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ORIGINAL ARTICLE

Abdominal adiposity distribution in elite rugby union athletes using magnetic resonance imaging

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Abstract

Purpose This study aimed to assess visceral adipose tissue (VAT), an established marker for cardiometabolic complications, in elite rugby union athletes, with specific consideration given to ethnicity. The ability of dual-energy X-ray absorptiometry (DXA) to estimate VAT in athletic populations compared to the criterion magnetic resonance imaging (MRI) was also explored.

Methods Thirty elite male rugby union athletes (age 23.9 ± 4.0 years; stature 186.7 ± 7.0 cm; mass 101.9 ± 11.2 kg) underwent assessment via DXA for body composition, and MRI for abdominal adiposity, at the start of the pre-season training period. Participants were ascribed a specific ethnicity when three or more of their grandparents were of either Caucasian or Polynesian descent.

Results MRI VAT did not differ between ethnicities (Caucasian 92.7 ± 26.7 cm^2; Polynesian 86 ± 27.3 cm^2; $p = 0.52$); however, there was a trend for forwards (96.7 ± 25.0 cm^2) to have higher VAT than backs (81.7 ± 27.3 cm^2; $p = 0.13$) which provides an area of interest for researchers. Thirty-seven percent of athletes (eight forwards, three backs) were found to have VAT > 100 cm^2, a threshold for increased cardiometabolic risk within the general population. Bland–Altman analysis indicated that DXA VAT underestimated MRI VAT by ~ 25 cm^2, with relatively wide limits of agreement (− 24.0 to 75.6 cm^2).

Conclusions Given the size of rugby union athletes, and the association between elevated VAT and cardiometabolic complications in "supersized" athletes from other sports, further investigation into VAT and other markers of cardiometabolic disease in rugby union populations is warranted. Further, DXA was found to underestimate VAT compared to the criterion MRI in this athletic population.

Keywords Polynesian · Caucasian · Obesity · VAT · Body composition · Ethnicity

Abbreviations

ANOVA	Analysis of variance
BMI	Body mass index
CV	Coefficient of variation
DXA	Dual-energy X-ray absorptiometry
ICC	Interclass correlation coefficients
MRI	Magnetic resonance imaging
NHANES	National Health and Nutrition Examination Survey
NFL	National Football League, American (gridiron) football
ROI	Region of interest
SAT	Subcutaneous adipose tissue
SD	Standard deviation
VAT	Visceral adipose tissue
VAT:SAT	Visceral adipose tissue to subcutaneous adipose tissue ratio

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Introduction

Rugby union is a high-contact, dynamic, field-based team sport in which athletes have a diverse range of physical attributes. This makes rugby union an atypical sport due to the heterogeneity of physique traits and physical

performance characteristics [1]. Backs are required to control possession of the ball and create scoring opportunities, whilst providing cover in defense, with speed, acceleration and agility being among their most important physical attributes [2]. In contrast, forwards are in continual close contact with opposition players, and need to be strong, powerful and robust to gain and retain possession of the ball. Indeed, a higher body mass is associated with greater force production in the rugby union scrum [3], and has been shown to have a strong correlation with overall team competitive success [4, 5].

Forwards have consistently been shown to be heavier, taller, and possess greater absolute and relative lean and fat masses compared to backs, whilst backs display proportionally lower body fat [6]. Furthermore, front row forwards have higher body mass relative to height (body mass index; BMI) and body fat compared to the second row and back row forwards [7]. Only 3 in 1000 Australians have been found to achieve and/or exceed the physique traits exhibited by the average national team forward, and with mass and BMI in rugby union athletes increasing at rates well above secular trends [4], the propensity to "supersize" forwards appears set to continue. However, it is important to consider that the relative fat mass of forwards, particularly those in the front row, may also exceed proposed general population thresholds for lifestyle-related disease risk [8]. Indeed, elite "supersized" American football (NFL) athletes with similar physique traits have higher stores of visceral adipose tissue (VAT) [9], and greater incidence of post-career health and cardiometabolic complications [10, 11].

VAT, which encompasses fat stores in the intra-abdominopelvic region bounded by the abdominal wall and pelvic floor [12], has been shown to be associated with incident cardiovascular disease [13], and is an established marker for cardiometabolic disease risk independent of body mass, fat mass and subcutaneous adipose tissue (SAT) in non-athletic populations [14]. Additionally, VAT is an independent risk factor for atherosclerosis in men [15], and there is a robust association between VAT and cardiovascular endpoints in non-athletic populations [16]. VAT diagnostic thresholds for increased risk (> 100 cm^2) and high risk (> 160 cm^2) have been established for use in general populations [17]. Further, the VAT to SAT ratio (VAT:SAT) has been proposed as a useful measure to screen for cardiovascular issues, with a cut-off of 0.4 used as a threshold above which individuals in the general population are likely to show glucose intolerance and hyperlipidemia [18]. However, the application of these risk thresholds in athletic populations has not been explored.

Magnetic resonance imaging (MRI) is the reference imaging method used to assess VAT [12]. It does, however, have limitations in practice given that MRI is expensive, and requires time-consuming post-assessment analysis by highly skilled technicians. Given these restrictions, there has been recent interest in the use of other body composition techniques to provide estimates of VAT, including dual-energy X-ray absorptiometry (DXA), which is increasingly being used to assess body composition in athletic populations [19]. Indeed, DXA estimates of VAT have been shown to be highly correlated with MRI in general populations [20]. VAT has not previously been investigated in a rugby union population using criterion assessment techniques [21].

Anecdotally, there is an increasing proportion of rugby union athletes at the elite level of Polynesian descent. This may be due to the morphology of Polynesians predisposing them to a body composition compatible with success in rugby union [4]. Polynesians exhibit lower total body fat levels at any given BMI compared to Caucasians [22]. However, they exhibit greater absolute and relative abdominal fat [23], potentially predisposing this population to an increased risk of cardiometabolic disease. Indeed, the proportion of obese Polynesian males far exceeds rates elsewhere in the world [24], with the prevalence of cardiometabolic disease through the Pacific region amongst the highest internationally [25, 26].

Given the sheer size of some rugby union athletes, the diversity of ethnic profiles within the sport, and the association between high levels of VAT and the development of cardiovascular disease, gaining a better understanding of the abdominal adiposity profile of elite rugby union athletes, some of which are "supersized", is warranted. The primary aim of this study is to investigate levels of VAT in elite rugby union athletes, incorporating comparisons based on player position and ethnicity. The study will also assess the ability of DXA to estimate VAT compared to the criterion MRI in a population of large athletes.

Methods

Participants

A convenience sample of 30 elite rugby union athletes was recruited via their involvement in a single Super Rugby squad, which is the premier professional rugby union competition in the southern hemisphere. All participants provided informed consent to partake in the study, and the protocols for testing on human subjects were submitted to, and approved by, the Human Ethics Committee of the University of the Sunshine Coast (EC00297, S/12/424).

Participants undertook body composition assessment at the start of the Super Rugby pre-season training period (which was subsequent to a 4-week transition phase involving 3 weeks of annual leave and 1 week of active rest) via DXA and MRI, with all assessments undertaken within a 72-h period. Ethnicity (Caucasian and Polynesian), and position (forwards and backs) were documented, with front row

forwards separated from the second/back row forwards for subsequent analysis.

Dual-energy X-ray absorptiometry

Prior to DXA assessment, body mass was measured using electronic scales (A&D Mercury, Adelaide, Australia) to 0.1 kg accuracy after an overnight fast with bladder voided. Stature was self-reported to the nearest 1.0 cm. BMI was subsequently calculated (mass [kg]/stature [m]^2).

DXA measures were taken using a fan-beam scanner (Hologic Discovery A, Hologic, Bedford, MA), with analysis performed using Apex 12.7.3 software (Hologic, Bedford, MA). The scanner was calibrated daily using a phantom as per the manufacturer's guidelines for quality control purposes. All scans were undertaken using the array mode.

Scanning presentation protocols were implemented as per techniques previously described to maximise technical reliability and minimise error [27]. Specifically, participants were scanned after voiding their bladder as the first thing in the morning prior to food, fluid, or exercise. Participants were tested wearing sports shorts, and those exceeding the size of the scanning bed undertook multiple scans [28]. For positioning consistency, the same experienced and qualified technician performed all measurements using the NHANES positioning protocol, with participants' leg position standardised using a set width foot strap that was placed over both feet anterior to the lateral malleolus [29]. VAT was analysed retrospectively by an experienced DXA operator with updated software Apex 13.4.2.7 (Hologic, Bedford, MA). Autopositioning of the VAT area was used, with manual adjustments made to the edge of subcutaneous fat placement and visceral cavity area if required.

Magnetic resonance imaging

Participants were placed supine on a 1.5 T Siemens Avanto scanner with their arms positioned beside them. Localisers were used to identify the L4/5 intervertebral disc space, which was used to centre the axial slice blocks for all sequences. The abdomen was interrogated with a T2-weighted true FISP sequence (balanced gradient echo, TR: 3.6, TE: 1.46, flip angle: 75°, slice thickness 8 mm) and a volume interpolated breath-hold examination (VIBE, TR: 7.48, TE: 4.76/2.38, flip angle: 10°, slice thickness 2.5 mm), both performed on inspiration. Examinations took 15 min to perform.

Two trained operators performed image analysis with OsiriX Imaging Software v5.8 using the T1W VIBE sequence, and the results were averaged. The level of the L4/5 intervertebral disc was determined from sagittal reconstructions and analysis was performed on the axial image at this level. A closed polygon region of interest (ROI) tool was used to generate a total abdominal area measurement. For SAT, threshold segmentation was used to manually select fat pixels. SAT was then "discarded" by setting the pixels within the measured SAT to a negative value and removing. VAT was measured using the same threshold segmentation technique. Diagnostic thresholds for VAT were set at >100 cm^2 for increased risk and >160 cm^2 for high risk [17]. VAT:SAT was calculated by dividing the VAT area by the SAT area, with a cut-off of 0.4 used as a threshold for increased cardiovascular risk [18].

Ethnicity

At the time of consent, the participants were requested to disclose the ethnicity of their grandparents, and their perception of their own ethnicity via open-ended questions. It was made clear that this was optional and would not impact participants' involvement in the research, or within the Super Rugby program.

A universally accepted method of distinguishing an individual's ethnicity was unable to be identified due to the inherent difficulty in defining "ethnicity" [30]. As this research investigated the phenotype expression and differences of ethnicity on body composition based on variances previously described in sedentary populations [22, 23], grandparental heritage was chosen as in previous research [6, 31]. Participants were ascribed a specific ethnicity when three or more of their grandparents were of the same ethnicity.

Statistical analysis

Statistical analysis procedures were completed using Microsoft Excel (Microsoft, Redmond, WA, USA). Descriptive statistics on body composition measures were calculated and presented as mean ± standard deviation (SD). Data were explored using box plots and Q–Q plots to identify any potential outliers. Assumptions of homogeneity of variance using Levene's test of equality of error variance were conducted. All measurements undertaken in the study were normally distributed. A two-way between-subject ANOVA was conducted to compare the effect of position and ethnicity on criterion MRI measures. Subsequently, independent *t* tests were run as post hoc analysis to investigate the differences in body composition measures based on position (forwards vs backs, and front row forwards vs second/back row forwards) and ethnicity. Bonferroni corrections were made to counteract multiple comparisons. Statistical significance was accepted at a p value of <0.05 throughout. Pearson's correlations (r) were used to assess the strength of the relationship between measures of VAT and SAT and ranked according to Hopkins [32]. A Bland–Altman plot was created to compare DXA to the criterion MRI measure

for estimating VAT. Interclass correlation coefficients (ICC) and coefficients of variation (CV) were used to determine the inter-tester reliability between the two technicians who analysed the MRI scans.

Results

All athletes were able to be ascribed an ethnicity, and descriptive characteristics of the population are presented in Table 1. All physique traits measured by DXA were significantly different between forwards and backs. Differences in body composition were also noted between front row forwards and second/back row forwards, with front row forwards having greater absolute and relative fat mass, and more relative fat distributed in the android region. Based on MRI VAT, 11 of 30 athletes had VAT > 100 cm^2, including 8 forwards (6 Caucasian, 2 Polynesian), and 3 backs (2 Caucasian, 1 Polynesian). No athlete had VAT > 160 cm^2. Twenty-three of the 30 athletes had a VAT:SAT > 0.4. The two-way between-subject ANOVA indicated there were no interactions between ethnicity and position for MRI VAT ($F = 0.15$, $p = 0.70$). The ICC (95% confidence interval) for abdominal total area was 1.00 (1.00–1.00), 0.99 for SAT (CI 0.99–1.00) and 0.96 for VAT (CI 0.93–0.98), with a CV of 0.4%, 2.4% and 4.3%, respectively.

Correlations between MRI VAT and SAT, with BMI and DXA measures of whole body and abdominal adiposity, are described in Table 2. A moderate correlation was found between MRI VAT and DXA VAT ($r = 0.46$, $p = 0.01$),

Table 1 Body composition characteristics of elite rugby union athletes categorised by position and ethnicity

	Ethnicity			Position			Forwards		
	Caucasian ($n = 19$)	Polynesian ($n = 11$)	p value	Forwards ($n = 17$)	Backs ($n = 13$)	p value	Front row ($n = 7$)	Second and back row ($n = 10$)	p value
Characteristics									
Age (years)	23.6 ± 4.0	24.5 ± 3.9	0.56	24.7 ± 4.8	22.8 ± 2.3	0.16	24.1 ± 3.0	25.2 ± 5.8	0.63
Stature (cm)	188.1 ± 7.2	184.5 ± 6.3	0.17	189.9 ± 6.9	182.5 ± 4.5	< 0.01*	184.7 ± 2.4	193.6 ± 6.7	< 0.01*
Mass (kg)	102.9 ± 10.9	100.1 ± 12.1	0.54	110.2 ± 6.6	90.0 ± 4.4	< 0.01*	110.3 ± 5.7	110.1 ± 7.5	0.94
BMI (kg/m^2)	29.1 ± 2.4	29.3 ± 2.3	0.75	30.6 ± 2.0	27.3 ± 1.1	< 0.01*	32.3 ± 1.3	29.4 ± 1.4	< 0.01*
DXA									
Bone mass (kg)	4.1 ± 0.4	4.1 ± 0.5	0.69	4.3 ± 0.3	3.8 ± 0.4	< 0.01*	4.3 ± 0.2	4.3 ± 0.4	0.94
Fat mass (kg)	14.5 ± 4.1	13.4 ± 5.4	0.56	17.1 ± 3.6	10.1 ± 1.7	< 0.01*	19.2 ± 2.7	15.7 ± 3.5	0.04*
Lean mass (kg)	82.3 ± 6.9	81.0 ± 7.7	0.66	86.5 ± 4.8	75.7 ± 4.4	< 0.01*	84.7 ± 3.9	87.8 ± 5.2	0.18
Total mass (kg)	100.8 ± 10.2	98.6 ± 11.8	0.60	107.9 ± 6.1	89.6 ± 4.3	< 0.01*	108.2 ± 5.3	107.8 ± 6.9	0.90
Body fat (%)	14.2 ± 3.0	13.3 ± 4.0	0.51	15.8 ± 2.9	11.3 ± 1.9	< 0.01*	17.7 ± 1.9	14.5 ± 2.8	0.01*
Android fat mass (g)	1007 ± 433	1039 ± 676	0.89	1302 ± 530	649 ± 159	< 0.01*	1562 ± 394	1119 ± 554	0.07
Android fat (%)	15.1 ± 4.5	15.1 ± 6.5	0.98	17.6 ± 5.3	11.8 ± 2.8	< 0.01*	20.4 ± 4.1	15.6 ± 5.3	0.05*
Est. VAT mass (g)	316.6 ± 98.7	301.1 ± 116.1	0.71	370.2 ± 97.9	233.3 ± 41.2	< 0.01*	392.9 ± 111.6	354.4 ± 89.9	0.47
Est. VAT area (cm^2)	65.6 ± 20.4	62.4 ± 24.0	0.71	76.7 ± 20.2	48.4 ± 8.6	< 0.01*	81.4 ± 23.0	73.4 ± 18.5	0.46
MRI									
Abdominal total (cm^2)	605.9 ± 89.0	602.1 ± 105.7	0.92	664.9 ± 79.8	525.6 ± 28.1	< 0.01*	713.6 ± 68.8	630.8 ± 71.0	0.03*
Abdominal SAT (cm^2)	146.9 ± 59.1	144.9 ± 76.7	0.94	182.0 ± 61.9	99.4 ± 28.9	< 0.01*	229.3 ± 42.8	148.9 ± 51.4	< 0.01*
Abdominal VAT (cm^2)	92.7 ± 26.7	86.0 ± 27.3	0.52	96.7 ± 25.0	81.7 ± 27.3	0.13	93.5 ± 30.3	99.0 ± 22.0	0.69

BMI body mass index, *DXA* dual-energy X-ray absorptiometry, *MRI* magnetic resonance imaging, *VAT* visceral adipose tissue, *SAT* subcutaneous adipose tissue

*Significant ($p \leq 0.05$) differences between Caucasians and Polynesians, forwards and backs, or front row and second/back row forwards

Table 2 Correlation between MRI measures of SAT and VAT and abdominal fat measures via DXA and surface anthropometry

	Abdominal MRI SAT (cm^2)			Abdominal MRI VAT (cm^2)		
	r	*p* value	Qualitative ranking	*r*	*p* value	Qualitative ranking
BMI (kg/m^2)	0.88	< 0.01*	Very large	0.21	0.27	Small
DXA android fat (kg)	0.91	< 0.01*	Almost perfect	0.42	0.02*	Moderate
DXA android fat (%)	0.88	< 0.01*	Very large	0.34	0.07	Moderate
DXA body fat (kg)	0.94	< 0.01*	Almost perfect	0.35	0.06	Moderate
DXA body fat (%)	0.94	< 0.01*	Almost perfect	0.26	0.17	Small
DXA estimated VAT (cm^2)	0.75	< 0.01*	Very large	0.46	0.01*	Moderate

Qualitative ranking of correlation defined as trivial, $r < 0.1$; small, $0.1 \leq r < 0.3$; moderate, $0.3 \leq r < 0.5$; large, $0.5 \leq r < 0.7$; very large, $0.7 \leq r < 0.9$; almost perfect, $0.9 \leq r < 1.0$; perfect, $r = 1.0$ [31]

BMI body mass index, *DXA* dual-energy X-ray absorptiometry, *MRI* magnetic resonance imaging, *SAT* subcutaneous adipose tissue, *VAT* visceral adipose tissue, *r* correlation coefficient, *p value* significance

with BMI seen to be a poor estimate of MRI VAT ($r = 0.21$, $p = 0.27$). Slight differences were noted in the ability of DXA VAT to estimate MRI VAT based on ethnicity, with a slightly higher correlation amongst Polynesians (Fig. 1a). Bland–Altman analysis indicated that DXA VAT underestimates MRI VAT by ~ 25 cm^2 with relatively wide limits of agreement (− 24.0 to 75.6 cm^2) (Fig. 1b).

Discussion

The primary finding of this investigation is that, on average, the levels of VAT in elite rugby union athletes do not exceed the diagnostic threshold for cardiometabolic complications (> 100 cm^2). However, one-third of the athletes had a VAT > 100 cm^2, with over two-thirds having a VAT:SAT > 0.4. All athletes with a VAT > 100 cm^2 also had a VAT:SAT > 0.4, whilst no athletes had VAT > 160 cm^2. VAT levels did not differ between Caucasian and Polynesian athletes; however, there was a trend for forwards to have higher VAT than backs, which provides an indication that this may be an area of interest to researchers moving forward [33]. Only a moderate correlation was found between the criterion MRI VAT and estimated DXA VAT, with DXA notably underestimating VAT.

Forwards in the present study exhibited higher total mass, plus absolute and relative (percentage) fat mass, compared to backs. Furthermore, forwards possessed greater abdominal SAT and tended to have higher VAT. The body composition characteristics of elite rugby union forwards in the present study are similar to those previously reported in rugby union [6, 34, 35]. Further, they are similar to body composition traits exhibited in NFL athletes, with linebackers, tight ends, and running backs exhibiting similar BMI (NFL 31.5 ± 1.9 kg/m^2 vs rugby union 30.6 ± 2.0 kg/m^2), lean mass (NFL 87.3 ± 4.7 kg vs rugby union 86.5 ± 4.8 kg), and body fat percent (NFL 17.0 ± 4.0% vs rugby union 15.8 ± 2.9%) [9]. Additionally, DXA-measured VAT was similar between these NFL athletes (0.3 ± 0.2 kg) and the rugby union forwards in this study (0.4 ± 0.1 kg). However, NFL linemen, who were heavier with higher overall body fat, were found to have significantly more VAT (1.2 ± 0.6 kg) compared to both the forwards in the present study, and other NFL players [9]. Furthermore, it has been reported that after NFL athletes reach a mass of 250 lbs (~ 114 kg) the rate of lean mass accumulation decreases, and that above 20% body fat the rate of VAT accumulation increases relative to SAT [9]. This detail is particularly pertinent given that in the present study, 41% of forwards were over 114 kg, and there is a gradual trend for rugby forwards to become even heavier over time, given forward packs possessing greater total mass are more successful [4, 5]. Although the literature suggests that the increasing mass in rugby union athletes is a result of increasing mesomorphy and decreasing endomorphy [2], it could be postulated that the need for "supersized" athletes in rugby union may evolve similar to the NFL, with absolute mass becoming an important physical attribute. In concordance with the present study, a 2015 paper reported that larger rugby union players had higher VAT levels, and that over a fifth of the athletes met the criteria for visceral obesity of VAT > 100 cm^2 [21]. However, the athletes in that study were not elite, and VAT was estimated via bio-electrical impedance which shows poor correlation with accepted measures of VAT [36].

It is important to note that the higher VAT levels in these "supersized" athletes may simply reflect their overall body size. Indeed, the reference ranges previously proposed for VAT area have been derived from older, shorter, and inactive populations [17]. Presently there are no VAT reference ranges established relative to size, or appropriate to athletic individuals able to be applied to this population. It has previously been reported in obese populations that a VAT:SAT > 0.4 is associated with disorders of glucose and lipid metabolism [18]. More recently in a population of Korean men (age 52.1 ± 9.9 years; BMI 24.0 ± 2.2 kg/m^2), VAT:SAT effectively predicted the presence of multiple

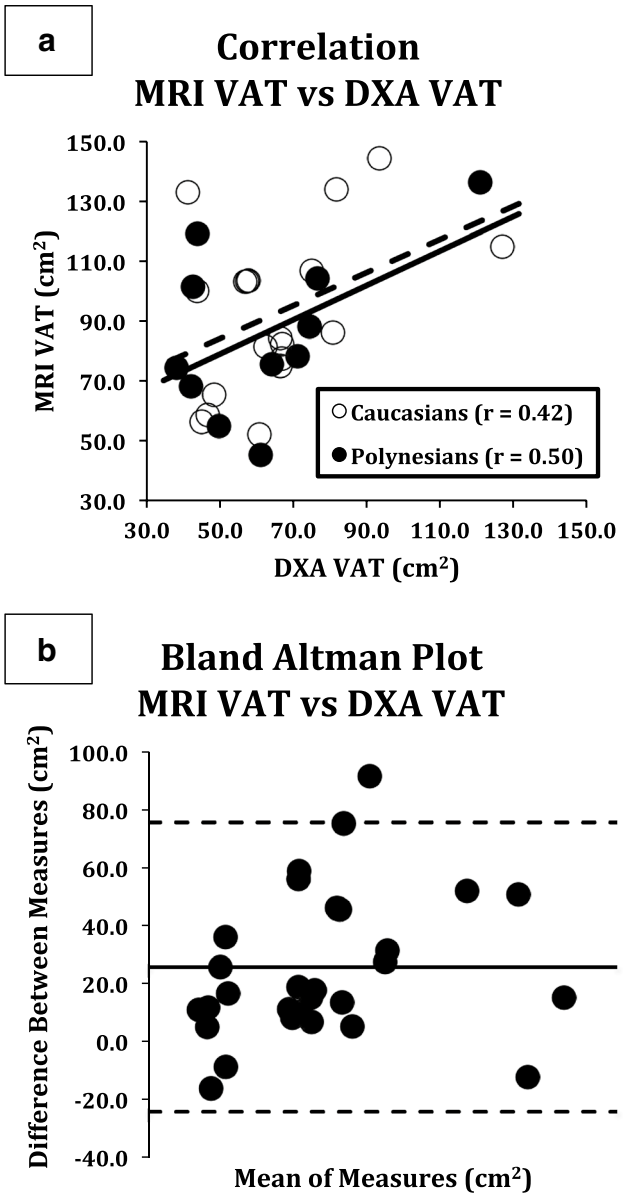

Fig. 1 **a** Correlation between criterion magnetic resonance imaging (MRI) visceral adipose tissue (VAT) and dual-energy X-ray absorptiometry (DXA) VAT. Lines of best fit for Caucasians (dotted line) and Polynesian (solid line); **b** Bland–Altman plot of criterion MRI VAT and estimated DXA VAT. Difference is MRI VAT less DXA VAT. Mean difference (solid line), upper and lower limits of agreement (dotted lines)

metabolic risk factors [37]. In the present study, over two-thirds of the athletes had a VAT:SAT > 0.4. However, given the VAT:SAT threshold of 0.4 was derived from an obese population, and this elite athletic population possessed relatively low SAT levels, the ratio may not provide an accurate indication of health status in rugby union athletes. Furthermore, the athletes in this study were all partaking in extremely high levels of activity which has been shown to be protective of cardiometabolic complications [38]. Indeed, cardiorespiratory fitness has been shown to be a far more important indicator of cardiovascular disease and all-cause mortality than obesity, with fit-obese persons exhibiting similar mortality risk compared to normal weight and fit individuals [39]. Moreover, higher levels of cardiorespiratory fitness have been shown to substantially reduce the adverse effects of obesity on morbidity and mortality [40], suggesting that during their athletic career "supersized" elite athletes may be protected from obesity-related cardiometabolic complications.

Although no currently available reference ranges are applicable to elite rugby players, "supersized" athletes with higher relative VAT levels have previously been linked with post-career cardiometabolic complications. In a study of retired NFL linesman, who have been shown to possess higher levels of VAT than other athletes in their sport [9], a significantly higher prevalence of type 2 diabetes (10.4% vs 4.0%) and metabolic syndrome (59.8% vs 30.1%) was noted in comparison to non-linesmen [11]. Coronary artery calcium (CAC), a marker of the presence and severity of subclinical atherosclerosis [41], can also be used as a surrogate of cardiovascular disease risk. Indeed, retired linemen have less likelihood of CAC absence (33.8% vs 47.7%, $p = 0.02$), and a higher likelihood of moderate to severe subclinical atherosclerosis (32.9% vs 26.4%, $p = 0.04$) compared to non-linemen [10]. Presently, there is nothing in the literature discussing post-career health status in elite rugby union athletes. Given the established long-term health complications identified in "supersized" NFL athletes, and their physique similarities with rugby union forwards, cardiometabolic disease markers in elite rugby union athletes, both during and post-career, deserve further exploration. This is particularly relevant given that a number of athletes in the present study displayed elevated VAT, despite their high levels of physical activity. Therefore, it could be postulated that these athletes may be more susceptible to complications following retirement when activity levels are likely to decrease.

In this study, no significant differences were noted between Caucasians and Polynesians in any of the abdominal body composition measures assessed. Previously, among non-athletic populations, Polynesians exhibited greater abdominal fat mass than Caucasians both in absolute terms (2.3 ± 1.0 kg vs 1.5 ± 1.0 kg, $p < 0.001$), and as a percentage of total mass ($9.0 \pm 1.7\%$ vs $8.0 \pm 1.5\%$, $p < 0.001$) [23]. It has been proposed that major changes in traditional lifestyle factors such as nutrition and a decrease in physical activity amongst Polynesians are the main cause of their poor cardiometabolic profiles [25]; therefore, participation in elite sport may be protective in this rugby union population. However, in this study dietary intake was not quantified, nor were haematological markers of cardiometabolic disease risk assessed. Given there is evidence describing increased blood-related cardiometabolic disease risk factors

present in Polynesians [26], investigations exploring changes in abdominal body composition and haematological status under controlled training conditions would be of value. Interestingly, VAT accumulation has been shown to be influenced by ethnicity in studies involving African Americans and Caucasians in both non-athletic [42] and athletic populations [10]. This has not been researched in Polynesians and may be a contributing factor to the immensity of cardiometabolic complications in this population. Furthermore, whether participation in an elite athletic environment remains protective for Polynesian athletes post-career is yet to be determined.

When comparing the criterion MRI VAT with DXA estimated VAT, only a moderate correlation was observed ($r = 0.46$, $p = 0.01$). However, given MRI access to screen for elevated VAT is limited outside of a research setting, the use of DXA estimated VAT may be of value since it provided the highest correlation of all the abdominal measures taken using DXA or BMI, and is increasingly being used to monitor body composition of athletes [19]. Specifically, elite athlete may have up to 3–4 DXA scans per year for body composition purposes, and the VAT value generated from these reports may be used as a screening tool for further investigations [19]. In this study, six of the highest seven recorded DXA VAT measures belonged to those with an MRI VAT > 100 cm^2. Given previous studies have reported very high correlations ($r > 0.90$) between MRI and DXA estimates of VAT [20], it was surprising to see the predictive power of DXA was not as strong in our population. This is likely because prior studies were undertaken on non-athletic groups where a larger proportion of individuals had considerably higher VAT. This suggests, as evidenced by the Bland–Altman results in this study, that DXA may underestimate VAT at lower body fat levels [20].

This study was limited by the fact that only a single MRI slice was analysed from within the abdominal cavity. This is often the case in research and clinical practice given the increased cost and time commitment in the analysis process to measure multiple slices and/or a volume [43]. Further, studies sampling a single slice have been observed to be affected by ethnicity, with maximum VAT being recorded at different vertebral levels [44]. Moreover, the best slice to take has been questioned, with the L2/L3 slice sometimes utilised as opposed to the L4/L5 slice as was taken in this study [45], identifying a potential limitation of this research. Ideally, volumetric measures of VAT would be taken to account for the different distribution of adiposity within the abdominal cavity [43], but this was not an option in this investigation as only a single slice was acquired at assessment due to time and cost constraints. Further, the present study was limited by the relatively small sample size, as is inherent in all elite-level studies due to the rarity and availability of elite athletes. Finally, the measures were taken at the beginning of the pre-season period, which for this particular group of athletes was preceded by a 4-week transition phase between seasons comprising of a reduced training load, and in some cases limited training due to off-season surgery. Thus, theoretically, the athletes' physical condition was at its poorest. Future studies would benefit from analysing VAT at multiple time points during the season to ascertain if the training stimulus influences abdominal adiposity. Additionally, further investigation is warranted into whether or not higher VAT levels than those of the general population in an elite group of athletes is indeed a risk factor. Such investigations would benefit from measures of lipid profiles and other cardiovascular disease risk factors. Finally, investigations looking into whether changes in lifestyle and body composition after the conclusion of the athletes' playing careers have the potential to put them at further risk once the protective effects of exercise are removed should be considered.

Conclusion

This study was undertaken with a view to develop a better understanding of whether those rugby union athletes who are more "supersized" are prone to possess elevated VAT levels. While larger athletes with higher total body fat possessed higher VAT, no differences were evident according to ethnicity. The results of this research provides sport scientists and medical professionals insight into the VAT levels of this group of athletes, which may direct further screening and/or interventions to establish and manage disease risk. Given the elevated VAT levels in some "supersized" rugby union athletes from this study, and the association between high VAT levels with post-career obesity-related complications in other "supersized" athletes, the exploration of VAT and other cardiometabolic risk factors in this population warrants further investigation.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent All participants gave written informed consent before participating in the study. All participants provided informed consent to partake in the study, and the protocols for testing on human

subjects were submitted to, and approved by, the Human Ethics Committee of the University of the Sunshine Coast (EC00297, S/12/424).

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