sensation of thirst (T) are all symptoms of dehydration. When two or more of these symptoms are present, dehydration is likely. If all three markers are present, dehydration is very likely. Athletes are advised to self-assess all the three WUT symptoms upon waking each morning. (Casa et al, 2019)

Assuming an athlete is in energy balance, daily hydration status may be estimated by tracking early morning body weight (BW) (measured upon waking and after voiding) because acute changes in BW generally reflect shifts in body water. (Kenefick and Cheuvront, 2012) BW should also be measured before and after exercise sessions to determine sweat loss. (Kreider et al., 2010) Routine measurement of pre and post-exercise BW, accounting for urinary losses and drink volume, can help the athlete estimate sweat losses during sporting activities to customize their fluid replacement strategies. In the absence of other factors that alter body mass during exercise (e.g., the significant loss of substrate which may occur during very prolonged events), a loss of 1 kg BW represents approximately 1 litre sweat loss. (Thomas et al., 2016) Urinary specific gravity and urine osmolality can also be used to assess hydration status by measuring the concentration of the solutes in urine. When assessed from a midstream collection of the first morning urine sample, a urinary specific gravity of <1.020 to <1.025, is generally indicative of eu-hydration. (Kenefick and Cheuvront, 2012) Urinary osmolality reflects hypo-hydration when >900 mOsmol/kg, whereas eu-hydration when <700 mOsmol/kg. (Kenefick and Cheuvront, 2012; Thomas et al., 2016) The 'pee' test can be used by athletes themselves to assess their hydration status. In this, the colour of urine is matched with the colours in the test chart and the hydration status is determined. (Panandiker, 2007) Figure 2.9 depicts the urine color chart used to compare the urine color for the pee test.

Figure 2.9: Urine colour chart- Pee test

The ISSN exercise and sport nutrition review document states that a decrease in sports performance is evident if 2% or more of an athlete's body weight is lost through sweat. The document also recommends that athletes should not only rely on thirst as an accurate indicator of fluid needs. It also highlights that extreme methods to decrease body weight like the use of diuretics, vomiting and saunas are inappropriate and dangerous to health. (Kreider et al., 2010) Ingestion of cold beverages (0.5 ºC) may help reduce core temperature and thus, improve performance in the heat. Flavored beverages may increase palatability and voluntary fluid intake. (Thomas et al., 2016)

- Hydration before exercise

Some athletes commence exercise in a hypo-hydrated state, which can adversely affect athletic performance. (Garth and Burke, 2013; Shireffs and Sawka, 2011) Purposeful dehydration to reduce weight as commonly observed in weight category sports may lead to a significant fluid deficit, which can be difficult to restore between weigh-in and the start of the competition. Athletes may also be hypo-hydrated at the onset of exercise due to recent, prolonged training sessions in the heat, or due to multiple events in a day. (Garth and Burke, 2013; Goulet, 2012; Shirreffs and Sawka, 2011; Thomas et al., 2016)

Athletes may achieve eu-hydration before exercise by consuming a fluid volume equivalent to 5 to 10 mL/kg BW in the 2 to 4 hours before exercise to achieve urine that is pale yellow while allowing for sufficient time for excess fluid to be voided. (Goulet, 2012; Thomas et al., 2016) Sodium consumed in pre-exercise fluids and foods may help with fluid retention. While some athletes attempt to hyper-hydrate before exercise in hot conditions where the rates of sweat loss or restrictions on fluid intake unavoidably cause significant fluid deficit, the use of glycerol and other plasma expanders for this purpose is now prohibited by the World Anti-Doping Agency (www.wada-ama.org) (Thomas et al., 2016).

According to the guidelines by ILSI, NIN and SAI document, athletes should consume 1.5 to 3 L of fluid above their normal intake the day before the event. Athletes should consume 0.5 L of water 1-2 hours prior to the event and 0.6 L of water/other fluids 10-15 minutes before the event. Emptying the bladder 15 minutes prior to the event is also a must. (Panandiker, 2007)

- Hydration during exercise

Sweat rates during exercise vary widely from 0.3 to 2.4 L/h depending on exercise intensity, duration, fitness, heat acclimatization, altitude, and other environmental conditions like heat and humidity.

(Kenefick and Cheuvront, 2012; Koehle et al., 2014; Mountjoy et al., 2012; Thomas et al., 2016) A variety of factors may impair the availability of fluid or opportunities to consume it during exercise and for most competitive, high-caliber athletes, sweat loss generally exceeds fluid intake. However, individual differences are seen in drinking behavior and sweat rates and result in a range of changes in fluid status from substantial dehydration to over-hydration. (Garth and Burke, 2013)

Typically competitive athletes develop a fluid deficit over the course of a workout session, but over the past 2 decades, it has been observed that due to the awareness about fluid deficit some recreational athletes drink at rates that exceed their sweat losses and over-hydrate. Overdrinking fluids above sweat and urinary losses is the primary cause of hypo-natremia (plasma sodium <135 mmol/L), also called water intoxication, moreover this can be exacerbated in situations where there are excessive losses of sodium in sweat and fluid replacement involving low sodium beverages.(Hew-Butler et al, 2015; Jeukendrup, 2011) Over-hydration is typically seen in recreational athletes as their work outputs and sweat rates are lower than competitive athletes, whereas their opportunities to hydrate may be greater. Women generally have a smaller body size and lower sweat rates than men and appear to be at greater risk of overdrinking and thereby hypo-natremia. (Thomas et al., 2016) Symptoms of hypo-natremia during exercise appear when plasma sodium levels fall below 130 mEq/L and include bloating, puffiness, weight gain, nausea, vomiting, headache, confusion, delirium, seizures, respiratory distress, loss of consciousness and even death if untreated. Although the prevalence of hypo-hydration and hyper-natremia is thought to be greater than reports of hyper-hydration and hypo-natremia, the latter are more hazardous and require quick medical attention. (Hew-Butler et al., 2015; Kenefick and Cheuvront, 2012; Thomas et al., 2016)

IOC suggests that sufficient fluid should be consumed during exercise to limit dehydration to less than approximately 2% of body mass. Athletes should not drink so much that they gain weight during exercise.(Shirreffs and Sawka, 2011) Sodium should be ingested during exercise when huge sweat sodium losses occur like in the case of athletes with high sweat rates (>1.2 L/h), salty sweat, or prolonged exercise exceeding 2 hours in duration. (Shirreffs and Sawka, 2011, Kenefick and Cheuvront, 2012; Thomas et al., 2016)Though highly variable, the average concentration of sodium in sweat approximates ~1 g/L (50mmol/L) and is hypotonic in comparison to plasma sodium content.(Goulet, 2012) Guidelines by ILSI, NIN and SAI recommend that athletes should drink 150 ml to 250 ml every 10-15 minutes to maintain fluid balance. Athletes should sip the water and not gulp it down. Athletes should drink cool water during the event as it is absorbed faster and cools the body better than water at room temperature. (Panandiker, 2007)

❖ Hydration post-exercise

The majority of athletes finish exercising with a fluid deficit and need to restore eu-hydration during the recovery period. (Garth and Burke, 2013; Thomas et al., 2016) It is recommended that rehydration strategies should mainly involve the consumption of water and sodium at a modest rate that minimizes urinary losses. (Shirreffs and Sawka, 2011) The presence of dietary sodium/sodium chloride (from foods or fluids) helps to retain ingested fluids, especially extracellular fluids, including plasma volume. Therefore, athletes should not be advised to restrict sodium post-exercise especially when large sodium losses have been incurred. (Kenefick and Cheuvront, 2012; Thomas et al., 2016) It is also recommended that sodium should be added to fluids during exercise that lasts > 2 hours, as well as in fluids that are ingested by athletes who have lost more than 3-4 g sodium in their sweat during exercise. (Shirreffs and Sawka, 2011) As sweat losses and obligatory urine losses continue during the post-exercise phase, effective rehydration requires the ingestion of a greater volume of fluid (e.g., 125% to 150%) than the final fluid deficit (e.g., 1.25 to 1.5 L fluid for every 1 kg BW lost) (Kenefick and Cheuvront, 2012; Thomas et al., 2016)

- **Dehydration**

Symptoms and results at different levels of loss in body weight due to dehydration are specified in table 2.7.

Table-2.7: Consequences of Dehydration

% Body Weight Loss	Consequences
1%	Thirst
2%	Stronger thirst, vague discomfort and sense of oppression, loss of appetite
3%	Increasing hemo-concentration, reduction in urinary output, dry mouth
4%	Increased effort for physical work, flushed skin, impatience, sleepiness, apathy, nausea, emotional instability
5%	Difficulty in concentrating
6%	Impairment in exercise temperature regulation, increased pulse and respiratory rate
8%	Dizziness, cyanosis and labored breathing with exercise, indistinct speech, weakness, mental confusion
10%	Spastic muscles, inability to balance with eyes closed, general incapacity, delirium and wakefulness, swollen tongue
11%	Circulatory insufficiency marked hemo-concentration and decreased blood volume, failing renal function
15%	Death

(Panandiker, 2007)

Although there is individuality in the response to dehydration, fluid deficits of >2% body weight can compromise cognitive function and aerobic exercise performance, especially in hot weather. (Shirreffs and Sawka, 2011; Goulet, 2012) Three to five percent of body weight loss due to dehydration commonly leads to decrements in the performance of anaerobic or high-intensity activities, sports specific technical skills and aerobic exercise in a cool environment. (Shirreffs and Sawka, 2011) Water deficits of 6% to 10% BW (severe hypo-hydration) have more pronounced effects on exercise tolerance, reduction in cardiac output, sweat production, and skin and muscle blood flow. (Panandiker, 2007)

- Studies on the impact of dehydration on cricketers

Studies have explored the impact of dehydration on cricketing skills. A study was conducted to assess the effects of dehydration on cricket specific motor skill performance among fast-bowlers, fielders and batsmen playing in a hot and humid environment. Ten fast-bowlers, 12 fielders and 8 batsmen participated in two field trials conducted 7 days apart: a fluid provision trial (FP) and a fluid restriction trial (FR). Mass loss was 0.6±0.3 kg (0.9±0.5%) in FP, and 2.6±0.5 kg (3.7±0.8%) in FR trials. Maintaining mass within 1% of initial values did not cause any significant skill performance decline. However, the dehydration in the FR trial induced a significant time and trial effect on bowling speed by 1.0±0.8% reduction (0.3±0.8% reduction in FP trial; $p<0.01$) and 19.8±17.3% reduction in bowling accuracy for line (3.6±14.2% reduction in FP trial; $p<0.01$), but no effect on bowling length. A significant decline was noted in the FR trial for throwing speed for over-arm (6.6±4.1%; $p<0.01$; 1.6±3.4% reduction in FP trial) and sidearm (4.1±2.3%; $p<0.01$; 0.6±4.7% increase in FP trial) techniques, and for throwing accuracy for over-arm (14.2±16.3%; $p<0.01$; 0.8±24.2% increase in FP trial) and sidearm (22.3±13.3%; $p<0.05$; 3.2±34.9% reduction in FP trial) techniques. Batsmen demonstrated a significant performance drop in making three runs (0.8±1.2% increase in time in FP trial and 2.2±1.7% increase in time in FR trial; $p<0.01$). The trial concluded that moderate to severe dehydration of 3.7% body mass loss significantly impairs motor skill performance among cricketers, mainly bowlers and fielders, playing in hot and humid conditions. The study also highlighted that fluid ingestion strategies maintaining mass loss within 1% prevented a decline in skill performance. (Gamage et al, 2016)

An observational study was carried out on competitive male cricket players (>16 y of age and n=18) from the Auckland Cricket Association during competitive 'one-day' cricket matches. Early morning pre-match dehydration ($\geq U_{sg}$ 1.020 g/ml) was reported in as high as 81.5% of participants. The minimum recommended pre-event fluid intake (5 ml/kg) was met by only 28% of participants (n=5). End of match body mass percent losses occurred in 59.2% and the highest loss reported was 2% (n=2). End of match body mass indicated that rehydration was insufficient in over two-thirds of the cases. Match fluid intake was positively associated with match sweat loss (*P*<0.001). The Researchers concluded that educating this group of cricket players on pre-match and match-day fluid requirements and individual hydration monitoring practices is warranted. (Mcdonald, 2018)

Thus, to sum Optimal hydration during exercise refers to avoiding fluid losses greater than 2-3% of body mass while also avoiding over-hydration. Current consensus recommends beginning exercise in a state of eu-hydration, preventing excessive hypo-hydration during exercise and replacing remaining losses following exercise prior to the next exercise bout. Moreover, everyday hydration assessment in athletes is recommended using the WUT (Weight, Urine and thirst) symptoms. It is recommended to ingest sodium in the case of athletes with high sweat rates (>1.2 L/h), salty sweat, or prolonged exercise exceeding 2 hours in duration. The presence of dietary sodium helps to retain ingested fluids, especially extracellular fluids, including plasma volume. In general, fluid deficits of >2% body weight are associated with compromised cognitive function and aerobic exercise performance and 3-5% leads to decrements in the performance of anaerobic or high-intensity activities, sports specific technical skills and aerobic exercise in a cool environment. Specifically in cricketers, fluid ingestion strategies maintaining mass loss within 1% are successful in preventing a decline in skill performance. Thus, due to the importance of adequate hydration and the adverse effects of dehydration, it is crucial to conduct more studies on the hydration status of Elite cricketers and educate them to maintain the same.

- **Commonly Encountered Problems by Athletes**

❖ Weight management in athletes

Athletes may attempt to lose weight to improve power to weight ratio, attain the desired body composition in a sport that has an aesthetic ideal or make a pre-designated weight to compete. Athletes and coaches are exposed to just as much misinformation about weight loss and dieting as the rest of the community. Unfortunately, this often leads to the use of unbalanced dietary regimens, nutrition supplements and drugs that lack scientific support or that are not permitted by sports drug agencies. Such approaches may result in decreased performance and have negative health consequences. The promotion of safe and effective weight-loss strategies is, therefore, a crucial function of the sports medicine team. (Burke and Deakin, 2010)

An effort to lose weight is seen more in weight category sports like boxing and wrestling. Athletes usually attempt to lose body weight a few days or a week prior to weigh in. The magnitude of weight loss is 5-10% of their body weight or even more in some cases in such a short duration. For this purpose, a variety of methods are employed like restricted fluid intake, low calorie diets, saunas, exercise wearing plastic suits, running in the sun, application of balms to increase sweating and fasting one day prior to the weigh in. Some other aggressive methods used are vomiting, diet pills, laxatives and diuretics. However, the use of diuretics is banned by the World Anti-Doping Agency (WADA). (Bhide and Mandalika, 2018)

Quick weight loss can lead to detrimental health effects in athletes. Rapid weight loss results in a reduction in body water, electrolytes and lean tissue that adversely affects physiological functions like thermoregulation, cardiovascular functions and metabolism, which are crucial to athletic performance and health. Energy restriction for an extended duration affects the endocrine organs and their homeostatic regulation. Moreover, rapid weight loss also can cause hormonal imbalance i.e. it can lead to reduced levels of testosterone and estrogen and increased levels of cortisol. Nutrient deficiencies and dehydration that accompany instant weight loss also increase the risk of injuries. (Bhide and Mandalika, 2018) Weight loss of 0.5 to 1 kg/week or for body fat a maximum of 5 mm reduction in total skinfold (over seven or eight sites) per week is desirable. (Burke and Deakin, 2010) Moreover, in addition to weight management, it's also important to maintain optimum body composition and this becomes more important in athletes due to the demands of training and competition.

- The Female athlete triad

The Female Athlete Triad is a health concern seen in women and girls who are driven to excel in sports. It involves three distinct and interrelated conditions: disordered eating (a range of poor nutritional behaviours), amenorrhea (irregular or absent menstrual periods) and osteoporosis (low bone mass which leads to weak bones and risk of fracture). (American College of Sports Medicine, 2011) The female athlete triad was first identified in 1992 and was originally characterized by disordered eating, amenorrhea and osteoporosis. (Brown et al, 2017,Nazem and Ackerman, 2012) However, the female athlete triad is now characterized as a spectrum of interrelated conditions and complications that include low energy availability (EA) with or without disordered eating, menstrual dysfunction and low bone mineral density, according to the 2007 American College of Sports Medicine's position stand. (Brown et al, 2017)

Studies have shown 1–4% prevalence of female athlete triad. Prevalence is expected to be much higher now that the definition is more inclusive (not all three components of the triad need to be present) and is likely underestimated due to a variety of factors including, failure by professionals to recognize symptoms, a spectrum of clinical presentation and lack of symptom reporting by athletes. Athletes presenting with one component of the triad are at risk for and should be evaluated for the other components as well. (Brown et al, 2017)

- Components of Female Athlete Triad

1. Energy deficit and Disordered eating

Energy availability is the amount of dietary energy for all physiologic functions after accounting for energy expenditure from exercise. Low energy availability or energy deficit may be the result of an eating disorder like Anorexia Nervosa (AN) or Anorexia Bulimia (BN) but can also occur in the absence of any such conditions. Athletes may have disordered eating simply by unknowingly failing to attain their energy requirements secondary to time constraints or lack of nutritional knowledge. Some studies have also found that athletes often lack the appetite necessary to promote food intake as compensation for energy expenditure from intense exercise regimens. (Nazem and Ackerman, 2012)

2. Amenorrhea

An unbalanced diet, inadequate caloric intake relative to exercise level and excessive training may predispose females to menstrual abnormalities. Amenorrhea is generally defined as the absence of menses for 3 months or more but can be subcategorized into primary and secondary types. Primary amenorrhea refers to a delay in the age of menarche (no menses by age 15 years in the presence of normal secondary sexual development or within 5 years after breast development if that occurs before the age of 10 years). Secondary amenorrhea is a loss of menses after menarche. Other types of menstrual irregularity include anovulation, luteal phase deficiency and oligo menorrhea. Amenorrhea can be caused by a variety of diseases and genetic abnormalities, as well as energy deficiency and even stress. The type of amenorrhea resulting from changes in energy availability is functional hypothalamic amenorrhea (FHA). FHA is characterized by the absence of menses due to suppression of the hypothalamic-pituitary-ovarian axis, without an identifiable anatomic or organic cause. This type of amenorrhea, commonly associated with exercising and stress, is most relevant to the female athlete. (Nazem and Ackerman, 2012)

3. Osteoporosis

Osteoporosis is a condition referring to low bone mass and fragility of the skeleton. Low estrogen levels and other hormonal changes, which accompany irregular or absent menses, may predispose females to osteoporosis, especially in adolescent age and twenties when bone mass is accumulating. Bone loss usually occurs later with menopause and aging. But in young female athletes with the triad, a compromise in bone strength, ranging from low BMD and stress fractures, osteoporosis may occur at a much younger age. Also, despite performing similar weight bearing exercises, amenorrheic athletes have lower BMD than their eu-menorrheic counterparts. In fact, amenorrheic athletes have 10% to 20% less lumbar spine BMD than eu-menorrheic athletes. (Nazem and Ackerman, 2012)

Disordered eating behaviors such as restrictive eating patterns and dieting was found to increase the likelihood of stress fracture occurrence in competitive club track and field athletes. (Mitchell et al, 2014) Amenorrhea and low BMD were reported to be associated with lower extremity musculoskeletal injury in 89 interscholastic female distance runners. Menstrual dysfunction has been associated with an increased risk of stress fracture or other bone stress injuries in collegiate athletes, competitive club track and field athletes and adult runners. Musculoskeletal injuries among female endurance runners caused by menstruation disorder result into higher training interruption. (Mitchell et al, 2014)

- **Vegetarian Athletes- Challenges faced**

A vegetarian diet is a plant-based diet that consists mostly of fruit, vegetables, grains, legumes, nuts and seeds, and excludes beef, pork, poultry and fish. Two main categories are lacto-ovo-vegetarian and vegan. Lacto-ovo-vegetarian excludes meat, poultry and fish but includes milk, dairy products and eggs. Whereas a vegan diet excludes all animal products including milk and eggs. (Fuhrman and Ferreri, 2010)Athletes may choose vegetarianism for a variety of reasons, including ethnic, religious, and philosophical views on health, food aversions, economical restrictions, or to conceal disordered eating. As with any self-imposed dietary limitation, it is vital to investigate whether the vegetarian athlete also exhibits disordered eating. (Thomas et al., 2016)

Scientific data on vegetarian athletes are sparse. (Fuhrman and Ferreri, 2010) There are several examples of vegetarian and even vegan athletes who are at the top of their game. (Craig and Mangels, 2009) As early as in the 1890's, vegetarian athletes and long distance walkers in the United States and Great Britain performed as well or better than their non-vegetarian counterparts did. In 1912, a vegetarian was one of the first athlete to complete a marathon in less than 2h 30 min. (Nieman, 1999) According to the American Dietetic Association, vegetarian diets can meet the requirements of competitive athletes. (Craig and Mangels, 2009) Based on the available literature it emerges that athletic performance is neither compromised nor enhanced by habitually consuming a vegetarian diet. (Venderley and Campbell, 2006)

Based on the extent of dietary limitations, nutrient concerns in vegetarian athletes may include energy, protein, iron, zinc, vitamin B_{12}, calcium and omega-3 fatty acids. (Craig and Mangels, 2009) Vegetarian athletes may at times face challenges like difficulty in gaining access to suitable foods during travel, restaurant dining and at training camps and competition venues. Vegetarian athletes may benefit from comprehensive dietary assessment and education to ensure their diets are nutritionally adequate to support training and competition demands. (Thomas et al., 2016)

To sum, it is crucial to educate athletes about maintaining the optimum body composition rather than just focusing on the weight management. As quick weight loss can be highly detrimental, athletes should be monitored against using such methods. Female athlete triad has severe health consequences and therefore regular screening and treatment if required is must. The needs of vegetarian athletes should be taken care of by educating them on the nutrients that require special attention like protein, B 12 and Iron.

Assessment of Nutritional Status of Athletes

- Anthropometry of athletes

Anthropometry involves the application of physical measurements to assess human size, shape, proportion, body composition, maturation and gross function. These measurements are useful to reflect both the growth and development of children and adolescents and give some indication of body composition in adults. They are also useful as an indication of overweight or obesity. (Burke and Deakin, 2010) The impact of anthropometric differences on the fitness levels of the players was studied among university club cricketers (n = 17; 9 batsmen and 8 bowlers) in South Africa. The finding revealed that the cricketers having taller stature (≥1.7 m) scored significantly higher for agility and power compared to their shorter (<1.7m) counterparts. Thus, the authors remarked that having a higher standing height is desirable in cricketers as it improves agility and power. (Noorbhai and Khumalo, 2022)

The difference in the anthropometric variables of cricketers belonging to different disciplines was explored in 60 male district level players with a mean age of 17.58±2.09 yrs from West Bengal. The study revealed that the height and weight of the bowlers (Height: 167.28±6.29cm; weight: 57.25±9.03kg) was higher than batsmen (Height: 164.96±6.49cm; weight: 54.52±6.48 kg) and all-rounders (Height:

161.32±7.43 cm; weight: 51.92±12.80 kg); the difference being non-significant. (Biswas & Ghosh, 2020) A study carried out on 40 odd cricketers of Goa aged 17-22 years revealed that the standing height, arm length and leg length were significantly higher in fast bowlers than spinners. The mean standing height in fast bowlers was 167.4 ± 4.3 cm versus 163.8 ± 4.2 cm in spinners. The mean arm length in pacers was 72.7 cm versus 68.8 cm in spinners. The mean leg length was 92.1 cm in pacers whereas 88.8 cm in spinners. (Lamani et al, 2016)

A study conducted on 40 odd cricket players in Pakistan concluded that the regional cricket players were superior in anthropometry compared to the school level cricketers of the same age group. The regional cricketers were significantly ($P <0.04$) taller, ($P < 0.03$) and heavier than their school counterparts. The regional players displayed significantly higher ($P <0.04$) sitting height, ($P <0.04$) arm span, ($P < 0.00$) arm length, and ($P <0.02$) leg length than the school cricketers. (Nazeer et al, 2018)

Anthropometric differences between state level female cricketers from Maharashtra (n=39) and Punjab (n=40) in the age group 18-25 years were studied. The differences in height, weight and BMI were not statistically significant. The mean height of Punjab players was higher (157.4±6.4cm) than in the Maharashtra cricketers (156.3±4.8 cm). The mean weight was the same in both the groups i.e. 53.1±4.1 kg. (Tahoor & Koley, 2019) A study was conducted to assess the differences in anthropometry of elite Pakistani (n=14) and Iranian (n=14) cricketers. The Pakistani players had a significantly higher mean height (188.91±1.97) cm than the Iranian players (176.5±806 cm). The Pakistani players also displayed significantly higher mean waist circumference than the Iranians (89.22±6.29 v/s 80.42±6.55); however, both of these values were in the normal range. (Ghalea and Peeri, 2016)

Thus, there is adequate literature on the anthropometry of cricketers however studies on Elite cricketers are sparse and therefore Research needs to be conducted in this area.

- Dietary intake of athletes

Dietary assessment measures energy and nutrient intake and can help identify athletes that require nutrition monitoring and support. (Thomas et al, 2016) Assessment of the dietary intake of athletes helps to determine nutritional adequacy, ascertain deficiencies and make appropriate dietary recommendations to help an athlete train and compete better. The methods usually employed for the assessment of dietary intake are 24-hour or multiple dietary recall, food frequency questionnaire, weighted diet record, duplicate portion analysis and chemical analysis. A few important considerations for assessing nutrient intake in athletes are:

- Serving sizes- the standard serving sizes in food models may be inappropriate for an athlete's diet as they usually consume greater amounts of food compared to the non-athletic population.
- Snacking – high intensity and long duration training schedules lead to snacking or discreet meals. It is important to document these food items to get an accurate estimate of nutrient intake.
- Beverage consumption- It is difficult to quantify sports drinks consumed, as during training or matches, at times athletes tend to sip from the same bottle and the frequency and quantity of beverages consumed vary based on their individual requirements on that particular day.
- Supplement intake- to meet the raised nutritional needs, many athletes routinely consume supplements. Supplement misreporting is usual among athletes and it is essential to check the credibility and claims of a supplement product.
- Weight control practices- athletes often skip meals, starve or adopt abnormal eating practices to maintain, reduce or increase body weight. Misreporting is usual in these athletes. (Bhide and Mandalika, 2018)

The use of new technologies and techniques to capture dietary intake is beneficial. Twenty-four hour dietary recalls using images and web-based food frequency questionnaires are effective. Tablet and smartphone applications can record food intake with images at every meal. The use of these methods to evaluate nutrient intake improves compliance and is strongly recommended. (Bhide and Mandalika, 2018) There is a clear need for careful validation of dietary assessment methods with emerging technical innovations being likely to show promise as they may assist with portion quantification, reduce the burden of collection, and problems with missing foods among athletes. (Capling et al, 2017)

During the Delhi 2010 Commonwealth Games, dietitians based in the dining hall recorded one day 24 hour dietary recalls of all athletes (n=44) who visited the nutrition kiosk. The athletes belonged to Endurance (n=4), Power (n=9), Racquet (n=6), Team (n=6), Weight category (n=13) and Skill sports (n=10). Analysis of dietary intake was conducted with FoodWorks (Xyris Pty Ltd., Brisbane, Australia). The median total daily energy intake was 8674 kJ (range 2384–18,009 kJ), with carbohydrate within the range of 1.0–9.0 g per kg of body weight (g/kg) (median = 3.8) and contributing to 50% of total energy (TE) (range 14%–79%). Protein and fat intake ranged from 0.3–4.0 g/kg (median = 1.7) to 10–138 g (median = 67 g), and contributed to 21% TE (range 8%–48%) and 24% TE (range 8%–44%), respectively. Athletes reported consuming between 4 and 29 different food items (median = 15) in the previous 24 h period, with predominately cereals, meats, poultry, fish, eggs and meat alternative items.

This suggests that dairy, fruit, and vegetable intake may be sub-optimal and intake of the micronutrients iron, zinc, calcium, and vitamins A and C may be of concern for a lot of athletes. (Burkhart and Pelly, 2016)

An observational study was conducted on competitive male cricket players (>16y) from the Auckland Cricket Association that took place during competitive 'one-day format' cricket matches. Dietary intakes were assessed using food records (pre-match) and direct observation (during match). Match data were collected from 27 cases over six games from 18 players. A pre-match carbohydrate (CHO) intake of <1 g/kg was reported for 66.6% of participants, and match CHO intake of < 30 g/h for 37% of them. The study highlighted that CHO intake was insufficient for two-thirds of players pre-match and for one-third of them during the match. (Mcdonald, 2018)

The nutrient intake of Indian cricketers around training and competition is largely unknown making the development of evidence-based nutrition guidelines for cricketers challenging. Thus, there is a dire need to collect data on the dietary intake of Elite Indian cricketers.

- Body composition

Various attributes of the physique like body size, shape and composition are considered to contribute to athletic performance. Athletes work upon body weight and composition to reach desirable targets. The assessment and manipulation of body composition may assist in athletic performance but it cannot accurately predict success in sports. (Thomas et al., 2016) Therefore, there should be some flexibility while recommending body composition targets to athletes. (Sundgot-Borgen et al., 2013) When energy expenditure is abruptly reduced during off season or injury, excessive gain in body fat is common and this should be avoided by making modifications to the athlete's training programme. (Thomas et al., 2016)

Some of the techniques used to assess the body composition of an athlete include Dual X-ray absorbsiometry (DEXA), hydro-densitometry, air displacement plethysomography, skin fold measurement and single and multi frequency bioelectrical impedance analysis. (Thomas et al., 2016) DEXA is quick and non-invasive but has issues around cost, accessibility and radiation exposure even though small. When standardised protocols are followed, DEXA has the lowest standard error of estimate whereas skin fold measures have the highest, air displacement plethysomography is an alternative method that is quick and reliable but may underestimate body fat by 2 to 3%. Skin fold measurement remains a popular technique of choice due to convenience and cost. (Ackland et al., 2012)

Micklesfield et al 2002 compared 34 cricketers to 23 physically active controls and found cricketers to have significantly greater lean mass (61.4 ±6.0 kg versus 56.8 ± 7.1 kg, p=0.010), than 23 physically active age-matched controls. (Micklesfield et al 2002 as cited in Payne, 2017) A study by Lees et al remarked that fast bowlers had significantly greater lean mass than non-athletic controls (67 ± 5.8 kg versus 56.5 ± 3.8 kg, p=0.001); also, a trend was seen towards lower body fat percentage in the fast bowlers compared to controls (17.4 ±2.9% versus 20.5 ±5.0%) (Lees et al, 2016 as cited in Payne, 2017)

A study consisting of 271 odd inter-district level male cricketers from several Indian districts reported total body fat percentage in the participants ranging from 13.8 ± 3.9% to 17.2 ±5.2%. Body density was measured following Jackson and Pollock (1978) formula and percent body fat by Siri's equation (1956) (Koley et al., 2012). American Council on Exercise (ACE), 2009 recommends percent body fat for athletes to be between 6 and 13% for men and 14 and 20% for women. Another published ideal range is 5-10% for males and 8-15% for females. (Bhide and Mandalika, 2018; Jeukendrup, 2010)

However, as the data on body composition indicators for Elite Indian Cricketers is inadequate, there is a need to carry out more research on exploring the body composition of cricketers.

Fitness

Similar to any other sport, physical fitness has a big role in the performance of a cricketer. The fitness assessment is a very important aspect of an athlete's program. Cricket traditionally did not have much importance given to fitness and overweight players were also seen occasionally at elite level cricket. However, with the rise in the number of competitive events being played in a year, physical demands on cricketers increased and therefore the importance of fitness in cricket increased to a noticeable extent. (Dana et al, 2014) Moreover, since last two decades, there are more stringent fitness tests to clear to be part of the cricket squad thus adding to the requirement of being fit.

- Components of physical fitness

Physical fitness can be classified into health-related fitness and performance-related fitness. Health related fitness components are classified as cardio-respiratory, metabolic, muscle strength and endurance, motor and morphological fitness. (Bhide and Mandalika, 2018) Table 2.8 describes the health-related fitness components.

Table 2.8: Health-related fitness components

Component	Definition	Benefits
Aerobic fitness/ Cardio-respiratory fitness	Relates to the ability of the circulatory and respiratory systems to supply oxygen during sustained physical activity	Enables an individual to sustain high levels of continuous exercise
Muscle strength	The ability of muscles to exert force	Muscle strength and endurance prevent injury
Muscle endurance	Muscular endurance is defined as the ability of the muscle or muscle groups to perform repetitive contractions over a period of time against a sub-maximal resistance, such as lifting a set amount of weight several times. (Riebe et al, 2018)	
Flexibility	Ability to move a joint through its complete range of motion (Riebe et al, 2018)	A basic level of flexibility is essential to maintain posture and for ease of motion or movement
Body composition	The relative proportion of muscle, fat, water and bone in the body	Higher muscle mass is linked with strength and a lower incidence of degenerative diseases. Excess abdominal fat increases the risk of cardio-vascular diseases.
Balance	Relates to the maintenance of equilibrium while stationary or moving	Balance is very important in sports-especially gymnastics, long and high jump, etc.

(Bhide and Mandalika, 2018)

Performance-related fitness refers to those components of fitness that are essential for sports performance. (Bhide and Mandalika, 2018) Table 2.9 describes performance-related components of fitness.

Table 2.9: Performance- related components of physical fitness

Component	Definition	Benefits
Motor skills	• Specific movement patterns e.g. hitting a ball with a bat, kicking a ball • Fine motor skills require small movements e.g. accurately firing a gun or large movements like long jumps	It helps an individual to participate in and enjoy sports activities
Coordination	Related to the ability to use senses such as sight, hearing, together with body parts performing motor tasks smoothly and accurately	A high level of coordination is required in bowling, hockey, gymnastics, skating and some other team sports.
Reaction time	The time between stimulation and reaction or speed of response to stimulus	A fast reaction to a stimulus is desirable in many sports that demand a quick response
Speed	The ability to perform a movement within a short period of time	• Time is crucial in many sports; quicker athletes win • In Sprints, swims, and team sports success is influenced by speed

(Bhide and Mandalika, 2018)

In cricket, fitness components like cardiovascular endurance, speed, strength, power, agility and flexibility are very important to excel. In cricketers, developing lower body speed (repetitive and explosive) and anaerobic upper body power is often emphasized as a part of a fitness programme. Greater flexibility in the lower lumbar and hamstrings is important for the bowlers due to the functional requirements during the delivery stride. (Mandrekar, 2017)

- Physical fitness tests

Assessment of physical fitness is a common and appropriate practice in exercise programs. Fitness tests vary across different sports depending on the demands of a particular sport. A fitness test should be both reliable and valid, and ideally, it should be relatively inexpensive. The information obtained from fitness testing, in combination with the individual's medical and exercise history, is used for the following:

- Collecting baseline data and educating participants about their present fitness status relative to health-related standards and age and sex-matched norms.
- Providing data that are helpful in the development of individualized exercise prescriptions to address all fitness components.
- Collecting follow-up data that allow evaluation of progress following an exercise prescription and long-term monitoring as participants age.
- Motivating participants by establishing reasonable and attainable fitness goals. (Riebe et al, 2018)

The fitness tests widely conducted for Cricketers are run a three test which assesses agility, 20 m speed test for speed, Yo-yo test, Repeated sprint ability test and Cardiovascular endurance test- 2 km for cardio vascular endurance, Vertical jump for power, Prone hold test, Squats test and Push-up test for muscular endurance.

- Physical fitness in Cricketers

Though research in the field of sports science has evolved considerably over time, not many studies have been conducted on the physical fitness of cricketers, especially as they relate to the 'specialist' disciplines within the sport. Since cricket consists of various disciplines, it is likely that players will display different physiques and diverse levels of physical fitness. (Dana et al, 2014)

A study conducted on 40 odd cricket players in Pakistan concluded that the regional cricket players (n=20, who played at a superior competitive level) had better physical fitness compared to the school level cricketers (n=20) of the same age group. The regional cricket player was (+ 0.23 s) faster, (+0.18 m) longer in standing broad jump, (+ 3.47 kg) stronger in right hand and (+2.59 kg) in left-hand strength than from the school cricket players.(Nazeer et al, 2018) A study was carried out on 40 odd (20 pacers and 20 spinners) state level cricketers of Goa aged 17-22 years who represented the Goa state team in BCCI age category tournaments. The body composition measurements were collected using skin fold calipers. The findings revealed that the skin fold measurements were significantly higher in spin bowlers (n=20) compared to fast bowlers (n=20) at p= 0.05. (Lamani et al., 2016)

Studies have explored the impact of training on the physical fitness parameters of athletes. A study on 30 players who had participated in state level cricket championship revealed that the pre-season training of 8 weeks consisting of 2 sessions per day and 6 days of training per week resulted in a significant increase in the speed component of the players. (Ravikumar, 2019) In a study conducted on 40 odd college level male cricketers from Jammu and Kashmir State, it was found that cricket specific training programme for 12 weeks resulted in statistically significant improvement in agility and strength endurance in the experimental group compared to the controls. (Bhat and Sreedhar, 2018) Thus the merits of sport specific fitness and well-structured training programme are quite evident.

To sum up, fitness plays a vital role in sports performance. There are several cricket specific fitness tests which are conducted in Elite and recreational cricketers. The fitness levels of the cricketers have been studied as cited above. Moreover, literature also depicts positive impact of training programmes on the fitness of the cricketers. But there are no studies assessing the impact of nutritional status on fitness levels and this gap needs to be addressed.

Morbidity- Injury in Athletes

Morbidities affect the dietary intake of an individual. In athletes, it leads to staying away from the sport or training and thus frequent morbidities can adversely influence performance. There is no literature available on morbidities in cricketers and this area needs to be explored. Injuries are sport specific and the quickest recovery from injuries is very important for an athlete in either the training or competition phase. In cricketers, injuries also differ depending on the discipline of the players e.g. bowlers would experience different injuries compared to batsmen or wicket keepers.

A study was conducted on injury and illness across several teams at a major international cricket tournament in 2011. Fast bowlers, slow bowlers and batters all showed a similar injury prevalence of approximately 5%. The study recommended that acute muscle strains, particularly thigh and hamstring injuries, should be the priorities for injury prevention programmes. (Ranson, Hurley, Rugless, Mansingh,

& Cole, 2013) A cross sectional study was conducted on 100 odd cricketers who trained in Bangladesh Krira Shikkha Protishtan (BKSP) and Bangladesh Cricket Board (BCB). From these, 40% had shoulder injuries, thigh and hip injuries (22%), hand and finger injuries (12%), knee and leg injuries (11%), ankle injuries (7%), spine back and trunk injuries (4%), foot injuries (2%) and head and neck injuries (2%). (Rahman et al, 2019) A longitudinal, observational study was conducted on thirty-two, healthy, injury free, male premier league fast, fast-medium and medium pace bowlers between the age group of 18 and 26 years (mean age 21.8 ± 1.8 years) from the Gauteng Cricket Board. The study revealed that fifty-three percent of the bowlers (n = 17) sustained injuries. (Olivier et al, 2015)

A study from New Zealand recorded injuries in cricketers only during match days and reported that lower limb injuries were the most common at both domestic and international level. In this study total of 268 elite male New Zealand cricket players from seasons, 2009–2010 to 2014–2015 were analysed from the New Zealand Cricket injury surveillance system. In the domestic tournaments the hamstring (8.2% injuries of total), while at the international level groin (13.5% of total injuries) was the most frequently injured body site. (Dovbysh, Reid, & Shackel, 2021)A study was conducted on the South African cricket team and 11 provincial teams to determine the incidence and nature of injuries in these elite cricketers during 4 seasons starting from 1998 to 2002. 1155 injuries were experienced by 594 cricketers with an average of 2 injuries per player. Most injuries occurred during Bowling (41%), followed by fielding and wicket-keeping (29%) and batting (17%). The lower limbs (50%), upper limbs (23%) and the back and trunk (23%) were the most commonly injured. The injuries primarily took place during first class matches (29%), practice (28%) and limited over competition (26%) and in the early phase of the season. Predominantly soft tissue injuries were reported and mainly attributed to muscle (41%), joint (18%), tendon (13%) and ligaments (6%). The mechanisms of injury included delivery and follow through of the fast bowler, running, diving, catching and throwing the ball when fielding (22%), overuse (19%) and various batting situations like being struck while batting (7%), running between the wickets (5%) and batting for long periods at a time (4%). (Stretch and Venter, 2003)

Due to the potential severity of various injuries, a range of protective gears ranging from body padding to gloves and helmets are commonly used by cricketers. Also, good stretching programmes before and after play, along with conditioning before and during the match season, are imperative injury prevention actions. (Finch et al., 1999)Injury and illness surveillance is considered an important first step in the management and prevention of an athlete's health problems. Effective collection, analysis and reporting of injury and illness types, rates, severity and causes allows sporting bodies to identify those that have the biggest impact on an athlete's availability and athletic performance. Concentrated efforts can then be made towards optimising player preparation and the training and competition environment to manage injury and illness risk. (Ranson et al, 2013) Cricket was the first sport to publish recommended methods for injury surveillance in 2005 and this International Consensus Statement on Injury Surveillance in cricket was later updated in 2016. (Orchard et al., 2016)

To sum up, bowlers (pacers) face the highest number of injuries followed by fielders, wicketkeepers and batsmen. The most common injuries reported are shoulder injuries, thigh and hip injuries and hand and finger fractures. Due to the negative impact of injuries on athletic career, injury prevention strategies like wearing the protective gears, stretching and conditioning regimens before and after training become crucial. Thus, there is some literature available on the injuries sustained by cricketers however regarding the morbidities experienced there are no studies which need to be conducted.

Muscle Damage and Recovery

Muscle damage from regular wear and tear is an integral part of Sports and quick recovery from this is very crucial for the next athletic performance.

Exercise induced muscle damage (EIMD)

EIMD occurs when muscle tissue is damaged following strenuous exercise, resulting in compromised force production capacity, muscle soreness and leakage of intracellular proteins into the circulation. (Hyldahl et al, 2017)

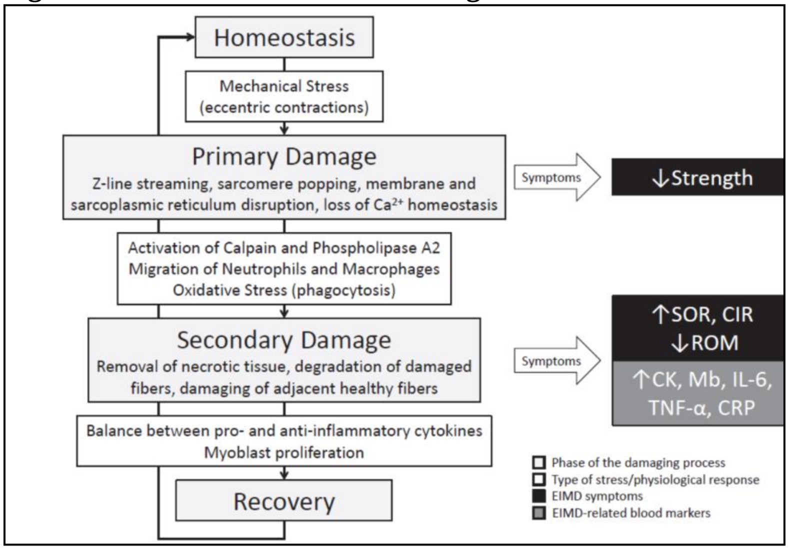
Delayed onset muscle soreness (DOMS)

DOMS is a common response to exercise experienced among competitive athletes and recreational physically active persons alike. Classic signs of DOMS include tissue point tenderness, clinical stiffness and often severe pain with movement that peaks within 24–48 hours post-exercise. (Cheung et al, 2003)

- Mechanism of Muscle Damage

Figure 2.10 depicts the muscle damage process.

Fig.2.10: Mechanism of muscle damage

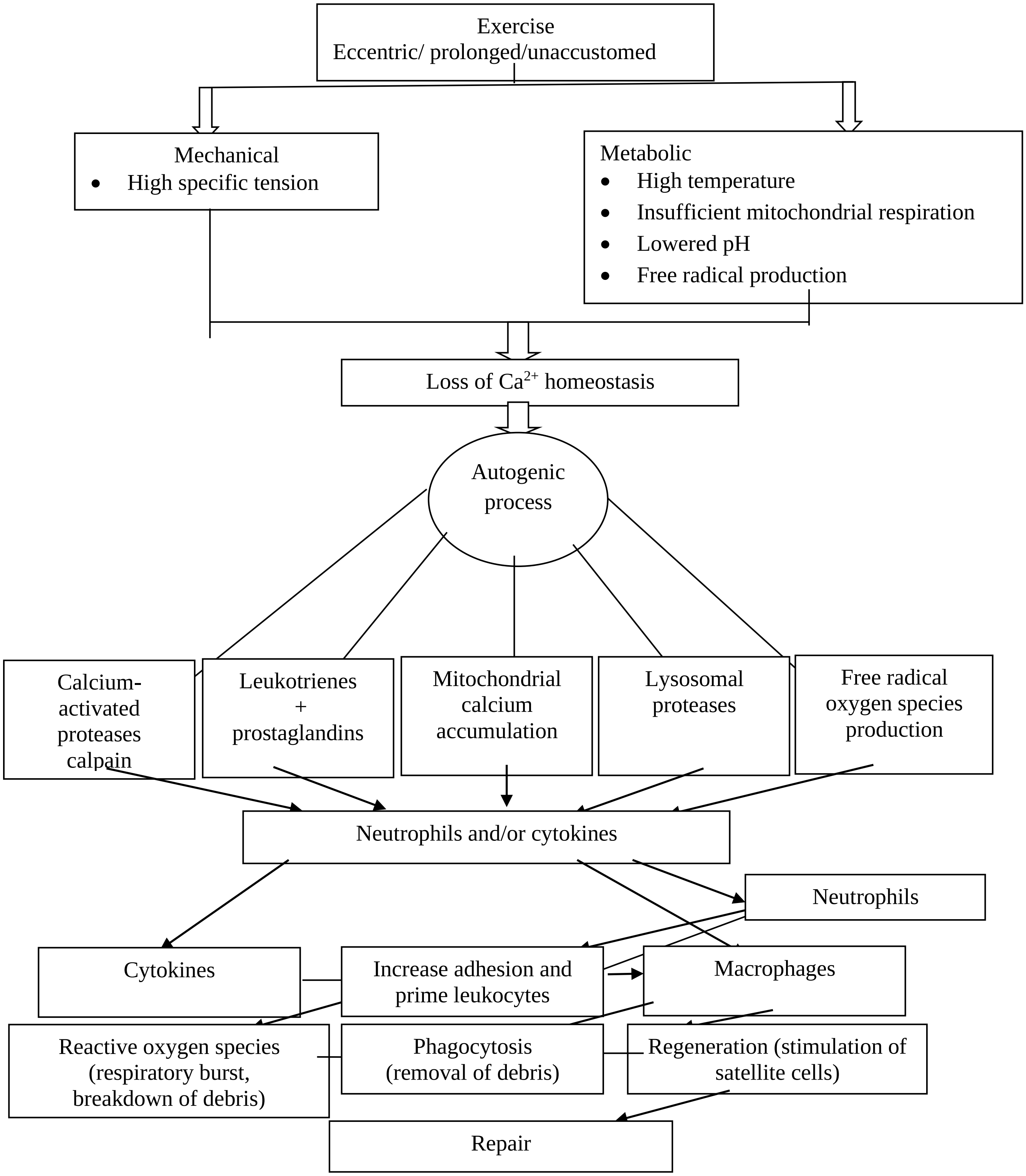


(SOR: muscle soreness; CIR: limb circumference; ROM: range of motion; CK: creatine kinase activity; Mb: myoglobin concentration in the blood stream; IL-6: interleukin-6; TNF-α: tumor necrosis factor alpha; CRP: C-reactive protein)

The exact mechanisms (Figure 2.10) responsible for muscle damage remain unclear but it is believed that both mechanical and metabolic pathways are involved and that the magnitude of damage is influenced by the mode, intensity and duration of exercise. (Torres et al, 2012,Bowtell et al, 2013) A damage model, divided into two general phases, has been proposed: (i) primary damage that occurs during the exercise, involving mechanical and metabolic alterations and (ii) secondary damage associated with the inflammatory response (Tee et al, 2007, Howatson and Someren, 2008) EIMD involves a complex interaction of events which seems to include sarcomere disruption due to the high mechanical tension on the myofibril, impaired excitation–contraction coupling related to altered intracellular calcium homeostasis, oxidative stress and inflammation. (Proske & Morgan, 2001, Warren et al, 2001, Favero, 2016, Peake et al, 2005) These events lead to structural damage of the skeletal muscle cells and degradation of the cell membrane, resulting in fibre necrosis and ultimately, fibre remodeling (Howatson and Someren, 2008)

Figure 2.11 depicts the theoretical model of muscle damage and repair cycle.

Figure: 2.11 Theoretical model of muscle damage and repair cycle



(Baird et al, 2012)

An unaccustomed, prolonged or eccentric workout initiates mechanical muscle damage. Metabolic muscle disturbance is thought to result in the release of cellular components which begin with depletion of ATP and results in the leakage of extracellular calcium ions into intracellular space, due to both Na-K-ATPase and Ca^{2+}-ATPase pump dysfunction. Intracellular proteolytic enzyme activity can increase and promote muscle protein breakdown and augmented cell permeability, which causes some cell contents to leak into the circulation. The mechanism of mechanical and metabolic initiated muscle damage is not completely understood however it is thought to consist of a complex range of events involving increased oxidative stress, inflammatory and immune responses. The release of cell myofibre proteins into the blood may occur at several stages. In cases of isolated mild to moderate damage in otherwise healthy individuals, the body has the potential of clearing released muscle components back to baseline levels within 7–9 days. (Baird et al., 2012)

- Biomarkers to assess muscle damage and recovery post Exercise induced muscle damage (EIMD)

Several biomarkers in blood have been studied to assess muscle recovery like Creatine Kinase, Myoglobin, urea nitrogen etc. These are discussed henceforth.

- Creatine Kinase

Creatine kinase (CK) is an enzyme which is found in the cytosol and mitochondria of the tissues. There are 3 tissue specific subunits of CK; CK MB (cardiac muscle), CK MM (skeletal muscle) and CK BB (brain). (Baird et al., 2012) CK leaks from the muscle into the circulation post muscle damaging physical activity. Creatine kinase levels peak approximately 24 hours after muscle damaging workout but may remain high up to 7 days after exercise. Chronically high CK may indicate insufficient muscle recovery. (Lee et al, 2017)

Athletes usually have elevated CK levels during training. The reference ranges for CK are 82–1,083 U/L in males and 47–513 U/L in females. However, a very wide range of CK levels is reported in literature i.e. 20 to 16,000 U/L, which reflects the inconsistent occurrence of subclinical disorders and minor injury, genetic factors, physical activity and medication. Moreover, CK levels as high as 20, 000U/L post eccentric workout in healthy individuals do not cause any kidney dysfunction or muscle disorder. (Baird et al., 2012) Monitoring CK levels during training in comparison with baseline levels may help athletes to monitor muscle status. (Lee et al, 2017)

CK levels are expected to elevate more in untrained individuals or those having poor fitness. Also, athletes have shown to be having more resting CK levels than untrained subjects probably due to their higher muscle mass and increased daily training. (Berriel et al., 2020) A positive correlation has been reported of CK levels post eccentric exercise with BMI and percent body fat. (Kim & Lee, 2015; Kim & So, 2018) Obese individuals are reported to have a high proportion of type II muscle fiber which is associated with increased muscle damage during eccentric exercise. Moreover, obesity can decrease muscular regeneration and muscle function recovery after damage. Obesity also decreases satellite cell activation, anabolic signaling, insulin sensitivity, and 50-AMP-activated protein kinase (AMPK) activity, which are required for muscular regeneration. Lipocyte accumulation in obese individuals causes chronic low-grade inflammation through increases in the levels of pro-inflammatory cytokines, such as interleukin-6 and tumor necrosis factor-alpha. These inflammatory responses can interfere with the processes involved in muscle protein synthesis. (Kim & So, 2018)

Other bio markers like myoglobin and lactate dehydrogenase (LDH) are also studied to assess muscle recovery in athletes. The glycolytic enzyme LDH is a bio marker for cytosol in various tissues and plays a role in the glycolysis pathway, production of ATP and cellular metabolism. (Khajehlandi and Janbozorgi, 2018) The reference interval of lactate dehydrogenase in the sedentary population is 105 – 333 IU/L and the LDH level in the athlete population is 2-3 fold higher than the sedentary population. (Srividhya et al., 2017) A common characteristic of CK, myoglobin and LDH is that under homeostatic conditions, they are only found in small concentrations in the blood, but following injury to either skeletal or cardiac muscle, there is a significant rise in the concentration of these markers. Myoglobin levels have demonstrated a positive correlation with muscle soreness. (Chase, 2017)The normal range for myoglobin levels is 25 to 72 ng/mL (1.28 to 3.67 nmol/L). (https://www.ucsfhealth.org/medical-tests/myoglobin-blood-test) LDH is influenced by factors like age, gender, type and intensity of physical activity. (Khajehlandi and Janbozorgi, 2018) Using multiple biomarkers like Creatine kinase, myoglobin and LDH is advisable to study muscle recovery. (Lee et al, 2017)

The most common strategies used to prevent and treat EIMD are nutritional, pharmacological, stretching, massage, electrical therapy, cryotherapy and exercise (Someren, 2008) The nutritional strategies are discussed in depth.

- Nutritional strategies to recover from EIMD and DOMS

Several nutritional strategies have been studied by Researchers for their impact on recovery from EIMD. These are discussed henceforth.

- ❖ Protein alone

The ingestion of amino acids seems to be able to attenuate muscle damage measured by creatine kinase (CK), aldolase, lactate dehydrogenase (Miyata, 2014) or muscle soreness, reduced sensation of fatigue and accelerate the functional recovery process. (Howatson et al., 2014, Sousa et al, 2013)Muscle protein synthesis (MPS) and net protein accretion can be promoted by early post-exercise protein consumption. (Phillips, 2011) For optimal stimulation of muscle protein synthesis, an intake of 20–25 g of protein following resistance exercise is suggested. (Moore et al., 2009, Phillips, 2011) Essential amino acids (EAA) seem to be primarily responsible for the stimulation of muscle protein synthesis. (Volpi et al, 2003)Twenty gram protein corresponds approximately to 8.5 g of EAA or 1.5 g leucine which is approximately the amount shown to maximally stimulate protein synthesis.(Phillips, 2011) Therefore, Phillips (2011) in his recent review recommends an intake of at least 25 g high-quality protein containing not less than 8–10 g EAA, delivered as soon as possible post-exercise, for maximal stimulation of MPS.

- ❖ Proteins plus carbohydrates

Although it has been demonstrated that the administration of CHO alone has little or no effect in attenuating signs and symptoms of muscle damage, the combined intake of CHO with proteins seems to be beneficial. (Someren, 2008) There is a strong body of scientific evidence showing that the simultaneous ingestion of CHO and protein may attenuate muscle damage. (Saunders et al, 2009,Pritchett et al, 2009,Cockburn, 2010) However, some studies do not support these findings (Cockburn, 2010). The possible reasons for these discrepancies are 1. the inherent inter-individual variability for indirect systemic markers of muscle damage, Creatine Kinase, which was the only blood parameter used to assess muscle damage in the studies that did not find positive results, and 2. the different exercise protocols applied. (Betts and Williams, 2010,Sousa et al, 2013)

Carbohydrate ingestion after exercise has been shown to improve net protein balance by attenuating the exercise-induced increment in muscle protein breakdown, which has been attributed to a rise in plasma insulin. The palatability of a CHO-protein solution has usually better acceptance than one with proteins only. (Sousa et al, 2013) Low glycogen levels have been shown to possibly have a negative impact on MPS. (Churchley et al., 2020)

❖ Food based interventions studied for their impact on EIMD and DOMS

Dietary antioxidants have been shown to reduce excessive oxidative stress; however, their effectiveness in facilitating recovery following EIMD is not clear. A double blind, placebo controlled research was administered to examine the effects of **anthocyanin-rich antioxidant juice** (AJ) on the recovery from EIMD and the running economy (RE) following downhill running (DHR). Thirty healthy young men were randomly divided into two blinded groups and consumed either AJ or placebo (PLA) for 9 days (240 ml twice-a-day). On day 5, the participants from both groups ran downhill (-15%) for 30 min at 70% of their maximal oxygen uptake (VO_2max) speeds. The changes in RE (oxygen uptake (VO2) and perceived effort (PE) during 5-min runs at 80% VO_2max) and EIMD (isometric peak torque (IPT), muscle soreness (SOR) and serum creatine kinase activity (CK) were compared over time and between the groups on the 4 days following DHR. VO_2 and PE increased ($p < 0.05$) immediately following DHR for both groups and remained elevated for PLA until 48h post-DHR while fully recovering 24 h post-DHR for AJ. SOR was greater ($p < 0.05$) for PLA throughout the study. CK increased for both groups and was greater ($p < 0.05$) for PLA at 96 h post-DHR. Isometric peak torque (IPT) decreased for both groups but recovered faster for AJ (72 h) compared to PLA (no full recovery). The authors concluded that consuming an anthocyanin-rich antioxidant juice 4 days prior to, at the day and four days following DHR resulted in the accelerated recovery of RE and muscle function as well as attenuated muscle soreness. These data suggest that this nutritional strategy might be useful to maintain satisfactory performance in condensed competitions and training camps. The study also suggested that future studies are required to clarify the mechanisms underlying faster recovery of RE when consuming antioxidant rich juice. (Lima et al, 2019)

Blueberries demonstrate antioxidant and anti-inflammatory properties. A randomized cross-over study was undertaken to determine the effect of **New Zealand blueberries** on EIMD after strenuous eccentric exercise. Ten females consumed a blueberry smoothie or placebo of a similar antioxidant capacity 5 and 10 hours prior to and then immediately, 12 and 36 hours after EIMD induced by 300 strenuous eccentric contractions of the quadriceps. Absolute peak and average peak torque across the knee, during concentric, isometric, and eccentric actions were measured. Blood biomarkers of oxidative stress, antioxidant capacity, and inflammation were assessed at 12, 36 and 60 hours post-exercise. A significant ($p<0.001$) decrease in isometric, concentric and eccentric torque was observed 12 hours following exercise in both treatment groups. During the 60-hour recovery period, a significant ($p = 0.047$) interaction effect was seen for peak isometric tension suggesting a faster rate of recovery in the blueberry intervention group. A similar trend was observed for concentric and eccentric strength. An increase in oxidative stress and inflammatory biomarkers was also observed in both treatment groups following EIMD. Although a faster rate of decrease in oxidative stress was observed in the blueberry group, it was not significant ($p<0.05$) until 36 hours post-exercise and interestingly coincided with a gradual increase in plasma antioxidant capacity, whereas biomarkers for inflammation were still elevated after 60 hours recovery. This study demonstrates that the ingestion of a blueberry smoothie prior to and after EIMD accelerates the recovery of muscle peak isometric strength. (McLeay et al., 2012)

❖ Nutraceutical Interventions studied for their impact on EIMD and DOMS

Recent research suggests that ingesting antioxidants during training may reduce exercise induced muscle damage (EIMD); therefore, a study was conducted for 12 days to examine the effect of **antioxidant** supplementation on the performance related symptoms of EIMD in female participants (n=10, age;21.6 ± 2.8 years). The antioxidant capsule consisted of 25,000 IU (15 mg/day) of beta-carotene, 500 mg of Vitamin C, 400 IU (268 mg/day) of Vitamin E, 350 mcg/day of riboflavin, 15 mg/day of Zinc, 200 mcg/day of Selenium, 100 mg/day L-cysteine, 100 mg/day Quercetin, 14 mg/day of grape skin extract, 10mg/day of Green tea polyphenol catechin extract (leaf), 4mg/day of Coenzyme Q10, and 2mg/day. There were no significant changes in range of motion (ROM), resting blood lactate, muscular strength, power output, or perceived muscle soreness between trials over the 96 hours following the exercise protocol. Therefore, the researchers concluded that antioxidant supplementation appears to have no effect on the performance related symptoms of EIMD in female participants. (Stone, 2016)

A randomized cross-over study was carried out to analyze the effects of oral consumption of **curcumin and piperine in combination** on the recovery from EIMD on ten elite rugby players. In the experimental condition, the participants consumed 2g of curcumin and 20mg of piperine, 3 times a day (MGD Nature, Brandérion, France), starting 48 h pre-exercise and continuing until 48 h post-exercise. Twenty-four hours post-exercise, the reduction (from baseline) in sprint mean power output was moderately lower in the experimental condition (-1.77 ± 7.25%; 1277 ± 153W) in comparison to the placebo (-13.6 ± 13.0%; 1130 ± 241W) (ES = -1.12; CI 90%=-1.86 to -0.86). However, no other effect was found between the two conditions. Therefore, it was concluded that curcumin and piperine supplementation before and after exercise can attenuate some, but not all, dimensions of muscle damage. (Delecroix et al, 2017)

A randomised, placebo-controlled, single-blind pilot trial was administered to test whether **curcumin** could attenuate damage from oxidative stress and inflammation related to acute muscle injury induced by eccentric exercise. Twenty healthy male, moderately active volunteers were randomised to curcumin given as the Phytosome delivery system 1 g twice daily (200 mg curcumin) or matching placebo. Supplementation was initiated 48 hours prior to the downhill running test and was continued for 24 hours after the test (4 days in total). Participants in the curcumin group reported less pain in the lower limb as compared with participants in the placebo group, although significant differences were observed only for the right and left anterior thighs. Significantly fewer participants in the curcumin group had MRI evidence of muscle injury in the posterior or medial compartment of both thighs. Increases in markers of muscle damage and inflammation were lower in the curcumin group, but significant differences were only observed for interleukin-8 at 2 h after exercise. No differences in markers of oxidative stress and muscle histology were seen. Researchers remarked that curcumin has the potential for preventing DOMS, as depicted by its effects on pain intensity and muscle injury. However, larger studies are warranted to confirm these results and further clarify the mechanism of action of curcumin. (Drobnic et al., 2014)

Isolated soy protein (ISP) contains isoflavones and saponins that possess anti-oxidative, anti-inflammatory, immune-regulatory, anti-carcinogenic and cardio-protective influences. A study was conducted to examine the effects of ISP on muscle damage indices following a bout of muscle damaging exercise. Forty males (20 boxers, 20 cyclists) aged 18 - 28 years consumed the ISP supplement and the placebo for 4 weeks. Following the damaging exercise, a significant reduction was observed post supplementation in both CK values and muscle soreness ($P < 0.05$) indicating the effectiveness of isolated soy protein in attenuating muscle damage and enhancing muscle recovery. (Shenoy et al, 2016) **Ginger** possesses analgesic and pharmacological properties mimicking non-steroidal anti-inflammatory drugs. It has been studied for its impact on EIMD and DOMS however the Creatine kinase levels do not show any positive impact of the same. (Matsumura et al, 2015)

- Cocoa Flavanols and Muscle Recovery from EIMD and DOMS

Cocoa powder is produced from the cocoa bean, which is the seed of the fruit of the cacao tree, Theobroma cacao L. The cacao is a fleshy, berry-like fruit. Cacao seeds are removed and fermented for 4-5 days, dried, deshelled and roasted at 100-150 °C. The roasted cocoa beans are then usually ground into a suspension, called cocoa liquor or chocolate liquor, which contains cocoa butter and nonfat fine, brown particles. Cocoa powder is made by mechanically pressing the liquor to expel most of the cocoa butter, leaving a solid cake, which is then ground into the product called cocoa powder. Typically, cocoa powders contain 10-12% residual cocoa butter, with the remainder being nonfat cocoa solids. The cocoa powder contains the majority of the chocolate flavor and polyphenols. (Miller et al, 2008)

Cocoa contains the monomeric cocoa flavanols (CF) epicatechin and catechin, and oligomeric procyanidins. (-)-Epicatechin, the most commonly found CF monomer, seems primarily responsible for beneficial effects. (Schroeter et al., 2006) Ingestion of pure (-)-epicatechin mimics vascular effects observed after Cocoa flavanols intake. (-)-Epicatechin is capable of mediating vasodilatation in vivo and increasing NO production. (Decroix et al, 2018) Several beneficial effects of cocoa flavanols have been studied. Cocoa flavanols stimulate nitric oxide production which causes improved vasodilation and endothelial function and a reduction in blood pressure. (Decroix et al, 2018) Cocoa flavanols impart cardiovascular health benefits including decreasing blood pressure by improving endothelial function and improving blood circulation. It is hypothesized that an improvement in blood circulation may allow for better delivery of nutrients and oxygen to working muscles and more efficient removal of waste products that are generated by the muscles. (Peschek et al, 2014) Moreover, Cocoa flavanols have strong antioxidant properties (Decroix et al., 2017) and therefore help attenuate oxidative stress and inflammation. They also improve insulin sensitivity and lipid profiles in individuals with or without cardiovascular risks. Cocoa flavanols can cross the blood-brain barrier and increase cerebral blood flow in healthy young individuals. (Decroix et al, 2018)

Cocoa powder is at times treated with alkali and the process is called Alkalisation or Dutching. Alkalisation darkens the cocoa ingredients, changes the taste by reducing bitterness, and increases the dispersibility of cocoa powder for use in beverages. However, alkalization reduces the flavanol content of cocoa powder to up to as high as 80%. (Miller et al, 2008)

The impact of supplementation with cocoa flavanols on muscle recovery post Exercise induced muscle damage has been studied. A randomized, double blind cross cover study was conducted on 12 well trained male cyclists (mean ± SD age: 30±3 years, VO_2 max: 63.0±3.5 ml/kg/min). On 2 separate occasions, participants performed two 30-min time trials 1.5 (TT1) and 3 (TT2) hours after 900 mg Cocoa Flavanols (CF) or placebo (PL, 13 mg CF) intake, interposed by passive rest. Lactate, glucose, heart rate, rating of perceived exertion (RPE) and power output were measured during the time trials (TTs). Blood was drawn at baseline, before and after each TT and analyzed for epicatechin serum concentrations, trolox equivalent antioxidative capacity (TEAC), uric acid (UA), malonaldehyde (MDA), L-arginine/ADMA, citrulline, interleukin (IL)-1, IL-6 and tumor necrosis factor (TNF)-α plasma concentrations. Epicatechin concentrations were increased by CF intake. Exercise-induced increase in TEAC/UA was improved by

CF intake (F (1) = 5.57; p = .038) (post-TT1: PL: 113.34 ± 3.9%, CF: 117.64 ± 3.96%, post-TT2: PL: 108.59 ± 3.95%, CF: 123. 72 ± 7.4% to baseline), while exercise-induced increases in MDA, IL-1 and IL-6 were not affected by CF intake. TNF-α was unaltered by exercise and by CF. Exercise-induced decreases in L-arginine and increases in citrulline were not affected by CF intake. TT1 and TT2 performance and exercise-induced physiological changes were unaffected by CF intake. Acute Cocoa flavanol supplementation increased total antioxidant capacity during rest and exercise but did not affect exercise induced lipid peroxidation, inflammation, or NO production in healthy athletes. It also did not improve time trial performance and recovery which were assessed by lactate levels. (Decroix et al., 2017)

The effects of acute post-exercise consumption of two cocoa-based beverages with varying flavanol content were studied on the indices of muscle recovery. Eight well trained male runners and triathletes between the age of 18 and 44 years were enrolled in a randomized, single blind, cross over study where the participants served as their own controls. The participants had to perform a downhill running session followed by a 48 h rest period and a 5 km time trial. The two beverages examined were: A cocoa based (processed with alkali) carbohydrate protein drink (CHOC) (0mg of flavanols) and a carbohydrate protein beverage plus natural cocoa (Cocoa CHOC) containing 350 mg of flavanols. The participants consumed 1 g per kg body weight of carbohydrate from a randomly assigned beverage. There was a 21-day washout period and then the protocol was repeated with the other beverage. Following the downhill running session, the participants consumed their beverages within 1 hour and 2 hours into recovery. The results suggested that the acute consumption of cocoa flavanols added to cocoa based recovery beverage provides no additional benefits on markers of muscle recovery and perceived soreness. The study concluded that acute administration of cocoa flavanols does not offer benefits in muscle recovery and the cumulative effect should be examined. (Peschek et al, 2014)

A cocoa based protein carbohydrate drink was examined for its effectiveness on skeletal muscle damage and perceived muscle soreness after exhaustive exercise. A repeated-measures experimental design was administered. Biomarkers for skeletal muscle damage assessed were creatine kinase (CK), urinary isoprostanes and inflammatory markers (IL-6, IL-8, C - reactive protein [CRP]). Self-reported perception of post-exercise soreness was also evaluated. Seven men participated in an exercise session consisting of a 30-minute run on a declined treadmill (210% grade). Running speed was adjusted so that participants consistently maintained a 75% maximal heart rate. Drinks were ingested immediately after exercise, 2 hours post-exercise and before bed. Blood was drawn 30, 60, 120 and 360 minutes post-exercise; urine was collected 24 and 48 hours post-exercise. A perceived soreness questionnaire was administered 24 and 48 hours post-exercise. The experimental drink had no effect on IL-6, CK, IL-8, CRP or urinary isoprostanes ($p > 0.05$). The drink showed no effect on biomarker creatine kinase but was effective in reducing the level of self perceived muscle soreness after exhaustive exercise. (Mcbrier et al, 2010)

To sum, cocoa flavanols have been researched for their effect on EIMD and DOMS due to their anti oxidant and anti-inflammatory properties. However, literature studying the impact of Cocoa flavanols on muscle recovery is limited. Moreover, food based interventions with cocoa flavanols are still lesser. The trial by Pesheck et al concludes that the acute administration of cocoa flavanols failed to have an impact on muscle recovery and therefore cumulative effect should be examined. (Peschek et al, 2014)

Ergogenic Aids

- Ergogenic aids- Background

An ergogenic aid is 'any training technique, mechanical device, nutritional ingredient or practice, pharmacological method, or psychological technique that can improve exercise performance capacity or enhance training adaptations.' Ergogenic aids may help prepare an individual to exercise, improve exercise efficiency, enhance recovery from exercise, or assist in injury prevention during intense training. (Kerksick et al., 2018)

- Nutritional ergogenic aids

Nutritional ergogenic aids are foods or dietary supplements that help improve athletic performance or health. Dietary supplements are used by athletes at all levels of sport reflecting the wide prevalence of their use. A dietary supplement is defined as 'A food, food component, nutrient, or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of achieving a specific health and/or performance benefit'.(Maughan et al, 2018) Dietary supplements include a wide range of products, including essential nutrients (vitamins, minerals, proteins, amino acids, etc.), herbals and botanicals, and specific products with the potential for maintenance of health and optimisation of performance. (IOC Expert Group Statement on Dietary Supplements in Athletes, 2018)

Dietary supplements come in many forms, including the following:

- Functional foods, foods enriched with additional nutrients or components outside their typical nutrient composition (e.g., mineral-fortified and vitamin-fortified, as well as nutrient enriched foods)
- Formulated foods and sports foods, products providing energy and nutrients in a more convenient form than normal foods for general nutrition support (e.g., liquid meal replacements) or for targeted use around exercise (e.g., sports drinks, gels, bars)

- Single nutrients and other components of foods or herbal products provided in isolated or concentrated forms
- Multi-ingredient products containing various combinations of those products described above that target similar outcomes.(Maughan et al, 2018)

Relatively few supplements that claim ergogenic benefits are supported by sound evidence. (Thomas et al, 2016) The Australian Institute of Sport has developed a classification system that ranks sports foods and supplement ingredients based on the significance of scientific evidence and whether a product is safe, legal, and effective in improving sports performance. (https://www.ais.gov.au/nutrition/supplements) A supplement manufacturer's claim of "100% pure," "pharmaceutical grade," "free of banned substances," "Natural Health Product- NHPN/NPN" (in Canada) or having a drug identification number are not reliable indications that guarantee a supplement is free of banned substances. Nonetheless, commercial third-party auditing programs can independently screen dietary supplements for banned and restricted substances in testing facilities (ISO 17025 accreditation standard) (British Standard-General requirements for the competence of testing and calibration laboratories, 2005) which provides a greater assurance of supplement purity for athletes.

Only after an athlete has a good training, recovery and nutrition plan in place, should the role of performance supplements to offer further marginal gains be explored. (IOC Expert Group Statement on Dietary Supplements in Athletes, 2018) However, athletes' supplementation practices are a majority of the time influenced by family, friends, teammates, coaches, internet, and retailers, rather than qualified sports dietitians which is a matter of concern and needs awareness. (Braun et al., 2009)

❖ Prevalence of Dietary Supplement Use by athletes

The prevalence of dietary supplement use is widespread among elite athletes, as well as in the general population. (IOC Expert Group Statement on Dietary Supplements in Athletes, 2018) The prevalence of supplementation among athletes has been estimated internationally at 37% to 89%, with greater frequencies being reported among elite and older athletes. (Thomas et al., 2016) Surveys generally suggest that supplement usage; differs across various sports, rises with the level of training/performance, increases with age and is higher in males than in females (Maughan et al, 2018)

Micronutrients often requiring supplementation in athletes are iron, calcium and vitamin D. Moreover, vitamin B_{12} might be required in those following a vegan or vegetarian diet. A few performance enhancing supplements might, at the present time, be considered to have an adequate level of support to suggest that marginal performance gains may be possible. These supplements include caffeine, creatine monohydrate, nitrate, sodium bicarbonate and possibly also Beta-alanine. (Maughan et al, 2018)

There are two main categories of Supplements; Muscle building and performance enhancement which are discussed below.

- Muscle building supplements

There is scientific evidence regarding nutritional supplements consumed to promote an increase in skeletal muscle in combination with the completion of a well-designed exercise-training program. (Kerksick et al., 2018)

- Strong evidence to support the efficacy and apparently safe - Hydroxy β-methylbutyrate (HMB), Creatine monohydrate, Essential amino acids (EAA) and Protein
- Limited or mixed evidence to support efficacy - Adenosine − 5′-triphosphate (ATP), Branched-chain amino acids (BCAA), Phosphatidic acid
- Little to no evidence to support the efficacy and/or safety - Agmatine sulfate, α-ketoglutarate (α-KG), Arginine, Boron, Chromium, Conjugated linoleic acids (CLA), D-aspartic acid, Ecdysterones, Fenugreek extract, Gamma oryzanol (ferulic acid), Glutamine, Growth hormone releasing peptides (GHRP) and secretagogues, Isoflavones, Ornithine-α-ketoglutarate (OKG), Prohormones and anabolic steroids, Sulfo-polysaccharides (myostatin inhibitors), Tribulus terrestris, Vanadyl sulfate (vanadium), Zinc/magnesium aspartate (ZMA)

- Performance enhancement supplements

- Strong evidence to support the efficacy and apparently safe - ß-alanine, Caffeine, Carbohydrate, Creatine monohydrate, Sodium bicarbonate (baking soda), Sodium phosphate, Water and Sports drinks
- Limited or mixed evidence to support efficacy - L-alanyl-L-glutamine, Arachidonic acid, Branched chain amino acids (BCAA), Citrulline, Essential amino acids (EAA), Glycerol, β-hydroxy β-methylbutyrate (HMB), Nitrates, Post-exercise carbohydrate and protein, Quercetin, Taurine
- Little to no evidence to support the efficacy and/or safety - Arginine, Carnitine, Glutamine, Inosine, Medium chain triglycerides, Ribose

Dietary nitrates are reduced (in the mouth and stomach) to nitrites and then to nitric oxide. During exercise, nitric oxide potentially influences skeletal muscle function through regulation of blood flow, glucose homeostasis and mitochondrial respiration. Nitrate supplementation has been shown to increase exercise efficiency by causing 4-5% reduction in VO_2 at a steady state and a 0.9% improvement in time trials. It has also been shown to reduce fatigue and decrease oxidative stress. (Beck et al., 2015)

Beta alanine is a precursor of carnosine, which is associated with many performance enhancing functions including reduction of acidosis, regulation of calcium and antioxidant properties. A systematic review concluded that beta alanine may increase power output and working capacity and decrease feelings of fatigue but the results are still not conclusive. Therefore, it is recommended to be cautious in the use of beta alanine as an ergogenic aid. (Beck et al., 2015)

The beneficial effects of cocoa flavanols on EIMD and DOMS are already discussed earlier (under cocoa flavanols and muscle recovery from EIMD and DOMS). In vitro and in vivo studies clearly indicate that Cocoa flavanols have a strong antioxidant capacity. (Decroix et al, 2017)

Protein supplements and Sports are discussed in the next section- Commercial Nutritional Supplements commonly used by Cricketers.

- Commercial Nutritional Supplements commonly used by Cricketers

Protein supplements and Sports drinks are commonly consumed by Cricket players. Protein supplements are consumed more during the training phase while Sports drinks are consumed during training as well as matches. Protein supplements and Sports drinks are discussed hereby.

❖ Protein supplements

The sports supplements market is flooded with Protein supplements. Various animal and vegetarian sources of protein are utilized in them. Many protein supplements are very expensive primarily due to the amount of marketing that accompanies these products and the processing involved. (AIS, 2009) Protein is effective at promoting lean mass gain when combined with resistance training. (Hector and Phillips, 2018)

The human body does not store amino acids like it does fatty acids or carbohydrates and therefore daily intake of amino acids is essential. Blood amino acid levels are relatively constant and if the dietary protein intake is suboptimal, muscle protein breakdown is increased. And in instances of excessive dietary intake, proteins are catabolized and used for energy. Ingestion of 20–30 g protein or 10 g EAA during or after exercise results in increased muscle protein synthesis (MPS) as well as improved nitrogen balance. However, higher protein doses (40 g) have not been shown to further enhance MPS. Protein ingestion before exercise seems to have less influence on MPS but may still enhance muscle reconditioning depending on the type of training that takes place. Consuming both protein and carbohydrate during prolonged exercise (resistance or endurance-type exercise for several hours) has been shown to stimulate MPS during the exercise period and to result in a positive whole-body net protein balance, compared to a negative net protein balance when only ingesting carbohydrates. Intake of 30–40 g casein after an evening workout has been shown to stimulate net muscle protein accretion throughout the night and improve whole body protein balance. (Karlund et al, 2019)

A meta-analysis was performed to examine the impact of protein supplementation on changes in fat free mass and strength. Data from 22 published studies that involved 680 participants were included in the analysis. It was concluded that protein supplementation had a positive effect on fat free mass and lower body strength in both younger and older participants. (Cermak et al, 2012) Another meta-analysis was conducted involving data from 49 studies and 1863 participants. The authors concluded that the ability of the protein to positively impact fat-free mass accretion increases up to approximately 1.62 g of protein per kilogram of body weight per day but amounts beyond that do not appear to promote greater gains in fat-free mass. (Morton et al., 2018) Although more research is necessary for this area, evidence clearly indicates that protein requirements during intense training are elevated and consequently those athletes who achieve higher intakes of protein while training promote greater changes in fat-free mass. It is the position stand of ISSN that exercising individuals need approximately 1.4 to 2.0g per kg body weight of protein per day.(Jager et al., 2017, Morton et al., 2018, Stokes et al., 2018)

The quality of dietary protein also plays a significant role. Consumption of protein with a high biological value to obtain adequate amounts of Essential amino acids (EAA) is advised in athletes. Animal and especially dairy-based proteins have the highest content of EAA and greatest anabolic properties when compared to plant proteins, which are low in one or more EAA. A trial was administered to examine the effect of three different sources of protein (hydrolysed whey isolate, micellar casein and soy isolate) on acute changes in muscle protein synthesis both at rest and after a single bout of resistance exercise. The authors concluded that all three protein sources significantly increased muscle protein synthesis both at rest and post resistance exercise. (Hartman et al., 2007) Increases in plasma leucine and total BCAA concentrations are linked with improved endurance performance and upper-body power. (Karlund et al, 2019)

International Olympic Committee has stated a recommended range for protein content per serving of the product which is 20-50 g. (Maughan et al, 2018) However, there are no guidelines in terms of the calorie content, sugar or sweetener content, protein quality of the product etc.

Certain risks are also associated with supplement use. Unsanitary and unsafe manufacturing can lead to microbiological contamination or the presence of hazardous foreign objects in the supplement. Expensive ingredients may be added in less than the labeled quantities or may be absent altogether in the product. Athletes have even failed doping tests due to the presence of undeclared ingredients in supplements they have ingested. Therefore it becomes imperative to be careful in choosing the right product if at all required. (Maughan, 2013)

❖ Sports drinks

In simplest terms, a sports drink is a beverage consumed in association with sport or exercise – either in preparation for exercise, during exercise itself or as a recovery drink after exercise. (Shirreffs, 2003) Intake of sports drinks during exercise is recommended to meet carbohydrate and to replace water and electrolyte losses. (Sawka et al 2007 , Serge et al, 2008) Researchers found that prolonged exercise greater than one hour can be increased through the consumption of CHO-electrolyte drink. (Khanna and Manna, 2005) Sports drinks are ubiquitous within the recreational and competitive sporting world. (Serge et al, 2008) Sports drinks provide carbohydrate which is rapidly absorbed by the gastrointestinal tract and helps to maintain optimal blood glucose levels, preventing hypoglycaemia while sparing endogenous carbohydrate reserves. (Jeukendrup, 2010) Sports drinks also aid to replace fluid and electrolytes lost during sweating and thereby prevent dehydration and early onset of fatigue. (Shirreffs, 2003)

The majority of sports drinks are manufactured and artificially flavored carbohydrate-electrolyte beverages. Carbohydrate-electrolyte sport drinks are highly recommended and appear to be the beverage of choice for most competitive athletes; especially aerobic athletes. (Serge et al, 2008) Sports drinks may improve performance by increasing blood sugar levels, enhancing carbohydrate oxidation and reducing fatigue perception. The ideal range for carbohydrate content in sports drinks is 4-8%. (Sawka et al., 2007, American College of Sports Medicine et al. 2007, American Dietetic Association et al. 2009). Sports drinks containing a concentration of 4 to 8% of carbohydrate ingested at a rate consistent with sweat loss may support fluid, energy and sodium requirements. Carbohydrate concentrations higher than 8% may delay gastric-emptying and should be avoided. (Sawka et al 2007 from Serge et al, 2008)

Increasing plasma volume can positively affect performance. Sodium in sports beverages may help achieve this by improving glucose and water absorption in the small intestine. (Serge et al, 2008) the recommended range of sodium in sports drinks is 23-69 mg/100 ml. (Sawka et al., 2007)(American College of Sports Medicine et al. 2007; American Dietetic Association et al. 2009). However, excessive ingestion of water or hypotonic beverages including sports drinks beyond sweat losses can lead to exercise-associated hyponatremia. (Montain and Cheuvront, 2006) Beverages containing sodium have been shown to maintain plasma volume better during exercise than water alone. (Shirreffs, 2003) Recent guidelines recommend ingestion of sodium with fluids during exercise. (Casa et al, 2005)

There are a few concerns regarding sports drinks. Some commercial sports drinks have hypertonic formulations i.e. the drink contains higher amounts of sodium chloride than the body's cells (osmolality of 280-350 mosmol/kg) which can delay gastric emptying and water absorption from the proximal small intestine and thereby lead to exercise-related abdominal pain in susceptible individuals. Moreover, commercial sports drinks are known for their high acidity levels (pH: 2.4-4.5) which have been linked to dental erosion if large amounts are consumed over time. (Mettler et al, 2006) Commercial drinks contain ingredients like preservatives, colourings, artificial sweeteners and flavours that are used to improve palatability and extend shelf life. (Shirreffs, 2003)

It has been suggested that sports drinks with neutral pH and hypotonic formulations (osmolality 200-250 mosmol/kg) can be easily prepared with low osmolality fruit juice (apple or tomato) diluted with water and a pinch of salt. (Shirreffs, 2003) Evidence suggests that commercial carbohydrate (CHO) feedings do not provide extra benefits to performance compared to natural CHO alternatives. Supplementation with a commercial CHO gel (dextrose) was as effective as a natural form of CHO gel (honey) in improving cycling time trial performance over 64 km compared to placebo. (Earnest et al, 2004) While commercial sports drinks are convenient, they are expensive as well. As long as athletes hydrate well during exercise alongside ingesting recommended nutrients (e.g., CHO, sodium and some potassium), it may be possible to achieve similar results more affordably and without adverse health effects. However, there is inadequate data on hand regarding the relative effectiveness of homemade versus commercial sports drinks on physiological or performance markers in athletes. (Begum et al, 2015)

Lately, consideration has been given to **coconut water** as a natural alternative to commercial sports drinks. A single blind cross over study was conducted on 12 exercise-trained men (26.6 ± 5.7 yrs). The participants received bottled water (BW), pure coconut water (VitaCoco: CW), coconut water from concentrate (CWC), or a carbohydrate-electrolyte sport drink (SD) [a fluid amount based on body mass loss during the dehydrating exercise] on four occasions (separated by at least 5 days) in random order. Hydration status (body mass, fluid retention, plasma osmolality, urine specific gravity) and performance (treadmill time to exhaustion; assessed after rehydration) were determined during the recovery period. No differences were noted between coconut water (CW or CWC) and SD for any measures of fluid retention ($p > 0.05$). Regarding exercise performance, no significant difference ($p > 0.05$) was noted between BW (11.9 ± 5.9 min), CW (12.3 ± 5.8 min), CWC (11.9 ± 6.0 min) and SD (12.8 ± 4.9 min). In general, participants reported feeling more bloated and experienced greater stomach upset (determined using a 5-point visual analog scale) with the CW and CWC. The authors concluded that an additional study with a more demanding dehydration protocol, as well as a time trial test to assess exercise performance is warranted. (Serge et al, 2008)

Thus, the above literature review suggests that the composition of commercially available protein supplements and sports drinks is not studied adequately. As these two categories of supplements are regularly and frequently ingested by cricketers, it becomes increasingly vital to investigate their composition. The amount of protein per serving should be considered when analysing the composition of protein supplements. In addition, it is necessary to investigate the influence of various protein sources and their prices. There are suggestions regarding the evaluation of the carbohydrate and salt content of sports drinks. As the kind and combination of carbohydrates in sports beverages play an important impact, research is required in this area.

Nutrition Awareness

- Nutrition awareness amongst athletes and their Support staff (Coaches, Trainers/Strength and Conditioning Coaches, Physiotherapists)

Nutrition awareness or knowledge about the basics of nutrition can help an athlete make better food choices and thereby consume a healthy diet. Nutrition knowledge is one of the few modifiable determinants of dietary intake and can have a significant impact on athletic performance. (Trakman et al, 2016)

Several Researchers have explored the nutrition knowledge of athletes and their support staff. Across-sectional study was carried out in National Collegiate Athletic Association Division I, II and III institutions across the United States. In all, 579 participants were enrolled consisting of Athletes (n =185), Coaches (n=131), Athletic Trainers (n=192) and Strength and Conditioning Specialists (n=71). The Athletic Trainers and Strength and Conditioning Specialists displayed adequate sports nutrition knowledge, whereas most Coaches and Athletes had inadequate knowledge. (Torres-McGehee et al, 2012)

Another Research was conducted on 343 odd students from the Sports Departments in Ankara. The results revealed that the participants who were university students receiving sports education and expected to continue their professional lives in sport related fields lacked knowledge on nutrition. (Ozdo and Ozcelik, 2011) A systematic review by Spronk et al (2014) examined the relationship between nutrition knowledge and dietary intake in adults. In this review, 29 relevant articles were identified, of which 22 were conducted in community populations and 7 in athlete populations. Most of the studies (n= 19/29) showed significant, positive, but weak ($r < 0{\cdot}5$) associations between nutrition knowledge and some aspect of dietary intake, most often a higher intake of fruit and vegetables.

A systematic review was carried out to assess the nutrition knowledge of athletes and coaches which included 36 studies that provided a quantitative measure of nutrition knowledge and described the measurement tool used. Due to the quality and heterogeneity of the included studies and assessment tools, it is difficult to determine the general and sports nutrition knowledge of athletes and coaches. Specific gaps in knowledge also remain largely unclear, although analysis of individual aspects indicates that it is likely that energy density, supplementation and the role of protein are commonly misunderstood topics. The authors, therefore, recommended that a new, universal, up-to-date, validated measure of general and sports nutrition knowledge be developed. Such a tool should consider health literacy, cultural appropriation and current consensus recommendations regarding nutrition for optimal athletic performance and should undergo rigorous validation that includes techniques from within an item response theory framework. Moreover, the questionnaire should have the capacity to report a knowledge profile, outlining gaps in knowledge and areas where knowledge is well understood. (Trakman et al, 2016)

Trackman et al (2017) developed a questionnaire to assess nutrition knowledge in athletes based on a recent review of sports nutrition guidelines. The tool has been validated using a robust methodology that incorporates relevant techniques from classical test theory and item response theory, namely Rasch analysis. The content and face validity of the tool were confirmed based on feedback from expert sports dietitians and university sports students, respectively. The internal reliability of the questionnaire as a whole is high (KR = 0.88) and most sub-sections achieved acceptable internal reliability. Construct validity has been confirmed, with an independent T-test revealing a significant ($p < 0.001$) difference in knowledge scores of nutrition (64 ± 16%) and non-nutrition students (51 ± 19%). Test-retest reliability has been assured, with a strong correlation ($r = 0.92$, $p < 0.001$) between individuals' scores on two attempts of the test, 10 days to 2 weeks apart.

Thus, there are few studies examining nutrition knowledge among athletes and their support staff. However, there is a dearth of research on cricketers that warrants investigation. The majority of researchers have found that athletes and their coaches, trainers, and physiotherapists have inadequate dietary understanding. A positive connection, albeit minor, is also documented between nutrition knowledge and fruit and vegetable consumption. Adequate nutrition knowledge can result into improved food choices and hydration practices. This ultimately has the potential to enhance the athletic performance and recovery.

The aforementioned literature review indicated certain research gaps. There is a dearth of research evaluating the energy expenditure of elite cricketers, particularly Indian cricketers. Moreover, there has not been much research on nutritional requirements of cricket players and there are no nutritional guidelines specifically targeted at them. Anthropometry is studied extensively in cricketers however there are hardly any studies on the Elite players. Inadequate information exists on body composition indicators of Elite Indian Cricketers. The fitness levels of cricketers have been researched, however there is a paucity of research on the relationship between dietary status and fitness levels. Iron being a critical mineral for athletes, it is quite surprising that the iron status of elite cricketers has not been examined adequately. There is some literature available on the injuries sustained by cricketers however there are no studies on the morbidities experienced.

Exercise induced muscle damage (EIMD) is common in athletes and quick recovery from the same is crucial for the next athletic performance. Several foods and nutraceuticals have been examined for their effect on muscle recovery from EIMD. Cocoa flavanols have also been researched though limited for their positive impact on muscle recovery. The evidence suggests that the acute administration of cocoa flavanols failed to show an impact on muscle recovery and the cumulative effect should be assessed.

Cricket players frequently consume the commercially available protein supplements and sports drinks, but neither their nutrient composition nor cost are investigated. The IOC recommends 20–50g of protein per serving for protein supplements. The ACSM and ADA recommend that sports drinks have sodium levels between 23 and 69 mg/100 ml and carbohydrate levels between 4 and 8 percent. It is important to assess if commercially available protein supplements and sports drinks adhere to these guidelines.

Assessment of nutrition knowledge among athletes and their support staff has been undertaken by a few researchers. There is, however, a dearth of research on cricketers in particular, which warrants investigation. Interventions can be created and put into action by determining the participants' knowledge gaps. This way a significant improvement can be brought in the nutrition knowledge of the cricketers and their support staff which can indirectly translate into better eating behaviors, hydration practices and ultimately improved athletic performance.

In conclusion, there is a lack of research on the assessment of nutritional status in elite Indian cricket players, their fitness level, iron status, haemoglobin levels, and injury profile. Data on the ingredients of commonly taken protein supplements and sports drinks are lacking. Elite cricket players' and their support staff's knowledge of nutrition is similarly understudied.