Evaluation of total-body-less-head dual energy X-ray absorptiometry for the assessment of lean, fat and bone mass in athletes

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September 2021

Abstract

Introduction: The routine assessment of body composition is common practice in athletic populations, particularly at the elite level. DXA is a criterion method of body composition assessment, providing precise measurements of bone mineral content (BMC), lean mass (LM) and fat mass (FM) from the standard total-body scan. More recently, a new scan application has been introduced, which measures body composition excluding the head region. The aim of this study was to investigate the precision of the new total-body less head (TBLH) application for the measurement of total body composition in athletes and compare precision with that of the standard total-body scan. The second aim was to compare the differences in total body composition outcomes between standard DXA total-body scans and TBLH scans.

Methods: This study compared in-vivo precision and total body composition outcomes from the standard total-body scan and the new TBLH scan (Lunar iDXA, GE Healthcare, Madison, WI). A total of 95 athletes (mixed sports) received repeated TBLH scans and 58 of these athletes also received standard total-body scans (overall mean age: 26.3 ± 8.8 years; male n = 63, female n=41). Participants ranged in body mass (42.7 to 129.1 kg), stature (1.55 to 2.04 m) and BMI (16.4 to 46.9 kg/m2). Precision was derived from repeat scans with re-positioning, and precision error was reported as the root mean square standard deviation (RMS±SD) and percentage co-efficient of variation (%CV).

Results: Precision error ranged from 0.38 % to 1.15 % (%CV) for standard total-body and 0.39 % to 1.28 % (%CV) for the TBLH application, depending on the body composition compartment. Body composition outcomes for the TBLH were significant lower than for the standard total body for BMC (2,865 g v 2,308 g), LM (50,276 g v 46,954 g) and FM (15,888 g v 15,183 g) , all $p<0.05$. Regional composition precision error was consistently lower for the TBLH application, particularly at the trunk region (TBLH = 0.54 - 2.86 %CV vs. standard total body = 0.78 - 2.57 %CV).

Conclusion: In-vivo total body composition precision of the TBLH iDXA scan is comparable to that of the standard total-body scan, and superior for regional composition assessment, in a mixed cohort of athletes. The TBLH scan may be particularly useful for monitoring body composition in athletes due to the exclusion of the head. However, new baseline

measurements should be performed if centres are to adopt the TBLH method, in order to ensure consistency and validity of longitudinal measurements for the monitoring of athlete body composition. Previous body composition assessments implementing the standard total-body application should not be compared with assessments using the TBLH application.

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2. This thesis is the result of my own investigations, except where otherwise stated and that other sources are acknowledged by footnotes giving explicit references and that a bibliography is appended.

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Acknowledgements

I would like to thank my supervisors Dr. Karen Hind and Dr. Caroline Dodd-Reynolds for their guidance and advice. I would like to thank Alice Pearson for helping and supporting with my data collection. Also, I would like to thank all the participants that were involved with this study. Finally, I would like to acknowledge the support and motivation my friends and family have given me throughout this research.

1.0 Introduction

1.1 Background

Dual energy X-ray Absorptiometry (DXA) is an imaging technique recognised by the World Health Organisation for the assessment of bone mineral density (BMD), osteoporosis and fracture risk (Blake & Fogelman, 2007). The central sites for DXA BMD assessment are lumbar spine L1-L4 and proximal femur (hip) whilst the peripheral site for assessment is the forearm (wrist), which should be used if spine and hip are not available (Abdelmohsen, 2017). However, over the last decade DXA has increased in popularity for the assessment of body composition, particularly for elite athletes in sports medicine and in sport and exercise science (Marra et al., 2019). The increase in the application of DXA imaging for the assessment of body composition has been suggested to reflect low precision error and the accurate estimation BMD, lean mass (LM) and fat mass (FM), known as the three-compartment model (Bilsborough et al., 2014). Although there are numerous other techniques available to measure body composition, such as skinfold callipers and bioelectrical impedance analysis, total-body DXA is widely utilised as a criterion method (Gomes et al., 2018).

DXA is also recognised by the International Olympic Committee as the preferred method for measuring body composition in athletes (Meyer et al., 2013) and for the measurement of BMD in athletes suspected of having relative energy deficiency in sport (RED-S) (Mountjoy et al., 2014). DXA scans are non-invasive and provide a rapid assessment of body composition, with typical scan time of approximately 6.5 to 14 minutes, depending on scan mode and DXA system. Further advantages of DXA include the provision of in-depth and detailed analysis for total and regional body composition and the ability to simultaneously assess BMD and body composition (Lees et al., 2017; Thurlow; 2018). DXA outputs can be of great value to strength and conditioning coaches and sport nutritionists (Hall et al., 2016), for goal setting at the onset of a training/dietary intervention and to gauge the success of interventions (Georgeson et al., 2012; Milanese et al., 2015). In elite sport, athletes are often required to achieve a specific body composition for their discipline, achieving an optimum physique has been argued to be key for successful performance (Salter & Kerr, 2018). While there is a lack of evidence linking body composition to performance outcomes, it is accepted that greater LM and lower FM are important, with absolute quantities dependent on the sport (Charlton et al., 2015). In early studies, Claessens et al., (1994) reported an inverse association between FM and performance, suggesting that athletes with lower body fat percentage had greater performance. Stoggl et al., 2010, reported that greater proportions of LM are more positively associated with performance than FM, suggesting that LM is more important.

DXA assessment of body composition can also forewarn on possible health implications and injury risks. For example, in weight category and aesthetic sports, individuals can develop disordered eating from purposeful energy restriction (Sundgot-Borgen et al., 2013). Another health concern in athletes and active populations is RED-S, which refers to potential health and performance consequences of insufficient energy intake for training and competition, termed low energy availability (Mountjoy et al., 2018). Bartlet et al., (2019) and Keay et al (2019) have reported the negative associations between RED-S and sports performance. Research has shown that RED-S may alter hormonal pathways and can lead to negative physiological adaptions, such as thyroid hormone signalling pathways, carbohydrate metabolism and growth hormone/insulin like factor, which has been reported for both sexes (Dipla et al., 2021). A webinar on https://iscd.org hosted by Dr Karen Hind, with speaker, Dr Gary Slater focused on key aspects of measuring athletes body composition using DXA. Dr Slater is the national performance nutrition network lead at Australian Institute of Sport and has published multiple papers on the relevant research topic. During this webinar Slater highlighted evidence to suggest that changes in FM can influence power-to-weight ratio and heat tolerance (Garthe et al., 2011). Changes in LM were proposed to alter power-to-weight ratio, power generation capacity, thermoregulation and substrate metabolism. Furthermore, Slater highlighted some of the unique challenges when assessing athletes. Examples of complications include the extreme physiques of athletes, the high daily energy requirements and body water influx and the habitual use of dietary supplements that can influence muscle solute content (Slater, G, (2021) ISCD, Webinar, Body Composition).

Total-body DXA scans

Standard total-body DXA scans begin at the head and end at the feet, measuring three compartment body composition (bone mineral content, fat mass and lean mass). There are three modes, which are dependent on the body thickness. Standard total-body scans are recognised as the criterion technique for the assessment of bone mineral density (BMD) and body composition in athletic and clinical populations. A new application by GE Healthcare has recently been introduced for the current version of Lunar DXA encore software (GE

Healthcare, Madison WI; encore version 18.0). This new software has total-body-less head (TBLH) as an assessment option which excludes the head from the scanning region, thereby reducing overall scan time and ionising radiation dose. TBLH imaging starts at the mandible and ends at the feet. It is plausible to hypothesise that the TBLH scan option might provide more sensitive detection of meaningful change in body composition and BMD Bone and soft tissue in the head region is unlikely to respond to exercise training and nutrition interventions, given the predominant cortical component of the skull and the tissue of the brain.

Given the infancy of this new software, to date, there have been no studies evaluating precision error of the TBLH application. Precision error is important to enable understanding of the performance of this method and to enable interpretation of meaningful change (Nana et al., 2016). This is particularly relevant when working with elite athletes. Outcome measures from training or dietary interventions for athletes seek to observe small changes in physiological adaptations (Nana et al., 2015). Such minor changes, especially in athletes at the elite level who are at or near their optimal conditioning could have a meaningful impact on sports performance. (Binkley et al., 2015).

1.2 Research aims and questions

The primary aim of the study was to compare DXA precision of the standard total-body scan with the new GE TBLH scan, for the measurement of total body composition variables. The precision error calculated lean mass (LM), fat mass (FM), fat free mass (FFM) percentage body fat (%BF), bone mineral content (BMC), bone mineral density (BMD) and bone area (BA) were also compared between the two scan applications.

The specific research questions were:

1.) What is the precision error for DXA TBLH body composition scans in athletes?
2.) What are the differences between standard DXA total-body scans and TBLH scans for the assessment of total LM, FM and bone mass in athletes?
3.) What is the precision error for standard DXA total-body scans and TBLH scans for the assessment of regional body composition in athletes?

2.0 Literature Review

In this literature review, the published evidence relevant to the current investigation is appraised. The primary focus is the importance of body composition in sport, for both performance and health. The review also looks to identify the available methods for the assessment of body composition, evaluating the advantages and disadvantages for use in athletic populations. The precision and best practice protocols of these methods for DXA assessment of body composition is also discussed.

2.1 Body composition in athletes

2.1.1 Desired goals for athletes in specific sports

In elite sport, a minor advantage can be a major factor influencing performance. Although there are many factors that contribute to overall athletic success, body composition is likely a key characteristic with regards to optimal performance. The routine assessment of body composition is common practice in most sports to inform and monitor dietary, training, and injury rehabilitation programmes (Chaabene et al., 2019; Reale et al., 2019). Non-injured elite athletes are presumed to have a body composition which enables them to perform at their best. However, through the vast spectrum of sport disciplines, e.g., team, athletics, combat, racket etc., the body compositions of individuals across the sports will vary. Different sports have specific requirements, typically to achieve optimum performance, the athlete may need to adapt their body composition to suit the sport they participate in. Callister et al., (1991) researched the physiological characteristics in elite Judo athletes. Assessments of body composition, strength and aerobic capacity were made in male and female athletes, across multiple weight categories. Results identified that as the weight categories increased, percentage body fat (%BF) and muscle fibres (Type I & Type IIA) cross-sectional area increased, however aerobic capacity decreased. This study highlighted the divergent physiological profiles between lower and upper weight classes and suggests that factors governing success may vary even within individual sports. These data also suggest an athlete needs to compromise between making weight and maximising physiological capabilities.

Research also suggests that assessment of body composition in elite athletes is key for developing training programs. Ramana et al., (2004) investigated the training loads and physiological responses of national level distance runners. Body composition was measured at a rested state, two types of ergometers were used (treadmill & cycling) for the assessment of $V0_{2max}$ and maximum work rate performance (WR_{max}). Physiological variables measured included heart rate and skinfold at four sites, these were performed during test and in recovery phase. Athletes with a lower body mass were able to perform at a 23% lower training load than the heavier athletes, meaning the athletes with the greater body mass need to work at a higher intensity to be able to achieve the same performance. This highlights the importance of accurate assessment of body composition in elite athletes, as a consideration of body composition is required before a training intervention to prescribe the necessary training load. Conversely, when athletes are aiming to achieve an undesirable body composition, meaning a target of %BF or LM which is not realistic, it could potentially have a negative effect on an athlete's anthropometry and performance. For instance, in the nutritional intervention by Garthe et al (2012) that aimed to increase lean body mass, some participants experienced FM gain, which was associated to impaired aerobic performance. Identifying the importance of accurately monitoring body composition, allowing the creation of realistic goals for an athlete to achieve, without having a negative effect on performance and body composition.

2.1.2 Body composition and athletic performance

Physiological attributes are key to athletic performance and considered the primary training factor in sport (Stone; 2002). Body composition has been associated with competitive success across a range of sports. For athletes competing in sports requiring high force production, LM appears to be related to performance outcomes (Stoggl et al., 2010). Gains in LM are associated with improvements in lower body speed and power in cyclists (Ronnestad et al., 2010) and rugby players (Waldron et al., 2014). Contact sports athletes, who are involved in repeated high force collisions, could gain an advantage by increasing lean body mass (Morehen et al., 2019). Newtons second law of motion (Force = Mass x Acceleration) explains why athletes aim to develop lean muscle mass. The simultaneous increases in total-body mass and lower body power can improve acceleration and lead to an overall increase in force production (Granacher et al., 2016). In male soccer players, Silvestre et al., (2006) assessed physical performance through a battery of tests (countermovement jump, running etc.,) and body composition with DXA during pre- and post-season. During the season, the athletes completed a strength and conditioning intervention that aimed to increase muscle mass while maintaining percentage body fat (%BF). Across the whole team, the mean increase in body mass was 1.5±0.4 kg, while overall LM increased 0.9±0.2 kg. This body composition modification was associated with 17.3% and 10.7% increase in total-body and lower body power, respectively, with a lack of change to all other physical performance measures. This research also identified that athletes who entered pre-season with high levels of fitness, maintained body composition variables such as %BF and had the ability to adapt and improve physiological attributes, which could result in improved performance.

Low total-body mass and body FM can be an advantage to endurance sport performance, such as distance running, given a reduction in energy costs (Larsen 2003). However, very low body mass and FM can be a consequence of RED-S, which is associated with both health and performance detriments (Mountjoy et al., 2014; Keay et al., 2019). Romana et al., (2004) assessed the body composition of long-distance runners during transition, pre-competition, and competition stages, alongside measures of VO_{2max} and work performance. During the transition to competition stage, lower body muscle mass increased by 4.7%, respectively there was also an increase in VO_{2max} of 18% and work performance of 37%. This study demonstrates that body composition is an important component in training-induced adaptations, influencing physiological parameters and enhancing athletic performance.

In weight-class sports, such as Judo, boxing and Olympic lifting, athletes may be required to reduce their total-body mass to compete in a lower weight category, to provide an optimum chance of achieving success, through physical and psychological advantages (Pettersson et al., 2013). Hence, it is important for the athlete to maintain lean muscle mass and reduce FM for competition to avoid any negative effect on performance (e.g., fatigued, force production, movement techniques) (Gallot et al., 2019).

2.1.3 Body composition and athlete health

The assessment of body composition in athletes is not solely focused on performance. Literature states that health implications may arise when athletes aspire for unrealistic body composition, which may go unnoticed if body composition is not monitored or assessed correctly. Sundgot-Borgen et al., (2013) reviewed research aiming to minimise health risks in weight sensitive sports. Athletes in weight sensitive sports typically focus on trying to maintain a low body mass and consistent low body fat percentage. Whilst there is not a single ideal body composition across a range of sports, athlete support teams should be able to identify and manage athletes aiming to achieve unrealistic body composition, typically to prevent potential eating disorders. Therefore, precision and accuracy in the assessment of body composition in elite athletes is critical when monitoring individual's body composition to help identify potential eating disorders. Which could adversely affect performance in weight sensitive sports, even if the athlete believes competing at a specific weight is gaining an advantage to achieve success.

Research also suggests that athletes may not struggle only with physical health but also mental health, when trying to maintain a low body fat percentage. Hagmar et al., (2013) performed a cross sectional investigation in male Olympic athletes. DXA, blood biomarkers (steroid hormone and biomarkers of nutritional status) and state of mood were assessed, and athletes were split into two groups dependent on leanness sensitive sport or not. Results indicated that the group striving for leanness had higher POMs score for depression and anger, results also showed that this group also had higher frequency of illness. Therefore, athletes in sports that emphasised the requirement to reduce body fat for a pro-longed period of time were more likely to be subjected negative health effects. To avoid physical and mental health issues, it is recommended that athletes should aim to lose body fat only within a professionally supervised and sustainable programme (Reale et al., 2018). For athletes and practitioners to achieve this, precision in the assessment of body composition is important to accurately monitor and set realistic targets for athletes to reduce body fat in pre-competition phase. Elsewhere, Fortes et al., (2011) demonstrated that even a slight energy deficit calculated using DXA- derived LM and FM, caused a negative effect to individuals body composition and performance. Similarly, another study identified that a negative energy balance had a decrease in lower body strength and power (Murphy et al., 2018).

The assessment of body composition has allowed practitioners to identify that LM mass can be increased when an athlete is in an energy deficit, even when adequate protein intake in consumed (Carbone et al 2019). However, studies have highlighted that longer term energy deficit (sustained daily over extended duration), is associated with a suppressed resting metabolic rate (RMR) and health implications associated with RED-S. Examples of this are, higher body fat, higher risk of injury and impaired physical performance (Schlabach et al., 1994; Saltzman et al., 1995; Benardot et al., 1996; Murphy et al., 2018). Bartlett et al., (2019) suggests that DXA assessment of body composition can be implemented to monitor longer term variations in energy balance, which in practice can be used as an assessment of training and nutrition practice/behaviours. This additional information can support practitioners to adapt interventions for athletes, making a desired body composition more easily obtainable.

Evidence suggests that the assessment of body fat in athlete is ineffective in monitoring the progression of an injury or even potentially identifying an injury or weakness in athletes. Duthie et al., (2006) focused on professional rugby players individual health and injury prevention. A framework for elite athletes' physical preparation to develop the performance and physical progression. Physical profiling of athletes identifies strengths and weaknesses, assessment of body composition is a part of physical profiling and is important to monitor physiology development. Athletes carrying injuries or weakness can be highlighted in preparation through body composition measurements. If injury or weakness has occurred using regular body composition assessment, practitioners are able to return the individual back to full fitness without gaining body fat or losing lean muscle.

2.1.4 Manipulation of body composition

In sport, body composition is manipulated for goals specific to the sport (Duthie, 2006). Two common interventions are strength and conditioning or nutrition, with the aim of improving physical performance (Sousa 2019; Trakman et al., 2019). In their meta-analysis, Preterson et al., (2014) investigated dose-response effects from strength interventions in athletes (37 studies). The general consensus was that 85% of 1 rep maximum (1RM) for 8 sets, 2 days a week, brings about a positive adaption in muscles and an ideal dose response to increase muscular strength. In another study, Robinson et al., (2015) carried out a 14-week strength and conditioning and nutrition program for a 21-year-old male natural (no performance enhancing drugs) body builder. The overall goal was competition preparation, reducing total-body mass through diet and exercise, but ensuring appropriate rest. Total body mass decreased by 11.7 kg, FM decreased 6.7 kg and LM decreased by 5 kg.

Witard et al., (2019) reviewed track and field athletes aiming to lose FM but retain lean muscle, through manipulation of dietary protein intake g/kg/day. From this review, protein intake was a large factor for the athletes aiming to achieve optimal body compositions, whilst allowing athletes to maintain and improve performance. Furthermore, Garthe et al., (2012) showed how nutrition interventions can adapt body composition across a mixture of disciplines, in addition to individual sports. This experiment split the elite athletes into two groups, a nutrition consultant group and an ab libitum group, where the objective of the intervention was to increase body mass through strength and conditioning interventions.

DXA was used to measure body composition and 1RM, jump and speed testing were performed, pre- and post-intervention. Whilst results indicated increased 1RM strength for each group, total body mass increased only for the nutrition consultant group (3.9±0.6% vs. 1.5±0.4%).

A common technique to manipulate body composition is diet supplementation, elite athletes use a wide range of these to aid recovery/muscle growth, strength, and energy requirements (Garthe & Ramsbottom, 2020). Bone et al., (2016) investigated the manipulation of muscle creatine and glycogen, and body composition was assessed using DXA. The male athletes were divided into two groups, both groups participated in glycogen loading but only one group supplemented creatine loading. Results indicated that glycogen loading in both groups led to an increase in total LM (3.0 ± 0.7% and 2.0 ± 0.9%) leg LM (3.1 ± 1.8%, 2.6 ± 1.0%), total-body water, glycogen loading (2.3 ± 2.3%) and creatine (1.4± 1.9%).

2.2 Measurement of body composition in athletic populations

Valid and reproducible body composition assessment methods are required for use in athletes, given the importance of detecting the smallest meaningful change (Slater et al., 2005). Popular methods for the assessment of body composition in athletes are bioelectrical impedance analysis (BIA), skinfolds, air-displacement (BOD-POD) and DXA (Meyer et al., 2013). These are generally the preferred methods for the assessment, due to low cost, practicality and portability, although DXA is widely assumed as a criterion method (Bilsborough et al., 2014).

2.2.1 Bioelectrical impedance

BIA is a non-invasive, inexpensive, and portable assessment technique, which measures the electrical properties of body tissue, estimating body composition parameters as total-body water and fat free mass. The transit time of a low voltage current is dependant of the body composition characteristics, BIA works by this principle (Kyle et al., 2004).

The protocol developed by Kyle et al., (2004) supports best practice procedures for the assessment of body composition using BIA. Prior to assessment, athletes body mass and height are measured, and standardised conditions are encouraged and address positioning, exercise status, food and fluid intake and skin temperature (Kyle et al., 2004). Precision has been found to be lower for BIA assessments of body composition in elite athletes, (Bilsborough et al., 2014). When compared to DXA and air displacement (BOD POD), BIA has a higher precision error. Kyle et al suggests that factors such as food and fluid intake, physical activity, or medical conditions have an impact on TBW and hence BIA outcomes (Kyle et al., 2004).

2.2.2 Air displacement plethysmography

Air displacement plethysmography is a method of body composition assessment which consists of two chambers, one the subject chamber and other the reference chamber. The pressure changes between the test chamber and reference chamber, this will determine the volume of the test chamber. Best practice protocols require athletes to be tested in lycra clothing and silicone swimming cap, with all jewellery and metal objects removed before assessment (Dempster & Aitkens, 1995). This is to avoid erroneous data, air displacement plethysmography manufacturers recommend that assessment should be performed when the participant is dry and rested, also the testing environment remains a stable temperature (Operators Manual, 2000). Best practice guidelines should be implemented to avoid potential under or overestimations of body compositions components.

The estimation of body composition is calculated through the application of the Siri equation as follows:

D(density) x Mass(scale) = Volume (BOD POD)

Body fat percentage (BF%) = (497.1 / body density) – 451.9

The Siri equation is applied to calculate body fat percentage (BF%) via estimated values of LM and FM (Siri, 1961).

Air displacement Plethysmography assessment has been shown to have good agreement with DXA. Farley et al., (2020) reported low precision errors for LM and FM, results were similar to precision error for LM and FM in DXA. The use of the BOD POD is widely applied in athletic populations, due to it precision in estimation body composition variables, when pre-scan preparation is correctly followed (Ballard et al., 2004).

2.2.3 Skinfolds

The standard approach to the estimation of body composition using skinfolds, is to take skinfold measurements at the following eight sites: triceps, biceps, subscapular, iliac crest, supraspinal, abdominal, quadricep and calf, using calibrated skinfold callipers (Norton et al., 1996). A calculation formula is then applied to the skinfold measurements to provide athletes %BF (Sutton et al., 2008). Typically, skinfold measurements sites are duplicated, as instructed and advised as the preferred practice technique by the International Society of the Assessment of Kinathropometry. In applied practice, it is also common to use the sum of skinfolds (5 or 8). Advantages of anthropometric techniques, such as skinfolds, include widespread use for assessing body composition in athletes (Ackland et al., 2012). Research by Farley et al., (2020) identified that skinfold method of assessment for both consecutive day and same day testing had a lower precision error for LM, when compared to DXA, air displacement and BIA.

2.2.4 Dual energy X-ray absorptiometry

DXA uses two X-ray beams of different energies that are diversely attenuated by soft tissue and bone (Marra et al., 2019). DXA involves ionising radiation, but the corresponding dose is small, where effective dose of a single standard mode, total-body scan is ~ 2 usv, which is lower than one day of natural background radiation in the UK (~ 5-8 usv) (Hind et al., 2018; Public Health England, 2020). Scans are non-invasive and provide a rapid assessment of body composition with a scan time of approximately 6.5 minutes or 12.5 minutes, depending on scan mode (Lees et al., 2017; Thurlow et al., 2018). DXA models are fan beam or pencil beam. Fan beam uses wider X-ray beams, which leads to shorter scan time and better resolution of the image (Soriano et al., 2004; Ackland et al., 2015). In pencil beam system the X-ray passes through a narrow collimator, the data is acquired by a rectilinear pattern separated by millimetres over the patient’s longitudinal axis (Pludowski et al., 2010). DXA is an imaging technique historically used for the assessment of bone mineral density (BMD) and the diagnosis of osteoporosis. Over the last three decades, it has also emerged as a leading method for the assessment of body composition through total-body scans. These scans distinguish three components of body composition: 1. Fat mass (FM) 2. Lean mass (LM) 3. Bone mineral content (BMC) (Thurlow et al., 2018). These components can be measured for total-body composition and regional composition (arms, legs and trunk). DXA is now widely recognised as the gold standard method (Gomes et al., 2018) and as the preferred assessment for body composition by the International Olympic Committee (Meyer et al., 2013).

DXA is more expensive and less accessible than other methods of body composition assessments, but it has been found to be effective in detecting changes in body composition in highly trained athletes (Bilsborough et al., 2014), more so than other available methods (Farley et al., 2020). Lean mass and bone mass measurements are the most reliable outputs from DXA, which is relevant given that small changes in lean may positively impact athletic performance (Stewart, 2001). This is also supported by Lohman et al., (2006), research indicated that in a healthy non-athletic population, the use of DXA to assess fat free soft tissue mass and fat mass, results in greater level of precision compared to skinfolds and BIA measures.

2.2.5 Precision of body composition assessments

Technical and biological error can influence the precision of all body composition assessment methods (Fields et al., 2000; Vescovi et al., 2002). Technical error can be affected by the level of technical expertise, equipment calibration, clothing and positioning (Marfell-Jones et al., 2012). Whereas biological variation arises as a result of food and fluid ingestion or exercise prior to assessment (Bone et al., 2017; Kerr et al., 2017). Given both technical and biological error, standardised protocols should be followed for all body composition assessments (Norton et al., 1996; Nana et al., 2016; Hind et al., 2018, Farley et al., 2020).

Farley et al., (2020) investigated precision error from different methods of body composition assessment in athletes, following standardised pre-scan preparation protocols (Table 1). Their findings demonstrated greater precision error for FM than LM measurements. There was variation in precision between methods especially measurements, with superior precision for DXA and skinfolds, indicating high test-retest accuracy and reliability.

Table 1. Comparison of precision error for different body composition assessment methods, with best practice protocols in place *(from Farley et al., 2020)*

	Fat mass		**Lean mass**	
Method	%CV	LSC	%CV	LSC
BIS	5.2	14.4	0.6	1.6
BOD-POD	2.5	6.9	0.5	1.3
DXA	1.5	4.2	0.5	1.3
Skinfolds	1.0	2.9	0.2	0.4

(%CV = Percentage Coefficient of Variation, LSC = Least Significant Change (%CV * 2.77), all methods assessed under best practice conditions)

In addition to FM and LM, DXA also measures bone mineral content (BMC). This has an advantage compared to the other methods, in athletes where an assessment of bone mass is also useful.

2.3 DXA in sport and exercise sciences

2.3.1 Application of DXA in athletic populations

DXA is currently considered the criterion method of the assessment for body composition (Hind et al., 2018). This method provides an in-depth and detailed analysis for total and regional body composition and bone density (Lees et al., 2017). The data derived from DXA can be of great value to strength and conditioning practitioners and sport nutritionists (Hall et al., 2016) for guiding training/dietary interventions and gauging their success (Georgeson et al., 2012; Milanese et al., 2015). DXA is also valuable for the assessment of bone health in athletes presenting with bone stress injuries, fracture and/or RED-S (Mountjoy et al., 2015). As such, the use of DXA in athletes has become increasingly popular (Bilsborough et al., 2014; Prokop et al., 2016; Hind et al., 2018; Keay et al., 2018).

In the past two decades, there has been an increase in published literature on the assessment of total and regional body composition in athletes, and specifically, an increased number of studies providing information on precision error (Hind et al., 2018). The increase in popularity amongst athletic populations may be linked to the additional advantages of DXA in comparison with other methods for body composition assessment (Table 2).

There are a number of important considerations to make when conducting DXA scans. DXA is prone to technical error and biological variation for example, varying hydration levels, which can impact estimates of LM (Kerr et al., 2017). Reduction in technical error can be achieved by minimising movement during the scan, the use of straps can be implemented, around the ankle above the foot and around the trunk at the level of mid forearms (Kerr et al., 2016; Farely et al., 2020).

Table 2. Advantages and limitations for body composition assessment utilising DXA

Advantages (adapted from Nana et al., 2015)	**Limitations**
Suitable for most athletes Fast (~5-14 min for fan beam depending on scan mode) Can provide an assessment of regional body composition Low radiation dose (~0.5 μSv) and safe for sequential measurements Nonintrusive	Not portable Not always accessible for all clubs/sports organisations Higher cost than other methods Regulatory requirements due to use of ionising radiation

2.3.2 Specific measurements of DXA in athletic populations

DXA assesses three compartments of body composition, namely fat mass, lean mass and bone mineral content. The precision error of these measures may be increased in athletic populations due to their unique somatotype (Van Der Ploeg et al., 2003). Further, there is a difference in the body composition, size and thickness of athletes across various disciplines, which can affect total and regional X-ray attenuation characteristics (Hind et al., 2018). In comparison with general populations, athletes tend to have a greater volume of muscle mass, resulting in an increase in LM, which can enhance the conductivity during assessment (Stewart & Hannah., 2000). Hind et al., (2018) and Barlow et al., (2015) highlighted that assessing individuals with greater LM can lead to greater error in LM estimates.

There are specific considerations to make when applying DXA in practice. Athlete must be able to be positioned within the scan boundaries but this can be challenging when working with athletes from sporting disciplines such as basketball or powerlifting, when athletes tend to be taller and heavier, respectively (Silva et al., 2013). One method to address this is to perform two scans, with at least half the body included in each scan. The total body estimate is then obtained from the sum of the outputs of each side. However, this technique has disadvantages such as, time consuming (multiple scans), increase of radiation exposure and increase in technical error due to several steps of analysis (Hangarter et al., 2013; Nana et al., 2015).

Precision

Precision error can be determined from repeat measurements on a population sample of n = 30 (Hangartner et al., 2013; Hind et al., 2018). Precision error can be presented as root mean squared (RMS-SD) and percentage coefficient variation (%CV) (Lees et al., 2017). Once the precision error of the DXA measurement is generated, the least significant change (LSC) value can be established (LSC = 2.77 * Precision Error) (Hangartner et al., 2013; Hind et al., 2018). The LSC infers 95 % confidence that actual change has occurred between the first and second DXA measurement (Baim et al., 2005). The ISCD outline minimal acceptance limits for precision error (CV%) as follows; total FM = 3%, total LM = 2% and body fat % = 2% (Hangartner et al., 2013; Hind et al., 2018).

Table 3 reports precision error for FM, LM and BMC from published literature dated 2000 - 2020 assessing the body composition in athletic populations. Precision error is given as a percentage coefficient of variation (%CV) and least significant change (LSC). Although, some studies did not provide a value for BMC, which suggests the investigation was primarily focused on FM and LM. The data clearly indicate that %CV and LSC for LM are lower than for FM, suggesting the measurement of LM is more precise than FM in athletic populations.

Table 3. Precision error data from studies using DXA for the assessment of body composition in athletes

	Fat mass		**Lean Mass**		**Bone Mineral Content**	
Study	**%CV**	**LSC**	**%CV**	**LSC**	**%CV**	**LSC**
Stewart & Hannah (2000)	3.0	8.31	0.9	2.5	0.9	2.5
Hind et al., (2011)	0.8	2.3	0.5	1.4	0.6	1.7
Barlow et al., (2015)	2.3	6.4	1.6	4.5	1.7	4.6
Nana et al., (2016) BP	3.5	9.6	0.3	0.9	N/A	N/A
Nana et al., (2016) RP	3.8	10.4	0.6	1.8	N/A	N/A
Lee at al., (2016)	2.3	6.4	1.6	4.5	1.7	4.6
Zemski et al., (2018)	1.8	5.1	0.3	0.9	0.6	1.7
Tinsley et al., (2018)	3.6	10	0.9	2.5	1.5	4.2
Farely et al., (2020) BP	1.5	4.2	0.5	1.3	N/A	N/A
Farely et al., (2020) RP	2.4	6.6	0.5	1.5	N/A	N/A

Studies are in date order; %CV = Percentage Coefficient of Variation, LSC = Least significant change (%CV * 2.77); Best Practice (BP) = Standardised pre-scan protocols followed, technical error present; Random Practice (RP) = Non-standardised pre-scan protocol followed, technical error and biological variation present

When assessing BMC in athletes, the %CV is low and studies obtain similar values between BMC and LM, showing that DXA precisely measures BMC. The recent study by Farley et al., (2020) highlighted the difference between best practice pre-scan protocol and random practice pre-scan protocols, by directly comparing technical error with technical and biological error. Results did not show much difference in LM with both %CV being 0.5%. However, the measurement of FM highlights a major difference in %CV between best and random practice protocols (1.5 vs 2.4 %CV). Nana et al., (2016) also compared best and random practice protocols, though the results were not in agreement with Farley et al., (2020). When following best practice protocols, both LM and FM demonstrated lower precision error compared to random practice protocol. All the studies in Table 3 describe the application of pre-scan protocols, following the guidance from Nana et al., (2016) and Hind et al., (2018).

2.4 Optimising DXA precision

Precision error can arise from both technical and biological factors (Nana et al., 2015). Therefore, care must be taken in order to standardise scan protocols, particularly in athletes where it is important to detect small changes. Sources of technical error include the subject positioning, region of interest (ROI) placements technician error, clothing, cross-comparison between DXA machines, scanning mode/speed. Sources of biological error include the effects of daily food and fluid intake, effects of exercises sessions. Nana et al., (2014) highlighted that technical error and biological variation are the key factors that directly affect precision error. Therefore, to allow best practice and obtain the highest precision athletes are asked to follow standardised pre-scan protocols (Nana et al., 2016).

Optimum and standardised protocol procedures must be followed to minimise precision error. To achieve the precision to detect small but meaningful changes in body composition, athletes should be in a fasted state, rested state, wearing minimal clothing, no jewellery and euhydrated (Nana et al., 2016; Hind et al., 2018). Furthermore, athletes should be provided with detailed guidance on training, diet and supplements used (e.g. creatine monohydrate) to facilitate athletes presenting in a glycogen repleted and euhydrated state. Nana & Slater (2015) reported that food and fluid intake substantially alters total and regional body composition measurements and can increase typical error by 10%. Furthermore, Nana suggests avoiding circadian rhythm effect, by the participant presenting in a fasted and rested state, at the same time of day.

Farley et al., (2020), investigated biological variation and the influence on precision error, this was performed through same-day testing scan (scan, reposition and scan) (technical error), following this a 24 - hour consecutive day scan was also performed (biological variation). The consecutive day scan meant the athletes could consume food and fluid and exercise without restrictions, thus increasing the chance of biological error. Results for the DXA same day shown in Table 4a and consecutive shown in Table 4b.

Table 4.a. Precision error DXA same day testing (Farley et al., 2020)

	Fat mass	**Fat Free Mass**
RMS-SD	435	528
%CV	1.5	0.5

Table 4.b. Precision error DXA consecutive day testing (Farley et al., 2020)

	Fat mass	**Fat Free Mass**
RMS-SD	585	710
%CV	2.4	0.5

RMS-SD = Root Mean Squared – Standard Deviation, %CV = Percentage Coefficient Variation, iDXA system used = GE enCORE software (version 13.60; GE Healthcare)

Precision error appears greater for FM with consecutive DXA assessments with little difference in precision for FFM. However, Nana et al., (2015) stated that biological variation, with regards to food and fluid intake has no influence on measurements for BMC and FM. Although Farley et al (2020) results clearly show a change in FM, suggesting biological variation can affect precision in only 24 hours.

2.4.1 Biological variation

Biological variation can cause changes in body composition that are attributed to variation in tissue hydration and gastrointestinal tract contents (microbiome and undigested dietary components) (Vilaca et al., 2009).

Effects of food and fluid intake

To limit the effect of biological variation, best practice requires athletes to present themselves rested, overnight fasted and voided bladder (Nana et al., 2015). However, this is not always possible if athletes are assessed in the afternoon or evening. Specific standardised protocols depending on the athlete appointment time are therefore recommended (Australia Institute of Sport Guidelines). The three key points that should be considered are 1.) meal size, 2.) content of food, 3.) time of consumption (Nana et al., 2012). Additionally, Nana et al., (2012) highlighted individuals that consumed food within an hour of assessment, the results for total mass and LM mass increased. Consequently, a predicted "cut-off" for volume of food that can be consumed to not detect a change in body composition, could not be found. A study conducted by Vilaca et al., (2009) reported no changes in body composition when elderly subjects were scanned one hour after ingesting a small meal (50 g bread roll, 6 g butter and 500 ml orange juice). Similarly, in young healthy subjects, Horber et al., (1992) reported no changes in body composition one hour post ingestion of 400 ml fluids.

Effects of exercise

Lohman et al., (2000) reviewed the hydration status of LM in humans and reported a range 72-74.5%. This is important as DXA technology identifies soft tissues as normally hydrated to accurately distinguish between fat and LM (Plank, 2005). However, earlier literature suggests a greater range in LM hydration, 67-85%, this variation can cause inaccuracies in the estimation of LM, directly influencing estimates for FM (Moore & Boyden, 1963). Nana et al., (2014) states that exercise influences tissue hydration status, which directly effects the whole-body hydration levels. During exercise the athlete could increase hydration through fluid intake or specifically decrease through fluid lose due to sweating. Exercise can also affect tissue hydration, given that exercise is associated with fluid shifts from one region to another (Maughan et al., 2007). Typically, an increase in blood flow to the muscles due to blood vessel vasodilation, leads to greater muscle tissue hydration in the working area (Coyle, 2004). Going et al., (1993) established that blood shifts in body compartments can affect results of fluid hydration in the muscle and this could have an impact on lean mass assessment. Similar to the effect that food and fluid intake has on the body, after exercise a muscle or region of the body, blood volume will shift to that compartment, this is known as blood shunting (Rowell, 2004).

2.4.2 Technical/system error

Positioning

Lambrinoudaki et al., (1998) studied subject positioning in a non-athlete healthy population, with the aim to illustrate the impact of positioning and establish the most accurate technique for DXA scans. The two positions assumed by the athletes were prone (lying face down) and supine (lying face up). Results reported a difference in total-body FM and LM by 5% and 3%, also a difference in estimates for trunk LM between prone and supine, precision error results for the supine position being the lowest. A potential reason for the differences in estimations could the loss of lower energy photons throughout the DXA assessment as a result of increased body thickness (Proir et al., 1997). Lohman et al., (2009) studied the effect of subject positioning (supine vs prone), results identified that upper and lower limb estimations had a weak correlation ($r = 0.72$). Lohman et al., (2009), explained the discrepancies as the beam hardening effect, due to an alteration in tissue depth and attenuation ratios.

Literature suggests even a small variation in positioning, will illustrate a difference in precision error results. Thurlow et al., (2017) investigated the influence hand positioning had on regional and total-body composition parameters and to identify protocol specific precision errors. Where the hand positions of the subjects were assumed as prone and mid prone, highlighted in *Figure 1.* Total-body and arm BMC were the major differences, as a result of the arm being in the mid-prone position, the ulna and radius is identified as one bone. Results for body composition variables at the arm region reported a significant decrease in FM and a significant increase in LM, when the hand was placed in the mid-prone position. This led to an overall difference in total-body composition parameters between prone and mid-prone positioning. Precision error results identified for fat mass and lean mass the mind prone position had lower precision error, however, for bone mineral content the mid-prone precision error was higher than the prone position.

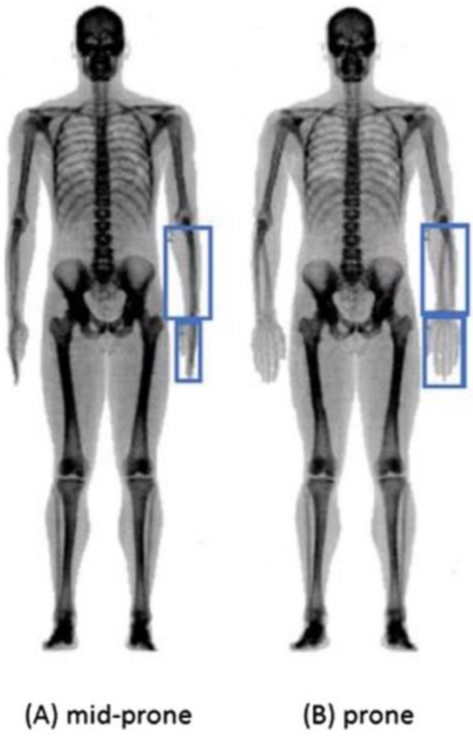

Figure.1. Total-body DXA hand mid-prone and hand prone (NHANES) position. NHANES, National Health and Nutrition Examination Survey. (Thurlow et al., 2017).

Thurlow further concluded that published studies using DXA for the assessment of body compositions, should fully describe subject positioning and standardised hand position remains consistent.

Regional body composition

Nana et al., (2014) reviewed literature focusing on how technical and biological error effected precision error. There was only one study identified that investigated the reliability of analysis of regional composition, between automatic or manual. The DXA software would automatically estimates regional composition (Trunk, Arms, Legs), however a technician can manually mark segmental lines on the scan. Lohman et al., (2009) established that better reliability for regional composition was reported when the DXA scans were analysed manually by a technician, (Automatic r = 0.74-0.98 vs Manual r = 0.93-0.95).

Clothing

Limited studies have researched the effected and influence clothing has on DXA precision error. However, the benefit of having standardised protocols for what the subject is wearing, i.e. minimal clothing (underwear), is placement of segmental lines, which makes it easier to line up the subject on the DXA scan bed. Also, clothing fabrics may contain chemicals, such as salt, water etc, which can change ratios in DXA energies (Nana et al., 2015).

DXA manufacturer and model

Literature suggests that a key limitation is the differences in estimates of body composition of DXA variables when comparing DXA manufactures (Soriano et al., 2004). The typical differences in manufactures are beam technology, scan mode, machine type and software version. Guo et al., (2004) reported significant variations in body fat percentage when using two Lunar prodigy machines with different scan speeds. Hull et al., (2009) demonstrated a centre-specific-cross-calibration in order to obtain regression equations, allowing results from longitudinal investigation to be interpreted precisely. This allows for direct comparison of scans from one study to another, for where the DXA software has been upgraded. However, the Hull (2009) equation only applied to a general population and not athletic. Highlighting that when using the centre-specific regression equations, the regression equations should also be population-specific.

Scan mode

Prior to the DXA scan, the subject's height (cm) and body mass (kgs) are measured and body mass index (BMI) is derived. The DXA machine has three scan modes, thin (<13 cm), standard (13-25 cm) and thick (>25 cm), the mode is initially selected from the BMI of the individual. However, the technician can override this at any stage and select another scan mode. The automatic selection on scan mode/speed is based on BMI, which is technically estimating body thickness. Some participants with high levels of muscle mass could automatically be selected for thick mode, however, these participants may be better suited to standard (Nana et al., 2014).

2.5 Total-body less head DXA application

Previous research has investigated the effect of different subject positions on scan outcomes, such as hand positioning from prone with mid-prone and whole body prone with supine (Lambrinoudaki et al., 1998; Thurlow et al., 2018). However, no study has yet investigated precision error utility of the total-body less head (TBLH) DXA scans.

In some sports, height can be an advantage (basketball, rowing), however one limitation of DXA is that whole body scans can only be performed on individuals who do not exceed the scan area (typically 195cm) (Evans, Prior & Modlesky, 2005). To address this, Silva et al., (2004) instructed subjects to bend their knees at 90° to allow the subject to fit within the scan area. However, some DXA scanning arms can be too low and make contact with the subject's knees. Another method performed was a partial scan method using a Hologic DXA systems, this is the sum of two separate scans, one starting at the neck and one starting at the hip. Results provided accurate estimations for body composition components, although the validity could be questioned as the technique was performed on 19 non-athletes (Evans et al., 2005). Santos et al., (2013) reported the most accurate technique to assess BMC, FM and LM, when using the sum of two scans, was the method that used a head scan and the other trunk and limb scan, also referred to as the subtotal. An investigation into this method was performed on males and females from athletic (31 subjects) and non-athletic (65 subjects) population, with an age range 16-55 years old. The study excluded obese subjects (>30kg.m^{-2}) and subjects taller than 195 cm.

Table 5. Precision of whole-body and subtotal DXA scans

	Whole-Body (%CV)	Subtotal (%CV)
Bone Mineral Content	1.40	1.66
Fat Mass	3.70	4.05
Fat Free Mass	1.09	1.20

%CV = Coefficient of Variation

Santos et al., (2013) reported results from whole-body scan and the subtotal scan and highlighted that the new technique provided accurate valuations, although the whole-body scans had greater precision (Table 5.). The subtotal method reported greater precision in comparison to the knee at a 90°, that was implemented by Silva et al., (2005). The subtotal scan technique highlighted individual error as it overestimated FM by 0.94 kg or underestimate it by 1.07 kg. The previous studies (Silva et al., 2004; Evans et al., 2005) aiming to resolve the limitation of a subject exceeding the scan area, both were in agreement as the two investigations overestimated and underestimated FM compared to BMC and LM. The main limitation to the subtotal method for assessment in taller athletes is the requirement of two separate scans, which can be time consuming and increases radiation exposure.

DXA is suggested to accurately estimate the composition of the head, due to the head presenting less sources of systematic error for FM and LM estimations. Since DXA excludes pixels that contain bone in addition to soft tissue to calculate FM and LM, values are estimated based on composition of the pixels on the adjacent soft tissue (Pietrobelli et al., 1996). However, no study has investigated the contribution of the head region to body composition analyses using DXA.

2.6 Summary

The routine assessment of body composition is common practice among elite athletic populations. Is widely recognised that body composition is associated with athletic performance and has an important role in monitoring athlete health. There are several methods available for assessing body composition in athletes, deriving LM, FM, %BF and FFM such as BIA, skinfolds and DXA- which all have specific advantages and disadvantages. However, DXA is recognised as the criterion method due to its superior precision and ability to assess three-compartments (FM, LM and BMC). It is important to optimise precision with DXA by controlling technical and biological variation where possible through quality assurance and standardised protocols. A number of studies have investigated DXA precision for standard total-body scans in athletic and general populations, with reports of good to excellent precision depending on the population studied and the compartment of assessment. The TBLH application is a recent development in DXA technology which reduces scan time and ionising radiation exposure, compared to the standard total body scan. This new scan may also be particularly useful in tall athletes who exceed the DXA scan boundaries. Therefore, as the first to do so, this study examined the precision of TBLH DXA for the assessment of body composition in athletes, and compared outcomes with the standard total-body scan.

3.0 Methodology

3.1 Study design and approach

This investigation was a methods study, designed to determine the precision of lean mass, fat mass and bone mass measurements derived using DXA standard total-body and TBLH scans in a heterogeneous cohort of male and female athletes. The research program adopted a realist approach, where one truth exists and cannot be changed, given that the current research performed direct physical measurements of the human body and produced objective, quantitative data to inform on the composition of body compartments. The precision error of the measurement was a key outcome and differences between repeated scans were calculated from the data. These results can be generalised to athlete populations similar to the sample used in the current study, using the same measurement method, and applied to other research and practice in sports science. The objective approach indicated that there was no direct influence with the data collection, assuming correct best practice protocol guidelines followed. The pattern followed in this research was observing from the outside, measuring the data and then performing and reporting the data analysis (Pike, 1967). The two different DXA assessment methods, standard total-body and TBLH, provided two separate results for precision error and directly compared. The study was methodically planned to eliminate contextual factors and used quantitative research for data collection, aimed to make generalisations based on the results reported.

3.2 Study sample

3.2.1 Participants

Participants were competitive male and female athletes, recruited from the University and local community. Athletes represented a range of different sporting disciplines, including high weight sports (for example, rugby) to low weight sports (for example, distance running), and were reflective of the athlete population usually scanned in the University Imaging Suite, in accordance with the ISCD recommendations for studies of precision (Hangartner et al., 2013).

3.2.2 Inclusion and exclusion criteria

The inclusion criteria for this research is given in Table 6. Male and female athletes were invited to take part in the study and were aged between 18 and 60 years. The broad range of age and multiple sporting disciplines was important for the validation of this study as to minimise bias in the inclusion criterion, alongside a large sample size of participants, including male and female, allowing the generalisability of results. The exclusion criteria followed standard DXA protocol guidelines, including pregnancy and orthopaedic metal devices.

Table 6. Participant inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• *Over 2 years of training experience* • *Competed at national or regional level in your discipline* • *Between 18 – 60 years of age*	• *Pregnancy* • *Long term injury causing the individual to be absent from training* • *Under 18 years of age* • *Orthopaedic or metal devices*

3.2.3 Sample size

The ISCD recommend that precision error should be derived from duplicate measures on a minimum of 30 participants or triplicate measure on 15 participants (https://iscd.org/knowledge-base/precision-assessment-calculator-faqs/). Blake & Fogelman (2010) argue that there are two important considerations to make when deciding on sample sizes for precision studies in medical imaging. First, that optimal assessment conditions can create an unrealistic optimistic setting, that is hard to replicate in general practice. The second consideration is that precision studies restricted to sample sizes of 30 participants, can have a wide variation error (Gleur et al., 1995).

It has also been argued that a greater sample size than 30 is required when there are wide ranges in body size and mass (Meredith-Jones et al., 2018). This is plausible because DXA precision has typically been found to be lower in higher weight groups. For example, in 45 elite level rugby league players (mean BMI: 27.8 ± 2.5 kg/m2) Barlow et al., (2015) reported the root mean squared standard deviation (%CI) for total-body LM: 321 g (1.6%), FM: 280 g (2.3%) and BMC: 24 g (1.7%). Furthermore, a study by Rothney et al., (2012) reported FM: 1.0 % & LM: 0.5% precision in non-obese adults compared to s a study by Stantos et al., (2013) reported FM = 3.70 %, LM = 1.09 % and BMC = 1.04 % precision in athletes from mixed disciplines.

Given the potential for variation in precision due to body mass and size, and in order to acquire representation of the usual population of athletes scanned at the University, recruitment targeted athletes from a range of sporting disciplines to reflect low (e.g. light weight rowing) and high weight sports (e.g. rugby). Therefore, the target sample size for this study was expanded to 60. A further consideration was the sex of the athletes in the study sample. The majority of precision studies in athletes have included predominantly males (Bilsborough et al., 2014; Barlow et al., 2015; Keil et al., 2016; Nana et al., 2016; Thurlow et al., 2018; Zemski et al., 2019; Farley et al., 2020). Therefore, equal representation from male and female athletes was sought.

3.2.4 Sampling approach and recruitment

Participants were recruited from elite level sports teams and clubs at the University and from the local community. Recruitment was facilitated through word of mouth, invitations sent to sports clubs via email, and through a call for participants various social media platforms including Twitter and Facebook. This non-probability, convenience sampling approach was primarily adopted to enable access to the target population. However, there was an element of purposive sampling, given that participants needed to be competitive athletes and fit the inclusion criteria. Sampling also aimed to increase diversity within the sample by recruiting athletes from various sporting disciplines, ages, sexes and ethnicities. Finally, another non-probability type implemented was cumulative. Those individuals who were recruited may then spread information by word of mouth, as body composition in elite sport is desirable information for athletes.

3.3 Ethical considerations and ethical approval process

The research received ethical approval from the NHS Research Ethics Committee, Newcastle upon Tyne. This study also received ethical approval from the University of Durham Department of Sport and Exercise Science Ethics Sub-Committee and NRES, given the involvement of ionising radiation. Particular considerations were given in light of COVID-19 and risk assessments and risk mitigation protocols were followed. Participants provided full written consent and were informed that they could withdraw from the study at any time without needing to give a reason.

The main ethical considerations associated with this study included primarily confidentiality and anonymity of each participant. All data protection techniques were adhered to ensure privacy. Participants were informed of what the study entailed, including potential risks and benefits of their involvements, through an information sheet (Appendix A) and they had an opportunity to ask any questions, before, during and after the data collection.

Another critical ethical consideration was the dignity of the participant. This research required the participant to wear minimal clothing (eg shorts and vest/t-shirt) when being assessed. To ensure the maintenance of dignity, the imaging suite provided a safe assessment environment and a private room, which the participants were informed of prior to their appointment. Participants were also provided with instructions (Appendix C) on how to prepare for the scan, including clothing.

One of the most important ethical considerations for this study was the ionising radiation from the DXA scans. Risk assessments were conducted, and ethical approval was obtained before any assessments using the equipment were performed. These measures ensured the safety of the participants and anyone else in the imagining suite at the time of the assessment.

3.3.1 Covid-19 precautions

Throughout the study the government and university COVID-19 guidelines were followed. Testing was conducted in the imaging suite at Maiden Castle, where the DXA machine was located. If a participant showed COVID-19 symptoms, the individual was to self-isolate for 14 days, as per government guidelines. These considerations were addressed by a booking system being implemented to use the imaging suite, enabling individual time slots for each athlete to be appointed. Following this, on arrival to Maiden Castle athletes were required to wear a face mask at all times when inside. Furthermore, participants were required to self-assess their temperature and sanitise their hands upon arrival. In addition, participants and staff were required to practice social distaining (2 m) when possible and adhere to a maximum occupancy of 3 persons in the imaging suite. After data collection from the DXA scans had been completed, all surfaces and equipment used during the testing were cleaned and sanitised. All individuals followed the one-way system when entering and exiting Maiden Castle, which was clearly marked out by arrows and signs.

3.4 Protocol

3.4.1 Calibration and quality assurance

Before using the DXA, a quality assurance (QA) was performed daily to assess the accuracy of the iDXA. importance of performing a daily QA is to ensure the iDXA is assessing body composition variables with precision and accuracy. If the results of the variables of the calibration block conform with the expected values, this provides the ability to assess participants with confidence. The QA was performed under the supervision of the research supervisor. The following procedure was followed to assess the calibration block and carry out QA-

1. Select the QA and start button on the computer.
2. Place the calibration block on the scan table.
3. Reset the laser light needed to be on the centre of the block, facing up and the brass facing down.
4. Select "ok" was selected on the computer and follow the screen prompts to complete a scan (all QA results were saved).

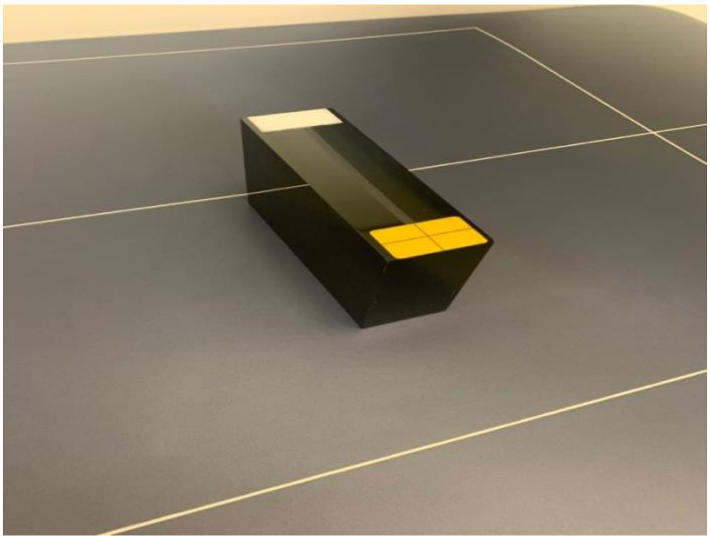

Figure 2. QA calibration block

The calibration block consists of three chambers simulating BMD values of 0.500, 1.000 and 1.500 g/m². If the results from the QA are within 0.030g/m², then the iDXA scanner is considered accurate. The results are reported as precision error, either as a standard deviation (SD) in g/cm² or percentage Coefficient Variation (%CV).

3.4.2 Pre-scan preparation

Prior to the appointment, athletes were asked to follow standardised pre-scan protocols to reduce biological variation (Nana et al., 2015), thus increasing precision (Hind et al., 2018). Athletes were required to wear minimum clothing or a gown and were asked to remove all jewellery/watches and other removeable metal objects prior to the scan (Nana et al., 2016). Athletes were assessed in an overnight fasted or 5 hours fasted, and euhydrated state, to minimise variation in tissue hydration and gastrointestinal tract contents (Horber et al.,1992; Convertino et al., 1996). If overnight fasting was not achievable due to appointment time being in the afternoon or evening, the participants were required not consume food or fluid 5 hours before the scan, following Australia Institute of Sport (AIS) recommended protocol on food and fluid intake. The DXA scan was performed with the athlete in a rested state, as recent exercise is associated with fluid shifts between body compartments and increased blood flow to muscle fibres due to capillary dilation (Maughan, Shirreffs & Watson, 2007; Nana et al., 2016). Evidence-based, standardised protocols were followed for pre scan preparation, scan acquisition and scan analysis (Nana et al., 2015; Hind et al., 2018).

3.4.3 Anthropometry

Anthropometric measurements were recorded (stature, body mass, waist circumference) to generate the participant’s body mass index (BMI). BMI was calculated using a the Quetelet formula of (mass/height²) (Kg/m²). The DXA software automatically identified scan mode based on the participant height and weight, either standard scan mode (153 mm/s) or thick scan mode (80 mm/s). The manufacturer’s protocol states that if abdominal thickness is between 16 – 25 cm standard mode is selected and if abdominal thickness is greater than 25 cm thick mode is selected. Some athletes have thick mode automatically selected even if their abdominal thickness is < 25 cm, the mode was then manually changed to standard (Thurlow et al., 2016).

3.4.4 DXA scanning

The DXA scans were performed using a GE Lunar iDXA (*GE Healthcare, Madison, WI*), which is a narrow fan beam densitometer with 64 – channel detector, with is a multi-element detector. The scans performed consisted of the standard total-body and new total-body less head. DXA equipment is made up of two main systems, the computer (software) and the scanner (hardware). The computer runs enCORE software, controls the scanner, and provides data storage and data analysis. The scanner contains the X-ray source, detector, patient table and mechanical system. The iDXA has an imaging performance of 1.2 – 1.6 Ip/mm and is limited by iDXA detector pitch of 0.8 mm at 3.3 times magnification (Version 18. Encore Manual).

Estimations for total-body variables require consistent participant positioning for accurate results. In those individuals with orthopaedic metal devices or previous surgical interventions, results can be difficult to interpret.

Figure 3. GE Lunar iDXA

3.4.5 Standard total-body positioning

The athlete mounted the scanning table and lay in a supine position. The hand position assumed by the athlete was mid-prone with no contact to the legs. Velcro-straps were positioned around the ankles to ensure a consistent position for the two scans, with the participants feet in a dorsiflexion position (Thurlow et al., 2018). This subject scanning positioning has been approved and implemented elsewhere (Nana et al., 2012a; Farley et al., 2020). In agreement with iDXA manual v18.0, the participants body was positioned in line with the central axis, and the head was positioned 3cm below the horizontal line in the frankfort plane. After the first scan was complete, the participant dismounted the scan table, then was re-positioned using the same method.

3.4.6 Total-body less head positioning

The TBLH scan process was carried out as described for the standard total-body scan, with the exception of head exclusion from the scan region. The scanner arm was manually positioned on the participants mandible, making sure the centre of the scanning arm was over the participants chin, this was performed via the controls on the scanner arm (Version 18 Encore manual). Following the first scan was complete, the participant dismounted the scan table and then be repositioned.

Figure 4. GE Lunar iDXA scanner arm highlighting the control systems to manually position the laser for the DXA scan

3.4.7 Precision study

DXA scan techniques were duplicated to generate the precision error following ISCD guidelines. A direct comparison between the standard total-body and the TBLH techniques could be made examine any relationship between these two methods. This method was used in previous research, where different hand positions were compared and its effect on precision error (Thurlow et al., 2017). The participant positioning and re-positioned method applied in this research replicates previous work, which reported good accuracy and low precision error (Barlow et al., 2015; Nana et al., 2016). The methods from these studies required the participant to fully dismount the scanning bed between each scan and re-positioned, with the aim of achieving the same positioning for every scan. Technical and biological factors were taken into consideration and strategies were made to minimise the influence these factors had on precision. Biological error was minimised by participants being emailed pre-scan guidance in advance to their appointment, which included information on food and fluid intake and exercise levels prior to the scan, previously mentioned in section 3.4.2.

3.4.8 Scan analysis

For both the total-body scan and the TBLH scans, the positioning, acquisition and regions of interest (ROI) were scrutinised following each scan. The software system (enCORE Version 18.0) frequently positioned the cut-off point lines correctly (*Figure 5)*. However, if there was an inaccuracy, manual adjustments were made. Point typing determined the placement of the bone edges, enCORE analysis automatically assigns point typing to an image, which identified cuts.

The software system automatically provides a total of 10 cuts:

1. Head
2. Left and right arm
3. Left and right forearm
4. Left and right elbow
5. Left and right spine
6. Left and right pelvis

7. Pelvis top
8. Left and right leg
9. Left and right knee
10. Centre leg

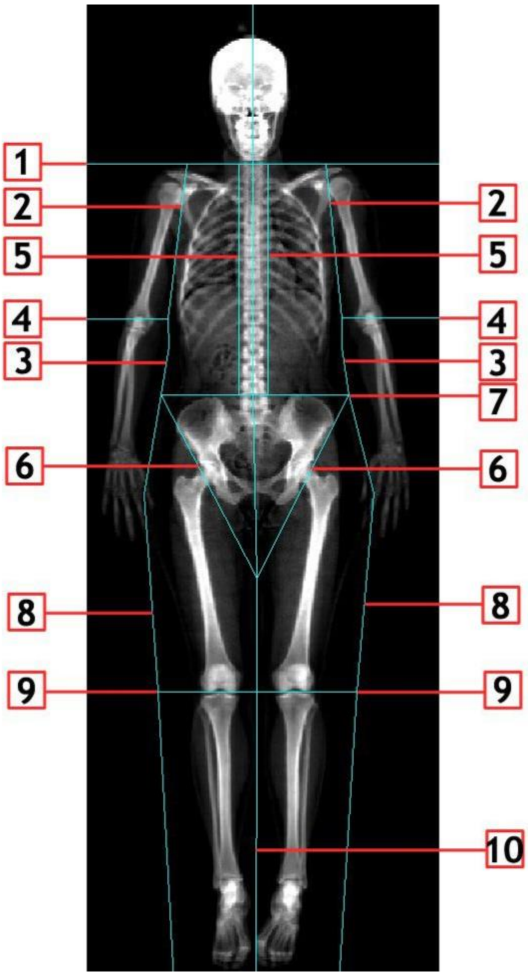

Figure 5. GE Lunar enCORE Version 18.0 user manual 10 cuts identifying the regions of interest

For body composition analysis, after selecting the analysis window followed by the composition tab to provide results, which included a multiple of derived DXA variables. Firstly, fat mass as a % of total tissue mass (tissue%fat) and as a % of total tissue mass and bone mass (region%fat). Other results include total mass in kg of soft tissue, fat tissue, lean tissue and bone mineral content (BMC). Participants BMI was reported, and the individual centile and Z-score were compared with reference population. For the specific regional analysis, individual cuts were applied and adjusted where necessary, to define tissue regions.

3.5 Statistical analysis

Statistical analysis was performed using the software programs Microsoft Excel (Version 16.50 (21061301), Product ID: 02954-089-861911) and IBM SPSS Statistics (Version 27, SPSS Inc, US). The distribution of the data was checked using SPSS descriptive statistics analysis. Data were found to be normally distributed and so presented as the mean and the standard deviation (SD) of the mean for all variables including the paired total-body and TBLH DXA scans. A Bland- Altman plot was used to compare repeated measurements for levels of agreement, with upper and lower limits of 95% CI, for bone mineral content, fat mass and fat free mass. The linear regression analysis from the Bland-Altman was to calculate proportional bias and the level of agreement of repeated scans, presented a *p value* and a beta mean.

Total and regional body composition precision error for both methods reported as the root mean square standard deviation (RMS±SD) and percentage co-efficient of variation (%CV), was calculated using the ISCD advance precision calculator. %CV was derived from the equation (%CV = (SD/mean) * 100). The least significant change (LSC) was derived from precision error (LSC = RMS-SD * 2.77), LSC at 95% confidence intervals (95% CI) (www.iscd.org) (Barlow et al., 2015).

Paired t-tests were computed to investigate differences in total body composition outcomes between the TBLH and the standard total body scan. Significance was identified at $p < 0.05$.

4.0 Results

4.1 Descriptive statistics

The total study sample comprised of 104 participants (n = 43 females, n = 61 males) from a range of sports (rugby n = 46, rowing n = 18, running n = 12, CrossFit n = 10, triathlon n = 8, athletics n = 2, resistance training n = 2, hockey n = 1, climbing n = 1, badminton n =1, swimming n = 1, kick boxing n = 1 and equestrian dressage n = 1). Four athletes were scanned using thin mode, 97 athletes were scanned using standard mode, and 3 athletes were scanned using thick mode. From 104 participants, 95 received repeat TBLH scans and 58 received repeated standard total-body scans (precision measurements). Overall, 57 participants received both a TBLH and a standard total-body scan which enabled comparisons between the two methods. The descriptive data for the total study sample are shown in Table 7. Athlete body size varied across sports, with BMI for the sample ranging from 16.4 to 46.9 kg/m^2.

Table 7. Descriptive results for the total study sample (n=104, males = 61, females =43)

	Mean	**Std. Deviation**	*Minimum*	*Maximum*
Age (years)	26.3	8.8	*16*	*60*
BMI (kg/m^2)	25.9	4.8	*16.4*	*46.9*
Height (cm)	177.1	10.9	*155.2*	*204*
Weight (kg)	82.2	21.3	*42.7*	*129.1*

BMI = body mass index, n = number of participants

4.2 Paired measurements

Table 8a and Table 8b present results for the repeat scans using the standard total body scan (n=58) and for the TBLH scan (n=95), respectively.

Table 8.a. Total-body composition in male and female athletes (n=58) from two consecutive GE Lunar iDXA measurements with re-positioning

	Measurement 1	**Measurement 2**
Body fat (%)	23.08 ± 6.86 *8.49 - 38.17*	23.11 ± 6.85 *8.64 - 38.39*
Fat mass (g)	16,045.9 ± 5,594.3 *6,428.17- 31,153.8*	16,057.1 ± 5,560.1 *6,408.2 - 30,648.7*
Lean mass (g)	50,997.1 ± 12,607.5 *29,596.3 - 83,838.4*	50,978.3 ± 12,629.45 *29,713.86 - 83,879.49*
Fat free mass (g)	53,898.1 ± 13,201.2 *31,413.3 – 88,236.1*	53,879.0 ± 13,219.57 *31,530.17 – 88,277.90*
Bone mineral content (g)	2,901.0 ± 640.8 *18,16.6 – 4,465.8*	2,900.6 ± 637.9 *1,816.3 – 4,434.7*
Bone mineral density (g/cm^2)	1.33 ± 0.15 *1.02 - 1.69*	1.33 ± 0.15 *1.01 - 1.69*
Bone area (cm^2)	2,156.8 ± 268.9 *1,732.0 – 2,740.8*	2,157.8 ± 269.3 *1,732.8 – 2,726.0*

Table 8.b. Total-body composition in male and female athletes from two consecutive GE Lunar iDXA total-body less head measurements with re-positioning (n=95)

	Measurement 1	Measurement 2
Body fat (%)	21.5 ± 6.5 *8.5 - 38.5*	21.5 ± 6.5 *8.8 - 38.2*
Fat mass (g)	16,493.4 ± 5,995.5 *5,727.0 – 32,003.7*	16,443.7 ± 5,969.3 *5,661.0 – 31,994.2*
Lean mass (g)	57,414.4 ± 16,603.8 *26,878.2 – 92,474.3*	57,486.6 ± 16,619.0 *26,745.1 – 93,538.9*
Fat free mass (g)	60,298.4 ± 17,456.6 *28,262.0 – 97,037.2*	60,368.4 ± 17,468.9 *28,134.8 – 98,078.8*
Bone mineral content (g)	2,884.0 ± 884.0 *1,355.0 - 5,281.4*	2,881.8 ± 882.1 *1,358.1 – 5,252.8*
Bone mineral density (g/cm2)	1.32 ± 0.21 *0.83 - 1.87*	1.32 ± 0.21 *0.82 - 1.83*
Bone area (cm2)	2,131.2 ± 349.6 *1,521.7 – 2,888.0*	2,132.0 ± 354.8 *1,508.6 – 2,893.7*

Presented as the mean ± SD, SD = standard deviation of the mean

Bland-Altman plots are presented in *Figures 6 - 11.* The mean axis unit for all figures is grams (g). Linear regression analysis was computed to assess agreement between the repeat measurements and the results are presented in Table 9. The difference between the two measurements was the dependant variable and the mean was the independent variable. For both the standard total-body and the TBLH method, there was no proportional bias ($p>0.05$). The β mean values were close to zero, indicating acceptable levels of agreement.

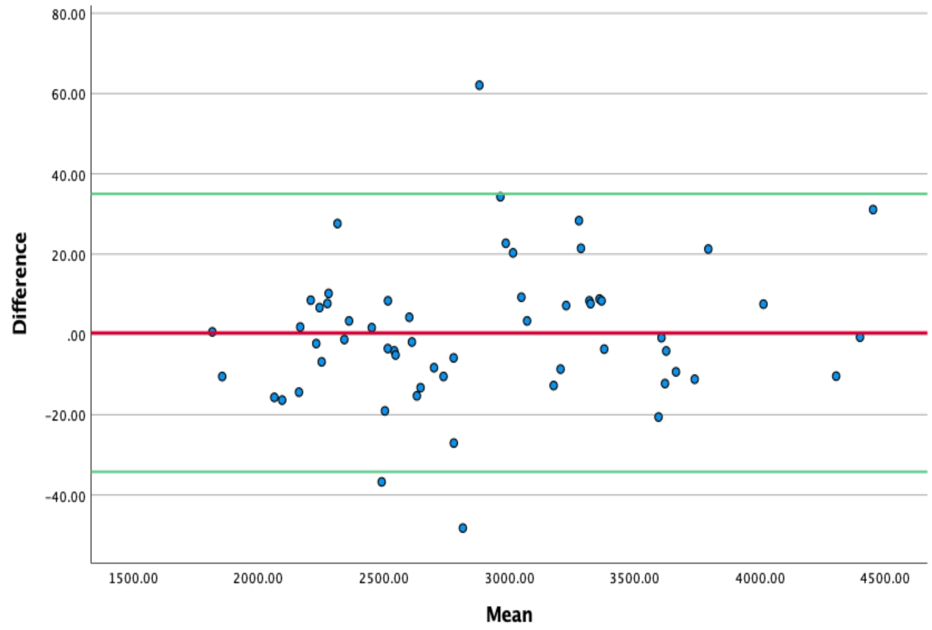

Figure 6. Standard total-body bone mineral content Bland-Altman Plot

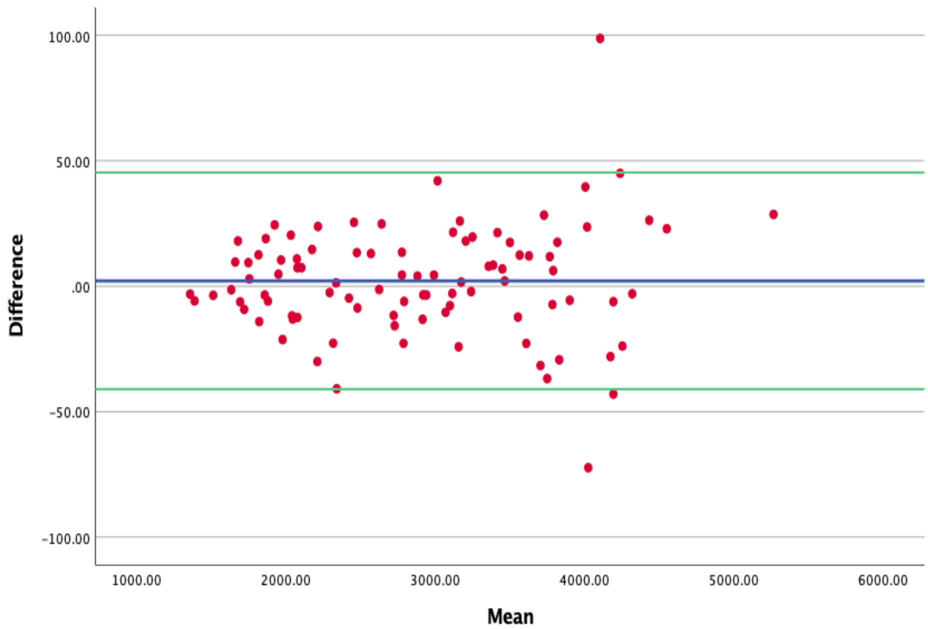

Figure 7. Total-body less head bone mineral content Bland-Altman Plot

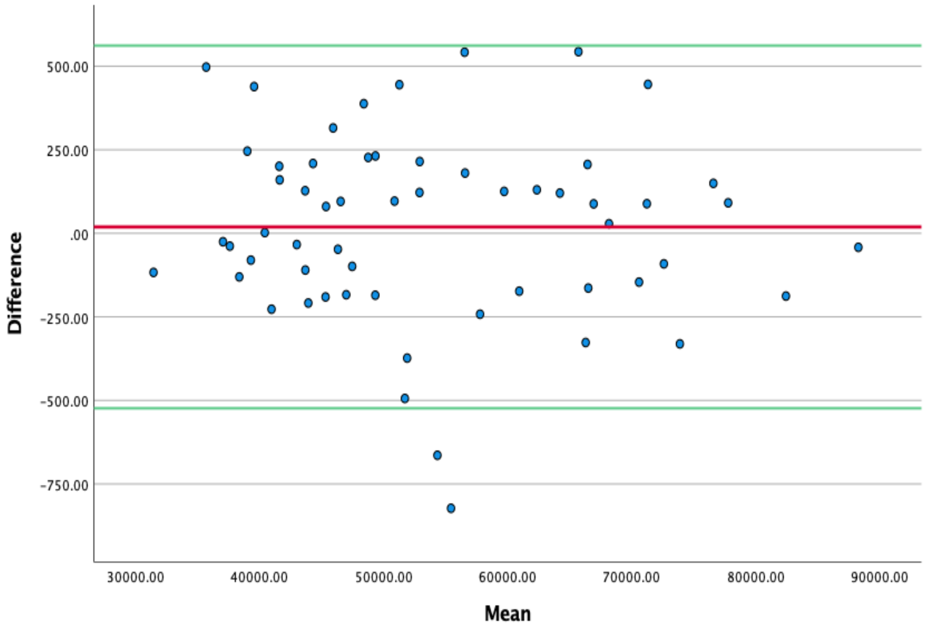

Figure 8. Standard total-body fat free mass Bland-Altman plot

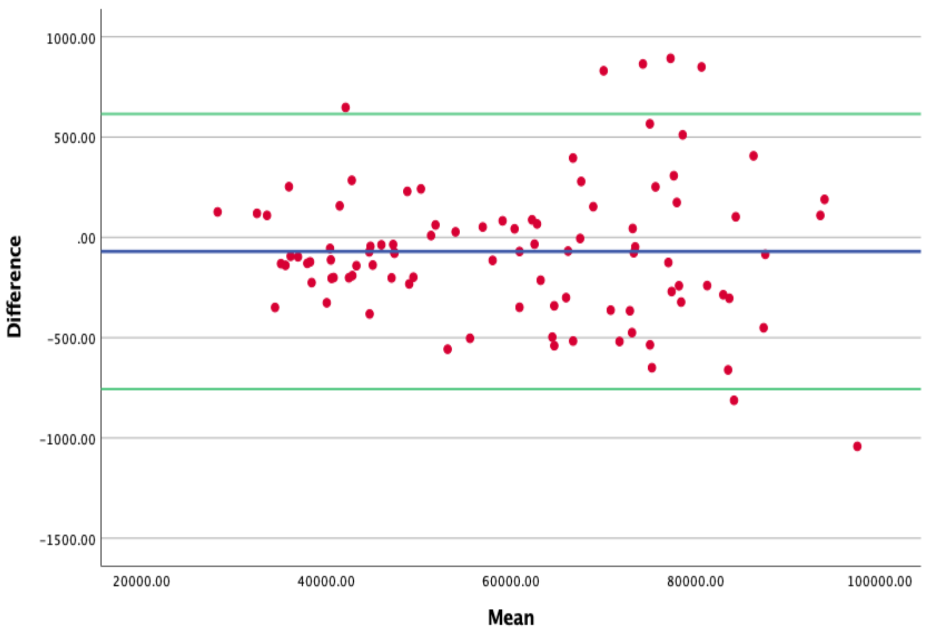

Figure 9. Total-body less head fat free mass Bland-Altman plot

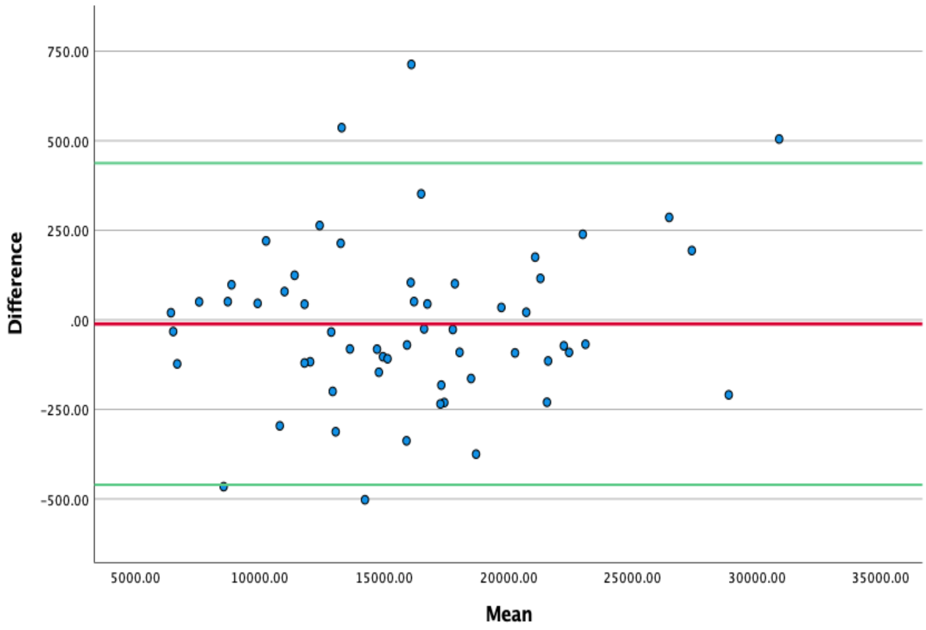

Figure 10. Standard total-body fat mass Bland-Altman plot.

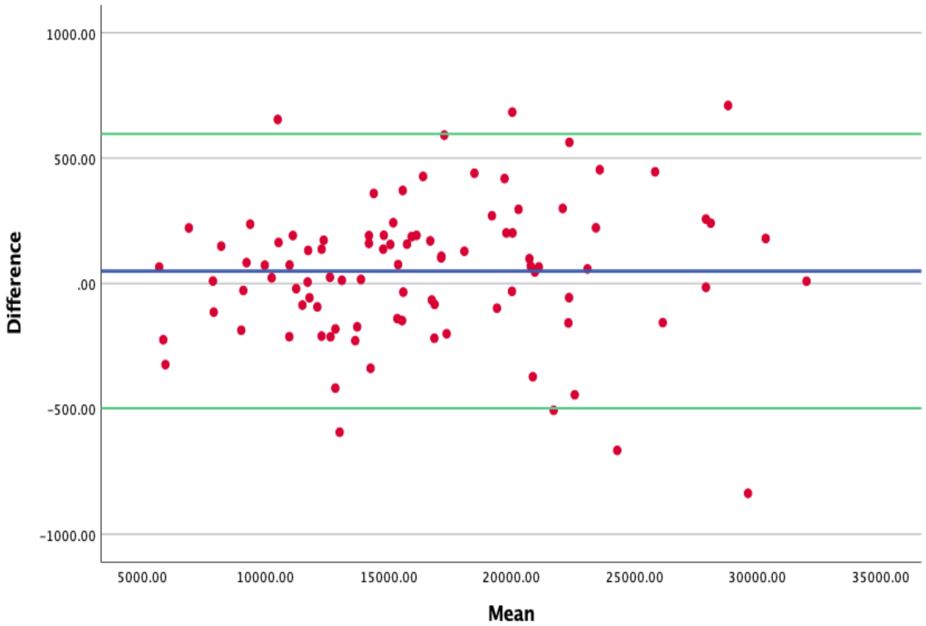

Figure 11. Total-body less head fat mass Bland-Altman plot

Bland-Altman Key:

Red Line = Mean difference for standard total-body

Blue Line = Mean differences for TBLH

Green Line = Upper and Lower Limits

Blue dot = Standard total-body the mean with the difference of the repeated scan

Red dot = TBLH the mean with the difference of the repeated scan

Table 9. Linear regression proportional bias from Bland-Altman plot for standard total-body and total-body less head in athletes, analysing level of agreements between paired measurements

	Standard total-body		TBLH	
BMC	Mean β = 0.005	p = 0.213	Mean β = 0.002	p = 0.424
FFM	Mean β = -0.001	p = 0.621	Mean β = -0.001	p = 0.734
FM	Mean β = 0.006	p = 0.263	Mean β = 0.004	p = 0.366

TBLH = total-body less head, BMC = bone mineral content, FFM = fat free mass, FM = fat mass, β = Beta

4.3 Total body composition precision error

The precision error is represented as %CV and RMS-SD, The least significant change (LSC) is given at 95% confidence intervals (CI).

Precision error (%CV) values for the standard total-body scan outputs (n=58) are presented in Table 10.a and ranged from 0.38 to 1.15 %CV. Precision errors were all less than 1% apart from %BF and FM at 1.15%CV and 1.13%CV respectively (Table 10.a).

Table 10.a. Precision error for standard total body composition GE Lunar iDXA scans in athletes (n=58). Data are presented as the %CV and RMS-SD with corresponding LSC

			LSC - 95% CI	
	%CV	**RMS-SD**	**%CV**	**RMS-SD**
Body Fat (%)	1.15	0.25	3.19	0.68
Fat Mass (g)	1.13	160.78	3.12	445.35
Lean Mass (g)	0.42	202.15	1.15	559.94
Fat Free Mass (g)	0.38	194.45	1.05	538.61
Bone Mineral Content (g)	0.44	12.38	1.21	34.29
Bone Mineral Density (g/cm2)	0.69	0.01	1.90	0.03
Bone Area (cm2)	0.72	15.35	2.00	42.51

The precision results for TBLH body composition outputs (n=95) are presented in Table 10.b and ranged from 0.39 to 1.28 %CV. Precision error was less than 1% for all outputs except %BF and FM, at 1.19 %CV and 1.28 %CV respectively.

Table 10.b. Precision error for Total-body less head GE Lunar iDXA scans in athletes (n=95). Data are presented as the %CV and RMS-SD, with corresponding LSC

			LSC - 95% CI	
	%CV	**RMS-SD**	**%CV**	**RMS-SD**
Body Fat (%)	1.19	0.22	3.31	0.62
Fat Mass (g)	1.28	199.41	3.53	552.38
Lean Mass (g)	0.41	254.30	1.14	704.42
Fat Free Mass (g)	0.39	251.08	1.07	695.49
Bone Mineral Content (g)	0.49	15.57	1.37	43.14
Bone Mineral Density (g/cm2)	0.71	0.01	1.98	0.03
Bone Area (cm2)	0.86	19.20	2.38	53.18

%CV = Percentage coefficient variation, RMS-SD = Root mean square – successive differences, LSC = Least significant change, CI = 95% confidence intervals

4.4 Differences between GE Lunar iDXA total-body and total-body less head body composition outcomes

Comparisons in body composition outcomes between the standard total-body scan and the TBLH scan (taken from measurement 1) in 57 athletes are shown in Table 11. There were significant differences for all outcomes ($p < 0.05$). Reflecting the inclusion of the head region, the standard total-body scans reported greater values for all the body composition variables measured except for %BF. The TBLH application reported 0.13% higher %BF than the standard total-body method. The greatest difference between the two methods was found for FFM.

Table 11. Comparison of total-body and total-body less head body composition outcomes in athletes (n=57) using the GE Lunar iDXA

	Standard total-body	TBLH	Mean difference	*P*
Body fat (%)	23.2 ± 6.9	23.3 ± 7.0	0.13	0.01
Fat mass (g)	15,888.3 ± 5,485.3	15,183.3 ± 5,491.2	705.01	<0.001
Lean mass (g)	50,275.5 ± 12,108.5	46,954.5 ± 11,783.2	3,321.10	<0.001
Fat free mass (g)	53,140.5 ± 12,670.9	49,262.6 ± 12,297.4	3,877.97	<0.001
Bone mineral content (g)	2,864.9 ± 610.4	2,308.1 ± 551.6	556.87	<0.001
Bone mineral density (g/cm2)	1.33 ± 0.15	1.19 ± 0.16	0.14	<0.001
Bone area (cm2)	2,139.9 ± 254.1	1,914.1 ± 235.9	225.6	<0.001

Data are presented as the mean ± SD

4.5 Regional analysis precision error

The precision error is represented as %CV and RMS-SD, The LSC is given at 95% confidence intervals. Results from regional analysis for total-body regional and total-body less head regional analysis are reported in Table 12a and 12b.

Table 12a. Precision error for standard regional body composition from GE Lunar iDXA scans in athletes (n=58).

			LSC - 95% CI	
	%CV	**RMS-SD**	**%CV**	**RMS-SD**

Arms				
Fat Mass	2.63	45.69	7.29	126.57
Lean Mass	1.69	91.42	4.68	253.22
Fat-free Mass	1.62	94.38	4.48	261.42
Bone Mineral Density	2.04	0.02	5.65	0.06
Bone Mineral Content	1.21	4.47	3.35	12.38
Bone Area	2.06	7.80	5.70	21.60
Legs				
Fat Mass	1.50	98.17	4.16	271.94
Lean Mass	1.03	177.51	2.86	491.69
Fat-free Mass	0.97	178.41	2.70	494.18
Bone Mineral Density	1.19	0.02	3.28	0.04
Bone Mineral Content	0.52	5.38	1.44	14.91
Bone Area	1.24	9.17	3.42	25.41
Trunk				
Fat Mass	2.57	154.49	7.13	427.94
Lean Mass	0.97	241.75	2.68	669.66
Fat-free Mass	0.93	241.12	2.59	667.90
Bone Mineral Density	0.78	0.01	2.17	0.02
Bone Mineral Content	1.29	11.31	3.58	31.34

Bone Area	1.15	8.83	3.20	24.47

Table 12b. Precision error for Total-body less head regional GE Lunar iDXA scans in athletes (n=95).

			LSC - 95% CI	
	%CV	**RMS-SD**	**%CV**	**RMS-SD**
Arms				
Fat Mass	1.93	31.91	5.35	88.39
Lean Mass	1.64	77.47	4.53	214.58
Fat-free Mass	1.57	79.64	4.35	220.62
Bone Mineral Density	1.23	0.01	3.40	0.034
Bone Mineral Content	0.93	3.16	2.57	8.76
Bone Area	1.52	5.71	4.20	15.82
Legs				
Fat Mass	1.23	65.01	3.42	180.08
Lean Mass	0.86	138.77	2.37	384.39
Fat-free Mass	0.80	137.82	2.21	381.77
Bone Mineral Density	0.72	0.01	2.00	0.03
Bone Mineral Content	0.49	4.54	1.37	12.58
Bone Area	0.68	4.85	1.88	13.42

Trunk				
Fat Mass	1.86	111.88	5.16	309.91
Lean Mass	0.84	205.87	2.32	570.26
Fat-free Mass	0.81	207.05	2.25	573.52
Bone Mineral Density	0.54	0.01	1.50	0.02
Bone Mineral Content	0.88	7.59	2.44	21.03
Bone Area	0.91	7.00	2.52	19.40

Precision error was greatest for arm region assessment, for both the standard and TBLH method. This was particularly apparent for arm fat mass (standard total-body = 2.63%CV; TBLH =1.93%CV). The lowest precision error for both methods of assessments was for bone mineral content of the legs (standard total body = 0.52%CV; TBLH = 0.49%CV). Regional composition precision error was improved for the TBLH method compared to the standard total body approach. This was especially apparent at the trunk region (TBLH = 0.54-2.86%CV vs. standard total body = 0.78-2.57%CV).

5.0 Discussion

This study had two main aims. First, to investigate the precision of the new GE Lunar iDXA TBLH scan for the assessment of total body composition in athletes. Second, to compare body composition outcomes between the standard total-body scan and the TBLH scan. The precision of both scan types was excellent, with total body composition precision ranging from 0.38 – 1.15 %CV and 0.39 – 1.28 %CV for the total-body and TBLH scan respectively. Regional body composition precision error was lower with the TBLH method. Direct comparison between the two methods indicated differences in derived body composition outcomes between the standard total-body scan and the TBLH scan, with all standard measurements providing greater values than TBLH scans, except for %BF. This study demonstrates that the TBLH DXA scan application can precisely measure body composition in athletes. However, if centres were to adopt the TBLH as default, then new baseline measurements would need to be performed for TBLH, due to the significant differences in body composition measurements compared to the total-body method. Similarly, any previous assessments implementing the standard total-body application cannot be compared with assessments made using the TBLH scan.

5.1 Precision

This study reported total and regional body composition precision derived from repeat measures for total-body and TBLH techniques, utilising a same-day scan approach. This consisted of test-retest with re-positioning between each scan, providing a total of four body composition scans per participant. Body composition values from the paired measurements for both the standard total-body and the TBLH scan, were comparable between measurement 1 and measurement 2 (Table 8.a. & 8.b.). Kerr et al., (2016) reported mean differences for repeated measurements in a healthy adult population, results for FM = 71 g, LM = 47 g and BMC = 4 g, using the standard total-body scan in the current study, the mean differences were less: FM = 11.2 g, LM = 18.8 g and BMC = 0.4 g, and for TBLH repeated measurements, FM = 49.7 g, LM = 72.2 g and BMC = 2.2 g.

In the current study, precision error was lowest for total FFM in both total-body (CV%: 0.38%) and TBLH application (CV%: 0.39%). The highest total body precision error for standard total-body was %BF (1.15 %) and for TBLH was FM (1.28%), but this is still within acceptable limits for precision error: FM = 3 %, LM = 2 % and %BF = 2 % (Hangartner et al., 2013). This study is also in agreement with previous research that reported precision error for LM was lower compared to FM, and that regional precision errors were higher than total precision errors (Hind et al., 2011; Beuhring et al., 2014; Bilsborough et al., 2014; Barlow et al., 2015; Thurlow et al., 2015; Kerr et al., 2016; Farley et al., 2020).

The results of the current study are comparable to those reported by Beuhring et al., (2014). The authors studied a similar sample of athletes from a variety of sports, and, the precision error was 0.3%CV for LM and 1.5%CV for FMThese results suggest that results are comparable, this may be due the study sample being similar to the current research. Barlow et al., (2015) reported greater precision errors for LM = 1.6 %, FM = 2.3 % and BMC = 1.7 %, which is likely explained due to the study sample specifically focusing on high performance rugby players and not across a range of sporting disciplines.

When comparing the results to average population, Hind et al., (2011) reported DXA (GE Lunar iDXA) precision error for adults, LM = 0.5 %, FM = 0.8 % and BMC = 0.6 %. Similar results to this study, apart from FM, precision error was lower for the non-athletic population. The TBLH precision was as follows: FM = 1.28 %, LM = 0.41 % and BMC = 0.49 % (Table 10.b.). Santos et al., (2013) investigated precision errors in athletes for multiple sporting disciplines. Precision error for FM = 3.70 %, LM = 1.09 % and BMC = 1.04 %, these three-precision errors for total-body scans are higher than the TBLH application in this study. When the TBLH precision error was compared with results from a single sporting discipline presented by Bilsborough et al., (2014), which researched Australian football players. Precision error for FM = 2.5 %, LM = 0.3 % and BMC = 0.6 %, providing similar results for LM and BMC with TBLH precision errors, whilst the FM results are significantly higher compared the current study. Rothney et al., (2012) reported precision errors in non-obese adults, FM = 1.0 % and LM = 0.5 %. These results are comparable to the precision error produced by the TBLH application in the current study, with LM more precise than FM. However, results for FM precision error in a non-athletic population are lower than an athletic population, except in an obese population (Hind et al., 2011; Rothney et al., 2012).
In summary, this is the first study to report precision error for the new TBLH DXA application in comparison with the standard total-body scan. The precision error for both methods was excellent, supporting use in athletic populations.

5.2 Differences in precision between the standard total-body scan and the TBLH scan

The new TBLH scan was found to have similar precision as the standard total-body scans in athletes (Table 13).

Table 13. Comparison of precision error presented as %CV, between total-body and total-body less head application in athletes

	Total-Body (%CV) (n=58)	TBLH (%CV) (n=95)
Percentage body fat (%)	1.15	1.19
Fat mass (g)	1.13	1.28
Lean mass (g)	0.42	0.41
Fat free mass (g)	0.38	0.39
Bone mineral content (g)	0.44	0.49
Bone mineral density (g/cm2)	0.69	0.71
Bone area (cm2)	0.72	0.86

%CV = Percentage coefficient variation, TBLH = Total-body less head

The results presented in this study indicated that total-body and TBLH application are unable to interchange, this is in agreement with previous research studying two different assessment protocols (Kerr et al., 2016). However, studies researching the difference between prone and supine position for the assessment of body composition using DXA, suggest that results of the two separate methods are interchangeable (Lambrinoudaki et al., 1998; Lohman et al., 2009). Lohman et al., (2009) found excellent repeatability in repeated measurements in the supine position, however found that the comparison between supine and prone scan repeatability to be slightly poorer. In comparison to this study the total-body to TBLH scan repeatability were significantly different.

Lambrinoudaki et al., (1998) investigated the difference between DXA scans implementing a full body supine and full body prone positioning. Results showed that the full body prone position reported lower values for BMC and FM measurements and higher values for LM measurements, in comparison to full body supine. The results from the study are illustrated in

Figure 12, which directly compares to full body supine and full body prone values. *Figure 12* also compares the differences for measurement 1 LM, FM and BMC, between total-body and TBLH application. This graph indicates that measurements for LM is greater for the total-body application compared to the TBLH application. Similar results were reported by Lambrinoudaki et al (1998), where LM had the greatest difference in comparison to BMC and FM, between full body supine and full body prone positions. This comparison between the two studies, suggests that LM is greater influenced that FM and BMC, when a new DXA protocol is utilised.

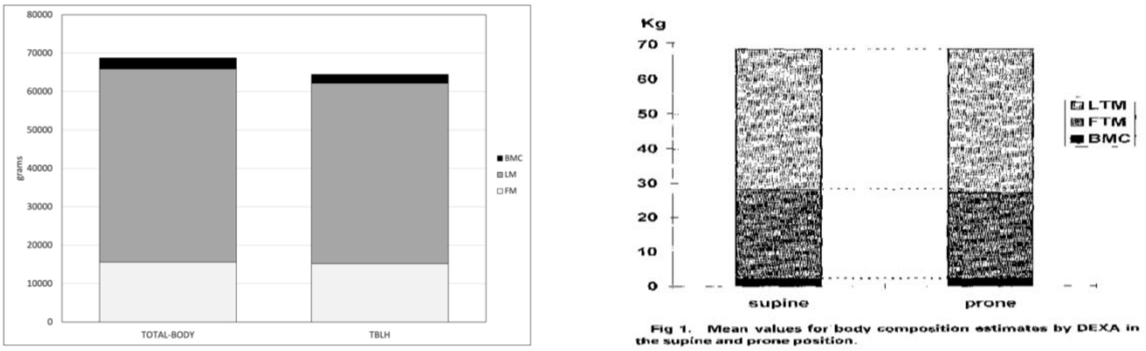

Figure 12. Mean values for body composition variables measurements for total-body and TBLH & Figure 1. Derived from Lambrinoudaki et al., (1998)

This study compared precision error between total-body and TBLH DXA scans, there is limited directly comparable published data. However previous research data is available that provides data of scans that excluded the head (Table 14).

Table 14. Lambrinoudaki et al., (1998) difference in mean body composition measurements between total-body and head excluded

	Total-body	**Head excluded**	**Mean difference**
Percentage body fat (%)	37.4	39.1	1.7
Fat mass (g)	25,949	25,128	821
Lean mass (g)	40,381	38,246	2,135
Bone mineral content (g)	2,231	1,738	493

Values for total-body and head excluded reported in Table 2 of Lambrinoudaki et al., 1998, mean difference calculated separately.

Table 14 shows results calculated from the data presented by Lambrinoudaki et al., (1998). This research did not aim to investigate TBLH scans, however, calculating the mean differences in body composition variables between total-body and TBLH enabled direct comparison to be made (Table 10) (%BF = 1.7 % vs 0.3 %, FM = 821 g vs 705.01 g, LM = 2,135 g vs 3,321.10 g and BMC = 493 g vs 556.87 g) (Lambrinoudaki et al., (1998) vs present study). The comparison highlights a difference in the mean differences for %BF and LM, with similar results for FM and BMC between the two studies. An explanation for the clear differences between Lambrinoudaki investigated healthy adults and this study investigated athletes. Referring to *Figure 12*, LM has the greatest difference between total-body and TBLH application, in this study when the head was excluded LM decreased by 4.71 times compared to FM (3,321.10 / 705.01 = 4.71) and LM decreased by 5.96 times more compared to BMC (3,321.10 / 556.87 = 5.96).

5.3 Differences in body composition outcomes between the standard total-body DXA scan and the TBLH DXA scan

This was the first study to directly compare the standard total-body DXA and the TBLH DXA scan for the assessment of body composition in athletes. The two techniques were directly compared by identifying the mean differences between standard total-body measurement 1 and TBLH measurement 1, body composition variables (Table 11). The paired sample t-test indicated that there was a significant difference between the two methods for all body composition measurements. The results suggests that the head has an influence on body composition assessment. When the two methods of assessment were directly compared, results reported that the measurements for all body composition variables were significantly different ($p < 0.05$). BMC, LM and FM were greater for the standard total-body scan compared to the TBLH scan (Table 15).

Table 15. Differences in total body composition outcomes from the TBLH and standard total-body scan in athletes (n=57)

Body composition variable	Mean difference
Body fat (%)	0.13
Fat mass (g)	705.01
Lean mass (g)	3321.10
Fat free mass (g)	3877.97
Bone mineral content (g)	556.87
Bone mineral density (g/cm2)	0.14
Bone area (cm2)	225.59

The mean differences were: FFM = 3,877.97 g, FM = 705.01 g and BMC = 556.87 g, reflecting the contribution of the head region to standard total-body composition outcomes. There is very little research available on DXA-derived composition of the head region which comprises the cranium, brain, meninges, cerebrospinal fluid (CSF) and musculature. The meninges lay between the skull and the brain and are made up of three layers of tissue, dura matter, arachnoid matter, and pia matter, which protect the brain. The brain is protected by CSF, this is a watery fluid that cushions the brain and the spinal fluid. The cranium is made up of 22 bones, having two regions, the neurocranium and the viscerocranium (Bradley et al., 2021). The head also consists of striated muscle under voluntary innervation - these muscles are used for facial expressions and give the ability to speak (Westbrook et al., 2021). The present study adds to existing knowledge on the imaged composition of the head, indicating that the head is predominantly imaged as fat free mass. Further research is needed to investigate if DXA-derived composition of the head region is static or changes in response to varying hydration for example.

In terms of scan procedure, the TBLH scan begins at the mandible and this is achieved by positioning the scanner arm laser directly above the chin. This ensured that the neck muscles were included in the DXA image. The trapezius is a major neck and shoulder muscle, that has different blood supply, muscle fibres and the mitochondrial distribution (Lindman et al., 1990); Eriksson et al., 1999). Athletes who engage in strength training, may have interest in the lean mass of this region, particularly in sports such as rugby, where neck strength is important (Yamada et al., 1989; McCormick & Schultz, 1992). Currently, DXA does not provide a separate region of interest for the neck, but this would be possible with the head in the frankfort plane and with both the standard and the TBLH scan.

5.4 Rationale for the use of the TBLH scan in athletes

The TBLH application may have advantages in a specifically athletic population. Firstly there is less radiation exposure due to a reduction of scan duration. A total-body DXA radiation exposure is generally accepted for being low, as one standard total-body scan is 2 uSv (Public Health England, 2013). However, any reduction of radiation is advantageous, to align with the 'as low as reasonably practicable' (ALARP) guidance directing radiation protection protocols (IRMER and IRR17; CQC, 2022). The reduction in radiation exposure utilising the TBLH method is important, especially for individuals or sports teams that are longitudinally monitored.

Secondly, certain sporting disciplines require athletes to have a tall stature (basketball and rugby), taller athletes may exceed the DXA scan boundaries for total-body application (Nana et al., 2012; Santos et al., 2013). Previous studies, Nana et al., (2012) and Santos et al., (2013) researched whole-body DXA scans for taller individuals, the method for this was the sum of two-three partial scans. Results indicate accurate estimation utilising this method; however, this technique is time consuming in comparison to one TBLH scan. The TBLH scan allows participants >195 cm to fit in the scan boundary and provides accurate measurements for meaningful body composition components. This in turn allows for standardised procedures for all athletes, especially within sports teams that have a range of different heights.

Thirdly, it could be hypothesised that the TBLH may be more relevant to measure the development of body composition, due to the head composition being more static (cortical bone of the cranium and constant tissue of the brain and fluid) and thus not changing with a training/diet intervention. There is currently no published research on the effects of training and diet interventions on the composition of the head region. The head composition is mainly identified as FFM, however the brain is a different organ to LM and has high cortical bone composition of the cranium.

Fourthly, technical differences between paediatric (under 20 years) and adult DXA scans are worth consideration when monitoring growth and development in athletes. TBLH body composition is the standard output for under 20's and the ISCD official paediatric position (2013) recommends the TBLH and posterior-anterior spine as the scan sites for individuals under the age of 20 years. Crabtree et al., (2017) reported sex and ethnic reference ranges for TBLH BMD. In relation to the present study, athletes usually start their competitive sports career before 20 years. In some sports individuals perform on a competitive level before 10 years, this is known as the initiation stage, then moving into the development stage and finally starting the mastery stage of the sporting discipline at 18 – 19 years (Wylleman et al., 2010). If the TBLH approach is only used for athletes under 20 years, comparisons with scans made post 20 years of age (standard scan, including the head) are not valid. However, if TBLH was implemented for the assessment of body composition measurement across all age groups, TBLH (not standard total-body) baselines are important.

Given that athletes at the highest level are at optimal physique, changes in body compositions after an intervention will be small, because the body is close to maximum adaptation. If the head does not develop throughout an intervention and it then becomes a common denominator, this will make it harder to identify the meaningful changes in body composition. When the head is removed, percentage increase or decrease will increase, allowing practitioners to identify if a strength and conditioning or a diet has been successful or not.

5.5 Study considerations

The current study utilised the same-day scan approach which produces lower precision error than consecutive day assessment. Up to 25% greater error has been previously reported using the consecutive day approach (Farley et al., 2020). Zemski et al., (2019) also found greater precision error with consecutive day scanning (FM: 1,216 g vs 660 g; LM: 2,083 g vs 617 g). The greater variability with consecutive day scan measurements is likely attributed to biological variation and technical error. While this study reported superior precision for the standard total-body scan and the TBLH scan, it should be considered that this was for same day scans and not consecutive scans.

A further consideration for this current study is that the total sample size was greater than for previous DXA precision studies in athletes (n = 12 – 60; Table 16). Precision studies are required to have a duplicate measure on a minimum of 30 participants or a triplicate measure on 15 participants, following ISCD guidance (2013) (Hind et al., 2018). Reflecting this, the average sample size for previous precision studies is n = 33. A larger sample size provides confidence in the results for precision error and repeated measures.
day scans and not consecutive scans.

Table 16. Published DXA precision studies in athletes (2013 to 2020)

Study	n	M	F	Age (yr)	Sport
Jones et al., 2021	97			16 - 60	Mixed disciplines
Behring et al., 2013	60	30	30	M = 18.3 - 23.4, F = 18.1 - 22.7	Mixed disciplines
Barlow et al., 2015	45	45	0	21.8 ± 5.4	Rugby
Zemski et al., 2019	39	39	0	25.7 ± 3.1	Rugby
Bilsborough et al., 2014	36	36	0	22.7 ± 3.0	Australian football
Thurlow et al., 2018	38	38	0	27.1 ± 12.1, 18 - 59.9	Physically active
Farley et al., 2020	32	32	0	31 ± 7	Resistance training > 2 yr
Santos et al., 2013	31	13	18	16 - 55	Mixed disciplines
Tinsley et al., 2020	27	17	10	M = 26.0 ± 6.5, F = 25.8 ± 5.4	Resistance training > 3 yr
Zemski et al., 2019	21	11	10	N/A	Resistance training >1 yr
Nana et al., 2016	21	21	0	20.2 ± 1.6	Cyclist
Keil et al., 2016	12	12	0	31 ± 7	Wheelchair basketball

The study sample in this research included both sexes, which was representative of the population usually scanned at this centre. Male and female naturally have wide differences in body composition which varies significantly between the two sexes (Bredella et al., 2017).

Previous research reports that the majority of studies only include male athletes. Similarly, Hind et al., (2018) reviewed literature focusing on precision error from 1980 - 2013 and identified that only 25 studies were accepted by the review's inclusion criteria. Out of these 25 studies only 3 studies were female only, 12 males only and 10 included both sexes. This highlights a lack of research specifically on female athletes. Several studies have included both male and female athletes (Santos et al., 2013; Behring et al., 2014; Zemski et al., 2019; Tinsley et al., 2020).

This research also included a wide range of sporting disciplines, this was done in accord with ISCD guidance that the study population should be similar to those usually scanned at the centre - so that precision is relevant and useable (Hangartner et al., 2013). The variety of sports gave the opportunity to measure different types of physiques (Table 15). The majority of previous DXA precision investigations in athletes have focused on a single sport, such as rugby, cycling and football (Bilsborough et al., 2014; Barlow et a., 2015; Nana et al., 2016; Lees et al., 2017).

5.6 Implications and future research considerations

This current research reported valid precision errors for TBLH body composition variables, providing values that correlate with the current standard total-body scan precision errors.

After extensive scanning it was quite evident that the precision and validity could be improved in the future through positioning, study sample size and best practice adherence.

The TBLH application needs an adjustment to accurately line up the start position. Throughout the assessment of the TBLH application, the start position was always manually positioned to the centre of the chin between the participants bottom lip and mandible. This created room for technical error, as there was no focus point to accurately achieve a repeatable start position. A simple laser or reference markers on the scanning arm would improve this, and thus reduce potential technical error, similar to the approach used on a hip or AP spine scan.

A potential improvement for future work comparing total-body and TBLH application, would be performing an equal number of repeat measurements techniques. This study provided precision error results from a total of 95 participants for TBLH and 58 for total-body techniques. For future work these numbers would ideally be the same, to get a direct comparison. However, for this current study the number of participants with duplicate measures (58) for both methods still exceed the required value needed for a precision study (Hangartner et al., 2013).

Due to COVID-19 government guidelines the opportunity for data collection was reduced, scanning did not start until June and ended on the first week of August. In addition, access to the imaging suite was limited to weekdays, resulting in only a month based on selective days to scan participants. Typically, some participants had late afternoon appointments, therefore making an overnight fast impossible, instead these participants had pre-scan guidance which instructed no food intake 5 hours prior to the appointment. However, it is well documented that overnight fasting is the best-practice pre-scan guidance, hopefully any future precision studies will have less time constraints and the standardised protocol can be fully implemented for all participants (Nana et al., 2016), thus improving precision errors.

It should also be considered that traditional body composition assessment methods (BIA, skinfolds, air displacement) cannot be compared to DXA as the criterion method, if TBLH is implemented. As discussed in the literature review (2.5), other body composition methods of assessment make assumptions which include the head, for the estimation of body composition variables. In athletes, the standard total-body DXA scan is widely accepted as the criterion method, for the assessment of FM and FFM (Stewart & Hannan, 2000). This is a potential reason why practitioners may prefer to continue utilising standard total-body scans, so that previous body composition data using BIA, skinfolds or air displacement can be compared to the standard total-body technique.

This study provided precision errors for regional analysis of body composition derived from the standard total-body and TBLH approach. Results for this analysis identified that precision error from both applications were higher when measuring the arm region. This may be caused by the set-up position before starting the scan, arm position must consistently be set in the mid-prone position, however, participants throughout the scan may move due the arms not be strapped in position. Another similarity highlighted in the regional analysis was the lowest precision error score for both methods was generated when measuring the bone mineral content of the legs.

Regional composition precision error was consistently lower for the TBLH method compared to the standard total body approach. The lower precision error was especially apparent at the trunk region (TBLH = 0.54 - 2.86 %CV vs. standard total body = 0.78 - 2.57 %CV). This may reflect a greater accuracy when using the TBLH approach for deriving trunk regional assessment. With the TBLH scan, the scanner arm is manually positioned to the edge of the mandible. The leg region had the least difference in precision error results between the two methods of assessment. The leg starting position is consistent for both approaches and utilises the Velcro straps to support consistent positioning, for both methods.

An important area of interest for future work utilising the TBLH application is to investigate longitudinal changes in body composition across a sporting season. The research could implement both total-body and TBLH techniques, then directly compare percentage changes after various competition and interventions. This research could determine if the TBLH application can identify more meaningful changes, as a result of the head being removed from assessment. The current study only reported the precision error and repeat measurements for these techniques at one point in time, not multiple measurements across a prolonged period of time. Additionally, future research in the assessment of head composition, where a longitudinal study could be applied, aiming to establish any changes of the head composition throughout an intervention.

6.0 Conclusion

In conclusion, this study found that total-body less head DXA scans yield similar precision errors for assessments of total body composition compared to those derived from standard total-body DXA scans. Further, the total and regional precision errors for both methods of assessments were well within acceptable ranges recommended by the ISCD. The results from this study indicate that precision error for the TBLH DXA is acceptable for the assessment of body composition in an athletic population and is superior for the assessment of regional composition. Measurements for LM, FM and BMC were significantly different between TBLH scans and standard total-body scans. The effect of exclusion of the head region resulted in significantly lower LM, BMC and FM.

The TBLH scan may be particularly useful for monitoring body composition in athletes due to the exclusion of the head which reduces scan time and suitability for assessments in taller individuals. However, new baseline measurements should be performed utilising the TBLH method to ensure consistency and validity of longitudinal measurements for athlete body composition monitoring. Finally, previous body composition assessments implementing the standard total-body application should not be compared with assessments using the TBLH application.

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Appendix A: Participant information sheet

Durham University

Department of Sport and Exercise Sciences

Study title

Participant Information Sheet

Evaluation of the total-body-less-head dual energy X-ray absorptiometry (DXA) scan for bone and body composition assessment

Section 1 - Background

Invitation and brief summary

You are invited to take part in this study which aims to evaluate a new dual energy X-ray absorptiometry (DXA) scan application to measure bone density and body composition. The study will compare the standard total-body DXA scan with the new total-body-less-head scan. We will examine how precise the new scan is compared to the standard scan and what the differences are in measured outcomes (lean mass, fat mass and bone density). We will also explore if the new scan can predict bone density at the lumbar spine and femur (hip) and so identify people who may be at risk of low bone density.

Why have I been invited to take part?

You have been invited to take part in this study because you are aged between 18 and 60 years. We are recruiting to two main groups - athletes (competing at club level or above) and non-athletes (not involved in competitive sports).

Do I have to take part?

The decision to take part in this study is completely up to you and should you decide to take part, you are free to withdraw at anytime without giving a reason. If you decide to take part, you will be given this information sheet to keep for your further reference and you will be asked to sign a consent form at your appointment. You will be able to ask questions at any time before, during or after the study.

Why are you doing this research?

DXA is recognised as the 'gold standard' method for the measurement of bone and body composition. We are doing this research to evaluate a new DXA scan application: total-body-less-head. The standard total-body DXA scan includes the head region. However, the head is a generally static region of the body in terms of lean mass and bone mass and therefore it will not change significantly in response to exercise, diet or other factors.

Our first aim is to identify the precision of this new scan, and we will directly compare it to the standard total-body scan. Our second aim is to find out if the new scan is better able to predict bone density at the lumbar spine and femur, which are areas of the body that are scanned for the clinical assessment of bone density. On the basis of this study, we will be able to make recommendations for the use of this new scan in practice.

What is involved?

If you would like to take part in this study, you will be invited to attend one appointment at the Sports and Wellbeing Park at Maiden Castle, Durham University, DH1 3SE.

This appointment will involve:

- • measurement of height, weight and waist circumference,
- • 1 x bioelectrical impedance assessment (BIA) of body water and body composition (~10 seconds).

  The BIA device is a stand on system, which involves holding the hand grips while a very small electric current is transmitted through your body to assess body composition. This is the standard device used in gyms.

- • bone and body composition DXA scans as follows:
  - 1 - 2* x standard total-body scans (7 - 14 minutes per scan)
  - 1 - 2* x new total-body less head scans (7 - 14 minutes per scan) - 1 x lumbar spine scan (1 minute)
  - 1 x total hip scan (<1 minute)

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* If you agree to take part in the precision part of the study you will receive 2 x total-body and 2 x TBLH scans.

The DXA machine is a GE Lunar iDXA (GE Healthcare, Madison, WI) (please see figure 1 overleaf)

Figure 1. DXA scanner, Truscott Imaging Suite, Maiden Castle.

The DXA scans involve lying on a couch, while the DXA scanner moves over your body (without touching it and with little noise). The DXA assessments will be performed and interpreted by a trained densitometrist. All scans will be overseen by Dr Karen Hind who has 18 years experience in DXA and is a certified clinical densitometrist.

The appointment will last around 45 - 90 minutes and free parking is available on site.

What are the possible benefits of taking part

The benefits of taking part in this study include receiving information about your body composition, bone density. You will be able to take a copy of your DXA results home with you. This research will also contribute wider benefits to society through increasing knowledge about the new DXA scan technique.

What are the possible risks of taking part?

There is a small dose of radiation associated with DXA.
The total amount of radiation for participation in the complete study (including precision study- repeat total

body and TBLH scans) is 21uSv. This is similar to 3 days of natural background radiation (22uSv). The dose for completion in the study (without the precision study) is 17uSv. This is 2½ days of natural

background radiation (18uSv) .

The dose associated with participation in this study has been formally assessed by a Medical Physics Expert and a Clinical Radiation Expert. We will not perform a DXA scan on you if you are a woman who is pregnant or if you suspect that you may be pregnant. If you are a woman of child-bearing potential ('child-bearing potential' excludes the following: i) abstention, ii) using a recognised contraception, iii) confirmed medical conditions whereby you do not have periods and are unable to become pregnant) you will be asked to confirm your pregnancy status prior to the scans by taking a pregnancy test.

What steps are being taken for preventing the spread of Covid-19?

If, within 14 days prior to your appointment, you have experienced any symptoms of Covid-19 or have been in close contact with anyone who has tested positive for Covid-19, you must not attend. Instead, you should rearrange for a later date. We are maintaining a list of all visitors to the research site in order to support the 'track and trace' system.

During your appointment, a distance of 2 metres will be observed between the researcher and yourself apart from when the physical tests are carried out. Hand hygiene will be followed at all times and hand sanitiser

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stations are in place and the researcher team will wear a face covering. A face covering should be worn when in the University building, unless you are exempt from wearing a face covering. All equipment will be sanitised between appointments.

Section 2 - Supporting information

What if something goes wrong?

All procedures used in this study are routinely conducted in our research centre and our researchers are highly skilled. In the unlikely event of you experiencing any problems that may be caused by this study, please tell us immediately and we will do our utmost to address these.

What if I don't want to continue with the study?

You are free to withdraw from the study at any time until the results have been submitted as a research paper for publication. If you decide to withdraw from the study, we will remove your data.

Will my taking part in the study be kept confidential?

All data collected will be kept strictly confidential. Any information that leaves Durham University will have names and addresses removed so that you cannot be recognised from it. In spreadsheets, your data will be coded and no names will be used.

What will happen to the results of the study?

The results will be analysed and written up for publication in medical and/or scientific journals and for conference abstracts and presentations.

Who is organising, conducting and funding this study?

This study is organised and managed by Dr Karen Hind in the Department of Sport and Exercise Sciences at Durham University. The research team involves Dr Caroline Dodd-Reynolds, Dr Lindsay MacNaughton, Mr William Jones and Miss Annie Williams.

Who has reviewed the study?

This study has been reviewed by the Durham University and NHS research ethics committees.

Section 3 - Data Protection and GDPR

This section explains how we will collect, store and use information provided in line with GDPR.

What type of data will be collected? Personal data will be recorded and held confidentially in secured storage. This data will be your name and email address, linked to your participant code. Data stored on the DXA scanner PC will include your participant code, date of birth, ethnicity, height, weight, waist circumference, body composition, and bone density. The DXA scan also generates an image of your body/region scanned. You are not able to be identified from these images. The data will be collected on the lawful basis through provision of participant consent.

How will my data be stored and processed? All data will be kept strictly confidential. The data collected will be stored in coded form on the DXA computer which is password protected and in a controlled access room. Data will also be stored electronically and this will be coded. These data will therefore be anonymous. Information that identifies you will be stored separately, electronically and on a password protected computer. This document will only be available to the researchers named on this information sheet.

The data collected for the DXA scan (including your participant code and date of birth) will be stored on the DXA computer which is password protected and in a controlled access room. The file for this project will have an additional password. Only authorised staff and postgraduate researchers have access to this room. Only the direct research team will know the project file password. The consent form will include your name and will be stored in paper version in locked storage in Durham University. We will hold identifiable data for up to 10 years. After this point, personal identifying information will be destroyed.

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How to object to the processing of your personal data: If you have any concerns regarding the processing of your personal data, or you wish to withdraw your data from the project, please contact the Lead Investigator.

Section 4 - Further information and contact details:

If you have any questions related to this study or your participation, please contact the Lead Investigator:

Dr Karen Hind, email karen.hind@durham.ac.uk.
Address: Department of Sport and Exercise Sciences, 42 Old Elvet, Durham, DH1 3HN.

Independent contact/Sponsor: Mr Niall O'Loughlin, Head of Research Policy, Research and Innovation Services, Durham University, Mountjoy Centre, Durham, DH1 3LE. Email; niall.c.o'loughlin@durham.ac.uk

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Appendix B: Consent form

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IRAS ID: 293387 Participant Identification Number:

CONSENT FORM

Title of Project: Evaluation of the total-body-less-head dual energy X-ray absorptiometry application for bone and body composition assessment

Please initial box

1. I confirm that I have read the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.
3. I understand that the information collected about me may be shared anonymously with other researchers.
4. I understand that the information held and maintained by Durham University may be used to help contact me.
5. I understand that I will be advised to contact my General Practitioner if my results indicate low bone density.
6. Women participants: I confirm that I am not pregnant and I do not suspect that I am pregnant. I confirm that I am not of child-bearing potential (please see definition in the Participant Information Sheet).
7. I agree to take part in the study
8. OPTIONAL I agree to take part in the precision part of the study which involves a repeat total-body and total-body less head scan.

Name of Participant Date Signature

Name of Person Date Signature taking consent

Appendix C: Pre-scan guidance

Durham University

Department of Sport and Exercise Sciences

Important Information

Pre-DXA Scan Preparation Guidance

The following pre-scan preparation protocol ensures that your DXA scan results will be as accurate as possible.

Please follow this guidance before attending your DXA scan appointment and if you have any questions, please contact: Dr Karen Hind karen.hind@durham.ac.uk.

- • □My appointment is before 11am = Please fast overnight (last meal no later than 10pm)
- • □My appointment is 11am or later = Please fast for 5 hours prior to your scan appointment
- • □Drink 500ml of water 2 hours before your appointment
- • □No moderate-vigorous exercise in the 12 hours before your appointment
- • □No caffeine in the 5 hours before your appointment
- • □No alcohol in the 24 hours before your appointment
- • □Please wear /bring light weight, close-fitting clothing that does not contain metal, underwire, plastic or reflective strips. Ideal clothing could lightweight shorts and t-shirt.

  A drinking water station (single use cups) is available for you to use following your scan.

  Please bring a snack with you for after your scan.