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Pre-season body composition adaptations in elite Caucasian and Polynesian rugby union athletes

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Authors

Adam J Zemski
School of Health and Sport Sciences, University of the Sunshine Coast, Maroochydore, Australia

Shelley E Keating
School of Human Movement and Nutrition Sciences, The University of Queensland, St Lucia, Australia

Elizabeth M Broad
US Paralympics, US Olympic Committee, Chula Vista, CA, USA

Damian J Marsh
Fiji Rugby Union, Suva, Fiji

Karen Hind
Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, West Yorkshire, UK

Gary J Slater
School of Health and Sport Sciences, University of the Sunshine Coast, Maroochydore, Australia
Australian Rugby Union, Sydney, Australia

Contact details of corresponding author

Adam J Zemski
School of Health and Sport Sciences
Faculty of Science, Health, Education and Engineering
University of the Sunshine Coast
Maroochydore DC, QLD, 4558, Australia
Email: ajz006@student.usc.edu.au

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Conflicts of interest

Nil

Pre-season body composition adaptations in elite Caucasian and Polynesian rugby union athletes

Abstract

During pre-season training, rugby union (RU) athletes endeavour to enhance physical performance characteristics that are aligned with on-field success. Specific physique traits are associated with performance, therefore body composition assessment is routinely undertaken in elite environments. This study aimed to quantify pre-season physique changes in elite RU athletes with unique morphology and divergent ethnicity. Twenty-two Caucasian and Polynesian professional RU athletes received dual-energy X-ray absorptiometry (DXA) assessments at the beginning and conclusion of an 11-week pre-season. Interactions between on-field playing position and ethnicity in body composition adaptations were explored, and the least significant change (LSC) model was used to evaluate variations at the individual level. There were no combined interaction effects with the variables position and ethnicity, and any body composition measure. After accounting for baseline body composition, Caucasians gained more lean mass during the pre-season than Polynesians (2425 ± 1303 g vs 1115 ± 1169 g; $F=5.4$, $p=0.03$). Significant main effects of time were found for whole body and all regional measures with fat mass decreasing ($F=31.1$–52.0, $p<0.01$), and lean mass increasing ($F=12.0$–40.4, $p<0.01$). Seventeen athletes (9 Caucasian, 8 Polynesian) had a reduction in fat mass, and 8 athletes (6 Caucasian, 2 Polynesian) increased lean mass. This study describes significant and meaningful physique changes in elite RU athletes during a pre-season period. Given the individualised approach applied to athletes in regards to nutrition and conditioning interventions, a similar approach to that used in this study is recommended to assess physique changes in this population.

Key words: dual-energy X-ray absorptiometry, fat mass, lean mass, training, ethnicity.

Introduction

Professional rugby union (RU) athletes may compete in several different competitions and tournaments throughout a calendar year. Following a period of rest (off-season), athletes typically embark on a high volume pre-season training program of increasing intensity that incorporates multifaceted aspects of physical conditioning (Argus et al., 2009; Bradley et al., 2015). The physical goals of pre-season are to increase aerobic and anaerobic fitness, speed, strength and power (Argus et al., 2010), in conjunction with undertaking rugby specific technical and tactical training. Adjustments in body composition, such as increases in lean mass (LM), are associated with favourable changes in a number of performance traits (Bilsborough et al., 2016; Crewther et al., 2013). Therefore, being able to accurately quantify pre-season physique changes is of value to sport science practitioners and coaches to facilitate further personalisation of training and/or dietary interventions.

The desire to increase body mass (BM), in particular LM, to gain a competitive advantage in RU has become more pronounced since the introduction of professionalism in 1995 (Olds, 2001; Quarrie & Hopkins 2007). Increases in LM can influence the power-to-weight ratio of players, thus increasing the potential to proliferate momentum, strength, power and speed (Bell et al., 2005). Excess fat mass

(FM) has negative implications for thermoregulation (Selkirk & McLellan, 2001), and concurrently increases energy expenditure during exercise, both of which may limit an athlete's ability to perform at a high intensity for the duration of a match (Duthie, 2006). Additionally, an increase in FM has the potential to attenuate force production according to Newton's second law of motion ($a = F/m$), whereby increases in FM (m) without a corresponding increase in muscle force (F) will reduce acceleration (a) (Duthie, 2006; Lees et al., 2017).

Pre-season increases in LM and decreases in FM have previously been reported in elite RU athletes using surface anthropometry (Argus et al., 2010; Bradley et al., 2015). However, there are limits to relying on anthropometric measures for estimating body composition in athletes, given the regression equations haven't been validated for use in RU, or to track changes in body composition (Silva et al., 2009; Zemski et al., 2017). Over recent years, the use of dual-energy X-ray absorptiometry (DXA) for body composition assessment in elite RU has increased (Lees et al., 2017; Zemski et al., 2015). This technology provides an in-depth analysis of whole body and regional bone mineral content (BMC), FM and LM, and is recognised as a valid and precise body composition assessment tool (Harley et al., 2009; Van der Ploeg et al., 2003) when client presentation is standardised in accordance with best practice guidelines (Nana et al., 2015).

In recent years there has been a surge in the number of Polynesian athletes securing professional RU contracts. One study has investigated three-compartment body composition in Polynesian RU players and reported different distributions of regional FM and LM (Zemski et al., 2015). In non-athletes, large differences in physique have been reported between Caucasian and Polynesian individuals, with Polynesians having more LM and greater LM:FM ratios (Rush et al., 2004; Swinburn et al., 1996; Swinburn et al 1999). To date, no study has explored differences in physique adaptations to training by ethnicity in RU. Therefore, the aim of this study was to investigate pre-season team and individual athlete DXA body composition adaptations in elite RU athletes, with sub-group analysis to compare changes between Polynesian and Caucasian individuals.

Methods

Participants

Twenty-two professional male RU athletes were recruited via their involvement in a single Australian Super Rugby franchise, which is the premier professional RU competition in the southern hemisphere. All athletes provided informed consent to participate in the study, and the research was approved by the Human Research Ethics Committee at the University of the Sunshine Coast (EC00297, S/16/959).

At the time of consent, all athletes provided researchers with the ethnicity of their grandparents via open ended questions. Given this research investigated potential differences based on phenotype expression, Ethnicity was ascribed when ≥ 3 grandparents were of the same ethnicity, as in previous studies in both athletic and sedentary populations (Rush et al.; 2009; Swinburn et al., 1996; Zemski et al., 2015; Zemski et al., 2017).

Study design

As part of routine training in preparation for the 2017 Super Rugby season, the athletes undertook a high-volume, high-intensity, 11-week pre-season training program. During the first three days of the pre-season period all athletes undertook body composition assessment via DXA, with the athletes re-assessed in the same order within the final three days of pre-season. The athletes undertook a similar training program the day before each assessment.

Body composition assessment

Body composition was assessed using a fan-beam DXA scanner (Hologic Discovery A, Hologic, Bedford, MA), with analysis performed using Apex 13.4.2:3 software (Hologic, Bedford, MA). A spine phantom was used to calibrate the scanner daily as per manufacturer guidelines for quality control purposes.

A standardised scanning protocol was implemented to maximise technical reliability and minimise error. This protocol has been described in detail elsewhere (Nana et al., 2015). Specifically, athletes were scanned first thing in the morning (between 5:00 am and 8:30 am) prior to food and fluid ingestion, or exercise. The athletes were requested to remain well hydrated the day before, and to consume their normal prescribed training diet the day before the assessment. They were scanned wearing sports shorts, and those taller than the 196 cm scanning boundary undertook two scans, the first of which captured the body from the menton (the inferior point of the mandible) down whilst the head was positioned in the Frankfort plane. The athletes were then repositioned on the scanner, with the subsequent scan capturing from the menton up to the vertex of the head. The results of the two scans were combined during the analysis process to yield whole body composition (Evans et al., 2005). None of the athletes in this study were too broad for the scanning area. To ensure consistency, the same experienced and qualified technician performed all measurements and post-scan analysis, including the manual adjustment of all regions of interest. Fat-Free Mass Index (FFMI) was calculated using the equation fat-free mass (kg) divided by stature (m) squared (Vanltallie et al., 1990).

Pre-season training program

Following a 4-week period of unsupervised annual leave which included an active rest program (strength x2/week, conditioning x2/week) after the previous competitive RU season, the athletes undertook an 11-week pre-season training period. This comprised a 4-week supervised training block prior to a 2-week unsupervised maintenance block, followed by another 5-week supervised training block. Throughout each training week technical (x2/week) and tactical (x4/week) rugby sessions along with sessions to improve underpinning physical qualities and body composition were performed (speed/agility x1/week, strength x4/week, conditioning x3-4/week, boxing x1/week). Training was typically executed Monday through Friday with an approximate weekly training load of 15 hours. Additional time was spent on individual recovery and regeneration modalities (flexibility, mobility, massage, hydrotherapy and physiotherapy). All athletes were under the management of an experienced sports dietitian, who was accredited with the national governing body, and received individualised dietary plans aimed at supporting training adaptations throughout the pre-season period.

Statistical analysis

Statistical analyses were completed using SPSS (Version 22.0, IBM Corp., Armonk, NY) and Microsoft Excel 2011 (Microsoft, Redmond, WA, USA). Before analysis, assumptions of normality in the data were made using visualisations of normality plots and the Shapiro-Wilk test. Changes in body composition over the pre-season period were analysed using mixed-model analysis of variance (ANOVA), with the pre-season period acting as the within-subject factor, and playing position and ethnicity as the between subject factors. Additionally, a two-way analysis of covariance (ANCOVA) was conducted using both position and ethnicity as independent variables, and the start of pre-season as covariate, to test for interactions between position and ethnicity controlled for baseline values. Significant effects were subsequently explored using Bonferroni post hoc tests to counteract multiple comparisons. Sphericity of the data was assessed using the Mauchly test, assumptions of homogeneity of variance using Levene’s test of equality of error variances, and Box’s test of equality of covariance matrices were conducted. Between subject-effects were evaluated using the partial eta squared (η_p^2) rankings of small (> 0.01), medium (> 0.09) and large (> 0.25). Data are presented as mean ± standard deviation (SD) with statistical significance for all analyses defined *as* $p \leq 0.05$.

The short term precision root-mean-square-standard deviation (RMS–SD), percent coefficient of variation (%CV), and corresponding least significant change (LSC) was calculated using standardised protocols as recommended by the International Society for Clinical Densitometry (Hangartner et al., 2013). This was done in a population of resistance trained athletes using the same Hologic Discovery A scanner used in this study (Zemski et al., 2018). Precision errors from same day scans (technical error) for whole body BMC, LM and FM, were 21.1 g, 238.4 g, and 222.7 g respectively. Precision error from consecutive day scans (technical error and biological variation) was calculated as the root-mean-square standard deviation (RMS–SD), with LSC subsequently derived as RMS–SD x 2.77 (95% confidence interval [95% CI]), and is presented in Table 1. Meaningful changes in individual athletes were identified if they exceeded the LSC as described elsewhere (Lees et al., 2017).

Results

Descriptive characteristics

Eleven athletes were identified as Caucasian (6 forwards, 5 backs), and 11 as Polynesian (5 forwards, 6 backs). Body composition according to position and ethnicity are presented in Table 2. There were no differences in whole or regional body composition between Caucasians and Polynesians. All whole body and regional DXA measures for BMC, FM and LM were greater ($p < 0.01$) in forwards compared to backs at both time points.

Team changes in whole and regional body composition

Pre-season body composition changes are presented in Table 2. There were no combined interaction effects between the variables position and ethnicity, with any body composition measure. After accounting for baseline body composition, Caucasians gained more LM during the pre-season than Polynesians (2425 ± 1303 g vs 1115 ± 1169 g; F = 5.4, $p = 0.03$). Significant main effects of time were found for whole body and all regional measures with FM decreasing (whole body F = 52.0, $p < 0.01$; arms F = 31.1, $p < 0.01$; trunk F = 44.8, $p < 0.01$; legs F = 39.5, $p < 0.01$), LM increasing (whole body F = 40.4, $p < 0.01$; arms F = 33.7, $p < 0.01$; trunk F = 14.8, $p < 0.01$; legs F = 12.0, $p < 0.01$), and trunk BMC increasing (F = 5.1, $p = 0.04$). Between-subject effects were found based on position for all variables (F = 3.8–13.2; p = 0.01–0.03; η_p^2 = 0.39–0.69 [large effect]).

Individual player body composition changes

Meaningful individual player changes were identified if they exceeded LSC (Table 3) and are illustrated in Figures 1, 2 and 3. Over the 11-week pre-season period, 17 athletes (9 Caucasian, 8 Polynesian) reduced FM, and 8 athletes (6 Caucasian, 2 Polynesian) increased LM. Meaningful increases in whole body BMC were observed in 4 athletes (3 Caucasian, 1 Polynesian), and 1 Caucasian athlete had a loss of BMC. Seven athletes both increased LM and reduced FM (5 Caucasians, 2 Polynesians). Only minor differences in whole body and regional individual body composition changes in FM and LM were observed in athletes based on position.

Discussion

This is the first study using an individualised approach in the analysis of pre-season body composition changes in RU athletes, which extends previous work looking at individual in-season changes (Lees et al., 2017). In doing so, we identified that over three-quarters of the athletes (17) decreased FM, while over one-third (8) increased LM. Further to this, 7 of the 8 athletes who increased LM also experienced meaningful reductions in FM. The changes in physique observed during the pre-season occurred independent of position or ethnicity; however, more Caucasian athletes increased LM in comparison to Polynesians.

Significant changes in body composition during pre-season training have been reported in as little as 4-weeks in a similar population of professional RU athletes (Argus et al., 2010). However, given that body composition changes were inferred via a surface anthropometry derived regression equation, the validity of such a marked increase in LM (2.0 ± 0.6 kg) in such a short time period is questionable (Silva et al., 2009). Indeed, only 8 athletes in the present investigation observed similar gains in LM, despite an 11-week pre-season period. FM losses in this study were slightly larger than in the aforementioned study (1.4 ± 0.4 kg), although this would be expected given the duration of the pre-season was considerably longer. Pre-season increases in LM and decreases in FM of a similar magnitude to those observed in this study have also been reported in professional Australian rules footballers (AFL) using DXA (Bilsborough et al, 2017), corroborating that the pre-season period in professional sport is a time of noteworthy body composition change.

An individualised approach to evaluating adaptations provides a unique insight not possible from a more traditional assessment, where group mean changes are reported.

For example, although statistically significant gains in LM were observed in the current investigation, only one-third of athletes had meaningful increases in LM based on LSC analysis (>2083 g). This may be a result of the challenges associated with increasing LM once high levels of muscularity are reached (Abe et al., 2018). Indeed, the rate of LM accumulation has been reported to decline in American football (NFL) athletes when BM exceeds ~114 kg (forwards in this study 112.5 ± 7.6 kg) (Bosch et al., 2014), and an upper limit in FFMI of 25 kg/m^2 has been suggested in non-steroid using males (Kouri et al., 1995). However, the validity of this FFMI cut-off has been questioned in athletic populations (Trexler et al., 2017). Specifically, professional RU forwards routinely exceed this threshold (Zemski et al., 2015), including all 11 of the forwards in the present study (26.1 ± 1.2 kg/m^2; range 25.5 – 29.0 kg/m^2). Characterising athletes and measuring adaptations at the group level may not tell the whole story, as was the case with LM adaptions in this study. Therefore, being able to evaluate changes in body composition at the individual level provides practitioners the opportunity to appreciate more deeply individual adaptations, which may provide benefits in program personalisation and performance optimisation.

Polynesians have consistently been shown to display higher LM and lower FM compared to Caucasians (Rush et al., 2004; Rush et al, 2009; Swinburn et al., 1996; Swinburn et al., 1999); however, longitudinal adaptions have not previous been investigated. More Caucasian athletes increased LM than Polynesians (6 athletes vs 2 athletes) particularly in the trunk region (3 athletes vs 0 athletes), and a statistically significant group main effect based on ethnicity was found. Future investigations incorporating ethnicity differentiated within and between season measures may provide further insight into the role ethnicity plays in training adaptations not only during the season, but also post-season in the absence of the training stimulus, where previously significant compromises in body composition have been noted in other elite contact team-sport populations (Bilsborough et al., 2017).

Few differences were observed between forwards and backs in regards to meaningful individual adaptions achieved, with the only substantial difference being that more forwards had significant increases in trunk LM compared to backs (3 athletes vs 0 athletes). As forwards are required to engage in more static match activities such as scrums, mauls, and rucks, greater core and upper body strength is advantageous (Roberts et al., 2008). As such, forwards undertake more field-based training activites that replicate these specific match performance movements, which may have amplified the observed adaptations.

The use of the individualised LSC method of analysis in this study has provided great insight into the individual adaptations of elite RU athletes over a pre-season period, as did the same approach when looking at in-season changes previously reported (Lees et al., 2017). Although research traditionally reports statistical significance in regard to group changes, the individualised approach is more closely aligned to the practical interpretation of results undertaken by sports scientists. As such, appreciating the precision error of the DXA equipment being used, and ensuring best practice protocols are followed (Nana et al., 2015), can facilitate the identification of true changes and thus influence interpretation of results. This would then enable practitioners to further personalise dietary and/or training interventions in the pursuit of improved performance outcomes.

There are a number of considerations to make when interpreting the findings of this study. Firstly, it was impractical for individual training loads and dietary intake to be quantified. While it would be invaluable to understand the association between energy intake, energy expenditure, and body composition changes, significant challenges exist in being able to quantify high intensity exercise energy expenditure (Drenowatz & Eisenmann, 2011), particularly in contact sports where the tools available are not suitable during physical collisions (Bradley et al., 2015). Additionally, due to the high number of routine measurements being taken on the athletes for monitoring purposes, training load could not be quantified. Further, given there is no gold standard assessment of energy intake, any method employed would be subject to considerable error, particularly over a long period in an athletic population (Magkos & Yannakoulia, 2003). Such information may have provided further insight into the underlying reasons for the observed individual physique changes, and warrants consideration when appropriate and reliable technologies are available. Also, researchers were not made aware of individual athlete body composition goals over the pre-season, which may have added to the interpretation of results. Secondly, off-season changes and events likely to influence body composition were not taken into consideration when interpreting the results. An appreciation of such changes would allow for a more meaningful interpretation of the pre-season adaptations in the context of each individual athlete. Finally, associations between body composition and physical performance changes were not explored in this study. Future research investigating the association between physique adaptations and specific performance measures and fitness traits over a pre-season would be of great interest, in particular how these changes impact game performance in-season.

In conclusion, we identified significant whole body and regional body composition changes in elite RU athletes during a pre-season period, at both the team and individual level. Practitioners are encouraged to take an individualised approach to the interpretation of adaptations when tracking physique variables longitudinally, for which knowledge of LSC data is required. Future work exploring ethnicity differentiated body composition changes across the entire season, including the post-season period, would provide practitioners with valuable information allowing for a more personalised approach to athlete training and dietary interventions.

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Conflicts of interest – Nil

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Table 1: Short-term prevision and corresponding SC in resistance trained athletes using the same Hologic Discovery A (Zemski et al., 2018)

	Same Day Technical Error				Consecutive Days Technical Error & Biological Variation			
	Precision		LSC–95% CI		Precision		LSC–95% CI	
	RMS–SD	%CV	RMS–SD	%CV	RMS–SD	%CV	RMS–SD	%CV
Whole body								
BMC (g)	21.1	0.6	59.0	1.7	25.2	0.7	80.5	1.9
Fat Mass (g)	238.4	1.8	660.4	5.1	455.2	2.9	1261.0	8.0
Lean Mass (g)	222.7	0.3	616.8	0.9	752.0	1.1	2083.0	3.2
Arms								
BMC (g)	5.6	1.1	15.5	3.0	6.8	1.3	18.9	3.7
Fat Mass (g)	43.5	2.5	120.5	6.8	89.1	5.3	246.8	14.5
Lean Mass (g)	101.1	1.2	279.9	3.3	154.1	1.9	426.7	5.2
Trunk								
BMC(g)	9.7	0.8	27.0	2.2	9.8	0.9	27.1	2.6
Fat Mass (g)	123.7	2.2	342.5	6.0	221.3	3.6	612.9	9.9
Lean Mass (g)	319.4	0.8	884.7	2.1	678.7	1.9	1880.0	4.1
Legs								
BMC(g)	20.2	1.5	56.1	4.2	18.6	1.5	51.6	4.1
Fat Mass (g)	146.0	2.7	404.4	7.5	230.7	3.4	639.1	9.5
Lean Mass (g)	335.6	1.1	929.6	3.0	406.5	1.5	1126.0	4.1

RMS–SD = root-mean-square standard deviation; CV = coefficient of variance; LSC = least significant change; BMC = bone mineral content

Table 2: Differences in surface anthropometry measures and indices, and dual-energy X-ray absorptiometry measured total and regional body composition characteristics of elite rugby union athletes over the course of a pre-season based on position and ethnicity.

	Position (n=22)				Ethnicity (n=22)			
	Forwards (n=11)		Backs (n=11)		Caucasians (n=11)		Polynesians (n=11)	
	Start Pre-Season	End Pre-Season	Start Pre-Season	End Pre-Season	Start Pre-Season	End Pre-Season	Start Pre-Season	End Pre-Season
Age (years)	22.9 ± 3.5	-	22.8 ± 3.0	-	22.1 ± 2.4	-	23.5 ± 3.8	-
Stature (cm) [c]	191.3 ± 7.5	-	182.2 ± 6.9	-	189.4 ± 8.7	-	184.1 ± 7.6	-
Mass (kg) [b c]	112.5 ± 7.6	112.1 ± 7.6	90.5 ± 8.6	90.4 ± 8.1	101.2 ± 14.3	101.7 ± 14.0	101.8 ± 13.9	100.8 ± 13.6
FFMI (kg/m^2) [b c]	26.1 ± 1.2	26.6 ± 1.1	23.8 ± 1.2	24.3 ± 1.1	24.4 ± 1.3	25.1 ± 1.2	25.5 ± 1.8	25.8 ± 1.9
WB BMC (g) [c]	4352 ± 439	4377 ± 437	3618 ± 379	3637 ± 364	4003 ± 553	4027 ± 548	3966 ± 571	3987 ± 569
WB FM (g) [b c]	19629 ± 3879	17166 ± 3837	13438 ± 2723	11449 ± 1872	15495 ± 4839	13338 ± 4353	17572 ± 4214	15278 ± 3897
WB LM (g) [a b c]	91087 ± 5489	92912 ± 5711	75598 ± 6971	77312 ± 6436	84005 ± 10306	86430 ± 10447	82680 ± 10173	83795 ± 10431
Arms BMC (g) [b c]	662 ± 76	661 ± 78	541 ± 68	535 ± 67	600 ± 106	602 ± 107	603 ± 85	594 ± 88
Arms FM (g) [b c]	2287 ± 426	2038 ± 415	1470 ± 228	1304 ± 157	1759 ± 535	1601 ± 489	1999 ± 554	1741 ± 494
Arms LM (g) [c]	11698 ± 1098	12162 ± 928	9742 ± 1314	10198 ± 1454	10706 ± 1672	11191 ± 1636	10734 ± 1452	11169 ± 1556
Trunk BMC (g) [b c]	1361 ± 179	1381 ± 193	1116 ± 117	1131 ± 127	1270 ± 186	1282 ± 196	1207 ± 205	1231 ± 219
Trunk FM (g) [b c]	8594 ± 2392	7179 ± 2224	5419 ± 1191	5370 ± 824	6326 ± 2183	5079 ± 1910	7687 ± 2627	6470 ± 2293
Trunk LM (g) [b c]	43339 ± 3136	44282 ± 3509	36259 ± 2564	36964 ± 2832	40498 ± 4305	41729 ± 4492	39100 ± 4939	39518 ± 5187
Legs BMC (g) [c]	1623 ± 183	1624 ± 175	1372 ± 162	1383 ± 148	1485 ± 212	1491 ± 198	1510 ± 222	1517 ± 212
Legs FM (g) [b c]	7570 ± 1745	6765 ± 1755	5527 ± 1373	4757 ± 983	6348 ± 2191	5584 ± 2086	6749 ± 1529	5938 ± 1357
Legs LM (g) [b c]	31977 ± 1872	32372 ± 1916	26056 ± 3616	26615 ± 3881	29126 ± 4553	29791 ± 4755	28908 ± 3888	29196 ± 3763

FFMI = fat-free mass index; WB = whole body; BMC = bone mineral content; FM = fat mass; LM = lean mass

Data presented as Mean ± Standard Deviation, significance set at 0.05

[a] Significant interaction between time and ethnicity

[b] Significant main effect for time

[c] Significant difference between forwards and backs

Table 3: Individual athletes who made meaningful dual-energy X-ray absorptiometry measured whole body and regional body composition changes (> LSC 95%CI – technical error and biological variation) during the pre-season.

		All (n=22)	**Position (n=22)**		**Ethnicity (n=22)**	
			Forwards (n=11)	**Backs (n=11)**	**Caucasians (n=11)**	**Polynesians (n=11)**
↑ Bone Mineral Content	**Arms**	1 (5%)	1 (9%)	0 (0%)	1 (9%)	0 (0%)
	Trunk [a]	9 (41%)	6 (55%)	3 (27%)	3 (27%)	6 (55%)
	Legs [b]	5 (23%)	2 (18%)	3 (27%)	3 (27%)	2 (18%)
	WB [c]	4 (18%)	2 (18%)	2 (18%)	3 (27%)	1 (9%)
↓ Fat Mass	**Arms**	10 (45%)	6 (55%)	4 (36%)	3 (27%)	7 (64%)
	Trunk	17 (77%)	9 (82%)	8 (73%)	9 (82%)	8 (73%)
	Legs	14 (64%)	8 (73%)	6 (55%)	8 (73%)	6 (55%)
	WB	17 (77%)	9 (82%)	8 (73%)	9 (82%)	8 (73%)
↑ Lean Mass	**Arms**	11 (50%)	6 (55%)	5 (45%)	6 (55%)	5 (45%)
	Trunk	3 (14%)	3 (27%)	0 (0%)	3 (27%)	0 (0%)
	Legs	2 (9%)	0 (0%)	2 (18%)	1 (9%)	1 (9%)
	WB	8 (36%)	4 (36%)	4 (36%)	6 (55%)	2 (18%)

Data shown as – number of athletes (% of athletes)

WB = whole body

[a] 2 athletes lost BMC in their trunk (Caucasian forward, Polynesian back)

[b] 2 athletes lost BMC in their legs (Caucasian forward, Polynesian back)

[c] 1 athlete lost BMC in their whole body (Caucasian forward)

Figure 1: Individual whole body and regional changes in bone mineral content by the least significant change (LSC) previously determined (Zemski et al., 2018) over a pre-season in elite rugby union athletes. Dashed lines indicate LSC-95% CI same day precision (technical error). Dotted lines indicate LSC-95% CI consecutive day precision (technical error and biological variation).

Figure 2: Individual whole body and regional changes in fat mass by the least significant change (LSC) previously determined (Zemski et al., 2018) over a pre-season in elite rugby union athletes. Dashed lines indicate LSC-95% CI same day precision (technical error). Dotted lines indicate LSC-95% CI consecutive day precision (technical error and biological variation).

Figure 3: Individual whole body and regional changes in lean mass by the least significant change (LSC) previously determined (Zemski et al., 2018) over a pre-season in elite rugby union athletes. Dashed lines indicate LSC-95% CI same day precision (technical error). Dotted lines indicate LSC-95% CI consecutive day precision (technical error and biological variation).