Distribution of Fat, Non-Osseous Lean and Bone Mineral Mass in International Rugby Union and Rugby Sevens Players

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Key words
- anthropometry
- physique
- body composition
- adiposity
- dual-energy X-ray absorptiometry

Abstract

Differences in the body composition of international Rugby Union and Rugby Sevens players, and between players of different positions are poorly understood. The purpose of this study was to examine differences in the quantity and regional distribution of fat, non-osseous lean and bone mineral mass between playing units in Rugby Union and Rugby Sevens. Male Rugby Union (n = 21 forwards, 17 backs) and Rugby Sevens (n = 11 forwards, 16 backs) players from the Australian national squads were measured using dual-energy X-ray absorptiometry. The digital image of each player was partitioned into anatomical regions including the arms, legs, trunk, and android and gynoid regions. Compared with backs, forwards in each squad were heavier and exhibited higher absolute regional fat (Union 43–67 %; ± ~17 %, range of % differences; ± ~95 % confidence limits (CL); Sevens 20–26 %; ± ~29 %), non-osseous lean (Union 14–22 %; ± ~5.8 %; Sevens 6.9–8.4 %; ± ~6.6 %) and bone mineral (Union 12–26 %; ± ~7.2 %; Sevens 5.0–11 %; ± ~7.2 %) mass. When tissue mass was expressed relative to regional mass, differences between Rugby Sevens forwards and backs were mostly unclear. Rugby Union forwards had higher relative fat mass (1.7–4.7 %; ± ~1.9 %, range of differences; ± ~95 % CL) and lower relative non-osseous lean mass (− 4.2 to − 1.8 %; ± ~1.8 %) than backs in all body regions. Competing in Rugby Union or Rugby Sevens characterized the distribution of fat and non-osseous lean mass to a greater extent than a player's positional group, whereas the distribution of bone mineral mass was associated more with a player's position. Differences in the quantity and distribution of tissues appear to be related to positional roles and specific demands of competition in Rugby Union and Rugby Sevens.

Introduction

Physique traits of players are important factors associated with success in international Rugby Union. In the Rugby World Cup, the height and mass of players increased progressively between 1987 and 2007, with higher ranking teams having taller backs and heavier forwards [31]. A greater body mass is advantageous during physical contests for the ball. However, when additional mass is carried as fat, a player's power-to-weight ratio, acceleration and metabolic efficiency may be compromised [35]. Higher relative fat mass is also associated with a greater reliance on carbohydrate metabolism [14] and may impair thermoregulation [32]. Quantifying a player's body composition therefore provides valuable information for dietary and training prescription.

Rugby Sevens is a shortened format of Rugby Union that will debut at the Olympic Games in 2016. Rugby Sevens competitions are contested in a tournament format where matches are played over 7-min halves (10-min halves in tournament finals) with 7 players on the field for each team. The relationship between kinanthropometric measures and performance in Rugby Sevens is unclear [26]. Given the higher relative movement demands and reduced emphasis on physical contact of Rugby Sevens compared with Rugby Union [11], it is likely the body composition of international-level players in each format also differ [12]. Understanding the physique characteristics of Rugby Union and Rugby Sevens players could assist in directing players into the Rugby format and positional group to which they are best physically suited. This information could also be used to increase the specificity of physical preparation and dietary programs.

Although body composition is typically described at a whole-body level, dual-energy X-ray

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absorptiometry (DXA) enables valid and reliable measurement of regional body composition [20]. Limited information exists regarding the relationship between regional distribution of tissue and sporting performance. Faster sprinters have lower relative body fat and greater muscle thickness in the upper thigh than their slower peers [15]. Deposition of mass more proximal to the joint may enhance biomechanical efficiency, offering a performance advantage [28]. Preliminary research has identified differences in the quantity and distribution of fat, non-osseous lean and bone mineral mass between Rugby Union backs and forwards [4]. These differences appear to be related to variations in competition requirements and playing roles of positional groups. However, to date no published data exist on players competing at the highest level of international Rugby Union or Rugby Sevens competition. The purpose of this study was to quantify and compare the regional distribution of fat, non-osseous lean and bone mineral mass measured by DXA between positional groups in international-level Rugby Union and Rugby Sevens.

Methods

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Experimental approach

A cross-sectional design was employed to compare the regional quantity and distribution of fat, non-osseous lean and bone mineral mass. Rugby Union players underwent a DXA scan 20 ± 3 days (mean ± SD), and Rugby Sevens players 43 ± 16 days, prior to the commencement of their respective international competitions.

Participants

Thirty-eight Rugby Union and 27 Rugby Sevens players in the national men's squads representing Australia in international competition (world ranking at the time of the study: Rugby Union, 2nd; Rugby Sevens, 6th) provided informed consent to participate in the study. Players in each squad were assigned to groups based on their playing position as either forwards (Union n = 21; Sevens n = 11) or backs (Union n = 17; Sevens n = 16). The study procedures had institutional ethics committee approval and conformed to the standards of the International Journal of Sports Medicine [10].

Standardized DXA measurement and analysis

The body composition of players was measured using a whole-body DXA scan. Players were scanned in the morning following an overnight fast and had not undertaken any exercise on the morning of the scan. Players were scanned with standardized positioning wearing light clothing and with all jewelry and metal objects removed [20]. Given geographical constraints and player availability it was not possible to use the same DXA scanner for all players. Rugby Union players were measured using a Hologic Discovery A scanner (Hologic Inc., Bedford, MA) and Rugby Sevens players with a Lunar Prodigy scanner (GE Healthcare, Madison, WI). Scanners were calibrated according to manufacturers' guidelines. One experienced operator conducted and analyzed all scans for Rugby Union players, and another experienced operator conducted and analyzed all scans for the Rugby Sevens squad. Players too large to fit within the scan area of the machine were measured using multiple scans [21]. The typical error of measurement expressed as a coefficient of variation (%) for whole-body and regional DXA measurements in males using the Lunar Prodigy scanner is 1.9–3.7 % for fat, 0.4–1.5 % for non-osseous lean and 0.5–2.2 % for bone mineral mass [20]. The Hologic scanner demonstrates coefficients of variation ranging from 0.2–3.5 % [29].

Scans of Rugby Union players were analyzed using Apex software (version 3.3, Hologic Inc., Bedford, MA) and Rugby Sevens players with enCORE software (version 13.6, GE Healthcare, Madison, WI). The digital image of the player was partitioned into anatomical regions including the head, arms, legs, trunk, android and gynoid regions. Horizontal lines were placed directly inferior to the mandible to mark the head and at the level of the iliac crests. Lines running through the glenohumeral joints, isolating the arms from the trunk, joined the superior and inferior horizontal lines. Oblique lines running from the horizontal line at the level of the iliac crest through the femoral necks separated the trunk and legs. Lines placed lateral to the legs separated the arms and legs, and a line placed medial to the legs separated left and right leg. The android region was defined by an inferior border at the iliac crest line, a superior border 20 % of the distance between iliac crest and mandible lines, and lateral borders at the lines separating the trunk and arms. The gynoid region was defined by a superior border below the iliac crest line at a level 1.5 times the vertical length of the android region. The vertical length of the gynoid region was twice the vertical length of the android region with lateral borders at the lines lateral to each leg.

Statistical analysis

Given differences in the partitioning of tissue measured using DXA scanners of different models and lack of population-specific cross-calibration equations for each tissue and region of interest [33], total mass along with absolute and relative quantities of each tissue mass in the arms, legs, trunk, android and gynoid segments were analyzed separately for the Rugby Union and Rugby Sevens squads. In the android and gynoid regions, only fat mass was analyzed. In the context of this study, "fat" refers to extractable lipids such as triglycerides and fatty acids, primarily found in adipose tissue but also present in skeletal muscle, organs and bone marrow. Conversely, "adipose tissue" refers to masses under the skin (subcutaneous) and surrounding muscles and organs (visceral) separable by dissection, composed chiefly of lipids, but also water, protein and minerals [6]. The proportion of mass in each region relative to DXA-derived whole-body mass was also analyzed for each positional group within each squad. Descriptive data are presented as mean ± SD. A ratio of each tissue mass in the arms, legs and trunk to the corresponding whole-body tissue mass was calculated to indicate the regional distribution of tissue independent of the absolute quantity of tissue. Principal components analyses were conducted on the ratio values to identify the distribution of each tissue for all players. Components with eigenvalues > 1.0 were considered meaningful. Component scores were compared between backs and forwards regardless of their squad, between Rugby Sevens and Rugby Union players and between positional groups within and between squads.

Magnitude-based inferences on differences between positional groups and squads were made by standardizing differences using the between-player SD. Positional group differences in whole-body mass and the absolute mass of each tissue in each region were assessed via log-transformed data to reduce the non-uniformity of error, and back-transformed to obtain differences in means as percents. Magnitudes of standardized differences in means were assessed as 0–0.2 being trivial, 0.2–0.6

Table 1 Differences in absolute regional tissue mass between forwards and backs in Rugby Union and Rugby Sevens.

		Rugby Union				Rugby Sevens			
		Forwards (n=21)	Backs (n=17)			Forwards (n=11)	Backs (n=16)		
Region	Tissue mass (g)	Mean±SD	Mean±SD	% difference; ±95% CL	Qualitative outcome	Mean±SD	Mean±SD	% difference; ±95% CL	Qualitative outcome
Android	Fat	1165±392	723±244	59; ±21	Large +	948±205	853±412	20; ±31	Unclear
Gynoid	Fat	3400±709	2116±568	61; ±16	Very large +	2689±490	2360±1058	22; ±28	Small +
Left arm	Fat	960±216	645±165	49; ±15	Large +	543±116	467±247	24; ±28	Moderate +
	Lean	6064±541	5020±464	20.8; ±6.4	Large +	5752±494	5391±571	6.9; ±8.2	Moderate +
	Bone	328±29	265±26	23.9; ±6.5	Very large +	328±33	304±26	7.8; ±8.1	Moderate +
Right arm	Fat	976±224	682±179	43; ±16	Large +	571±127	485±257	25; ±29	Moderate +
	Lean	6409±632	5252±428	21.8; ±6.3	Very large +	6029±305	5608±584	7.9; ±6.5	Moderate +
	Bone	354±31	282±28	25.6; ±6.5	Very large +	345±28	314±31	10.2; ±7.5	Moderate +
Left leg	Fat	3373±721	2040±472	65; ±15	Very large +	2249±436	1896±800	26; ±29	Moderate +
	Lean	15889±1483	13821±979	14.7; ±5.5	Large +	13723±799	12673±957	8.4; ±5.4	Moderate +
	Bone	814±86	724±68	12.3; ±6.8	Moderate +	856±59	797±67	7.4; ±6.2	Moderate +
Right leg	Fat	3418±714	2114±530	62; ±16	Very large +	2236±414	1892±755	25; ±27	Moderate +
	Lean	16082±1530	14086±1038	14.0; ±5.7	Large +	13679±924	12811±1013	6.9; ±6.0	Moderate +
	Bone	813±96	710±63	14.2; ±7.1	Large +	849±58	809±58	5.0; ±5.8	Moderate +
Trunk	Fat	7056±2312	4202±1390	67; ±20	Large +	6676±1096	5842±2625	23; ±28	Moderate +
	Lean	42751±2733	36912±2902	15.9; ±5.0	Large +	35075±2598	32396±2898	8.4; ±6.8	Moderate +
	Bone	1391±203	1149±134	20.7; ±9.1	Large +	1593±127	1447±181	10.5; ±8.6	Moderate +

Lean = non-osseous lean tissue; + indicates a substantially larger tissue mass in forwards compared with backs

small, 0.6–1.2 moderate, 1.2–2.0 large and >2.0 very large. To reduce the chance of errors regarding inferences, precision of estimates were indicated with 95% confidence limits. Differences were reported as unclear when the confidence interval of the standardized difference crossed the threshold for both substantially positive (0.2) and negative (−0.2) values.

Results

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Age and body mass

Rugby Union forwards (25.3±3.4 years) and backs (24.5±1.9 years) were older than their Rugby Sevens counterparts (forwards 22.4±2.3 years; backs 21.5±2.0 years), but there were no clear differences in the ages of backs and forwards within the same squad. Backs were lighter than forwards in each squad. There was a large difference in whole-body mass between Rugby Sevens forwards (95.0±5.1 kg) and backs (87.4±7.3 kg), whereas the difference between Rugby Sevens forwards and Rugby Union backs (92.3±6.8 kg) was unclear. Rugby Union backs were moderately heavier than Rugby Sevens backs, while Rugby Union forwards (111.7±7.9 kg) exhibited very large differences in body mass compared with all other groups.

Absolute regional tissue mass

Forwards in Rugby Union had large to very large positive differences in every tissue mass across all regions compared with backs, with the exception of only moderately greater bone mass in the left leg (▶ **Table 1**). Forwards in Rugby Sevens had more absolute fat mass in the gynoid region, but an unclear difference in the android region compared with backs. Rugby Sevens forwards also had moderately greater fat, non-osseous lean and bone mineral mass than backs in the arms, legs and trunk (▶ **Table 1**).

Relative regional tissue mass

Relative to the total mass in each region, non-osseous lean tissue proportionately comprised the greatest mass in both Rugby Sevens and Rugby Union players, while bone comprised the least (▶ **Table 2**). In Rugby Union players, forwards had moderately lower relative bone mineral mass in the legs than backs (▶ **Table 2**). Compared with Rugby Union backs, forwards had greater relative fat mass in all regions, offset by lower relative non-osseous lean mass in the arms, legs and trunk. With the exception of lower right leg bone mineral mass in forwards compared with backs, there were no clear differences in relative tissue mass between positional groups in Rugby Sevens when tissue mass was analyzed as a proportion of total regional mass (▶ **Table 2**).

Distribution of mass

There were no clear differences between positions in Rugby Sevens players when regional mass was expressed relative to DXA-derived whole-body mass (▶ **Fig. 1a**). Rugby Union forwards had higher proportional mass in the arms than backs (small standardized differences), but unclear differences in other regions (▶ **Fig. 1b**). Players in both squads carried the largest proportion of their mass in the trunk, followed by the legs and arms.

Distribution of tissue

Two principal components were considered to be meaningful for each tissue distribution, collectively explaining 72–96% of the variance in distribution (▶ **Table 3**). The first principal component of fat accounted for 74% of the variance in regional mass distribution in all players. The first component of fat distribution characterized a trunk-extremity contrast, representing a continuum from total fat deposition at the trunk to total deposition at the limbs, through a high negative loading of the trunk (−0.98) and high positive loading of the arms (left 0.81, right 0.83) and legs (left 0.82, right 0.84) (▶ **Table 3**). The second fat component accounted for 22% of the distribution variance and identified a lower limb-upper limb contrast. The first non-osseous lean

Table 2 Differences in relative regional tissue mass between forwards and backs in Rugby Union and Rugby Sevens.

		Rugby Union				Rugby Sevens			
		Forwards (n=21)	Backs (n=17)			Forwards (n=11)	Backs (n=16)		
Region	Tissue mass (%)	Mean±SD	Mean±SD	Difference; ±95% CL	Qualitative outcome	Mean±SD	Mean±SD	Difference; ±95% CL	Qualitative outcome
Android	Fat	16.0±4.0	12.3±2.5	3.7; ±2.2	Moderate +	16.5±3.0	15.9±6.0	0.6; ±3.7	Unclear
Gynoid	Fat	18.5±3.1	13.9±2.7	4.7; ±1.9	Large +	17.8±2.8	16.5±5.8	1.4; ±3.5	Unclear
Left arm	Fat	13.1±3.2	10.8±2.0	2.3; ±1.7	Moderate +	8.2±1.7	7.5±3.2	0.7; ±2.0	Unclear
	Lean	82.4±3.1	84.7±1.9	−2.3; ±1.7	Moderate −	86.8±1.7	87.6±3.2	−0.7; ±2.0	Unclear
	Bone	4.5±0.3	4.5±0.4	−0.0; ±0.2	Unclear	4.9±0.2	5.0±0.4	0.0; ±0.3	Unclear
Right arm	Fat	12.7±3.2	10.9±2.2	1.7; ±1.8	Moderate +	8.2±1.7	7.5±3.2	0.7; ±1.9	Unclear
	Lean	82.7±3.4	84.5±2.2	−1.8; ±1.8	Moderate −	86.8±1.7	87.6±3.2	−0.8; ±1.9	Unclear
	Bone	4.6±0.4	4.5±0.3	0.0; ±0.2	Unclear	5.0±0.3	4.9±0.4	0.1; ±0.3	Unclear
Left leg	Fat	16.7±3.0	12.3±2.3	4.5; ±1.7	Large +	13.3±2.4	12.2±4.5	1.2; ±2.8	Unclear
	Lean	79.2±2.9	83.4±2.1	−4.2; ±1.7	Large −	81.6±2.4	82.6±4.4	−1.1; ±2.7	Unclear
	Bone	4.1±0.4	4.4±0.3	−0.3; ±0.2	Moderate −	5.1±0.2	5.2±0.3	−0.1; ±0.2	Unclear
Right leg	Fat	16.8±3.0	12.5±2.5	4.3; ±1.8	Large +	13.3±2.4	12.1±4.3	1.3; ±2.7	Unclear
	Lean	79.2±3.0	83.3±2.4	−4.1; ±1.8	Large −	81.6±2.4	82.7±4.3	−1.1; ±2.7	Unclear
	Bone	4.0±0.3	4.2±0.3	−0.2; ±0.2	Moderate −	5.1±0.2	5.2±0.3	−0.2; ±0.2	Small −
Trunk	Fat	13.6±3.7	9.8±2.4	3.8; ±2.0	Moderate +	15.4±2.2	14.5±5.5	0.9; ±3.2	Unclear
	Lean	83.7±3.6	87.4±2.2	−3.8; ±1.9	Large −	80.9±2.3	81.9±5.7	−0.9; ±3.3	Unclear
	Bone	2.7±0.3	2.7±0.3	−0.0; ±0.2	Unclear	3.7±0.3	3.7±0.3	0.0; ±0.2	Unclear

Lean = non-osseous lean tissue; + or − indicates a substantially larger or smaller proportional tissue mass in forwards compared with backs, respectively

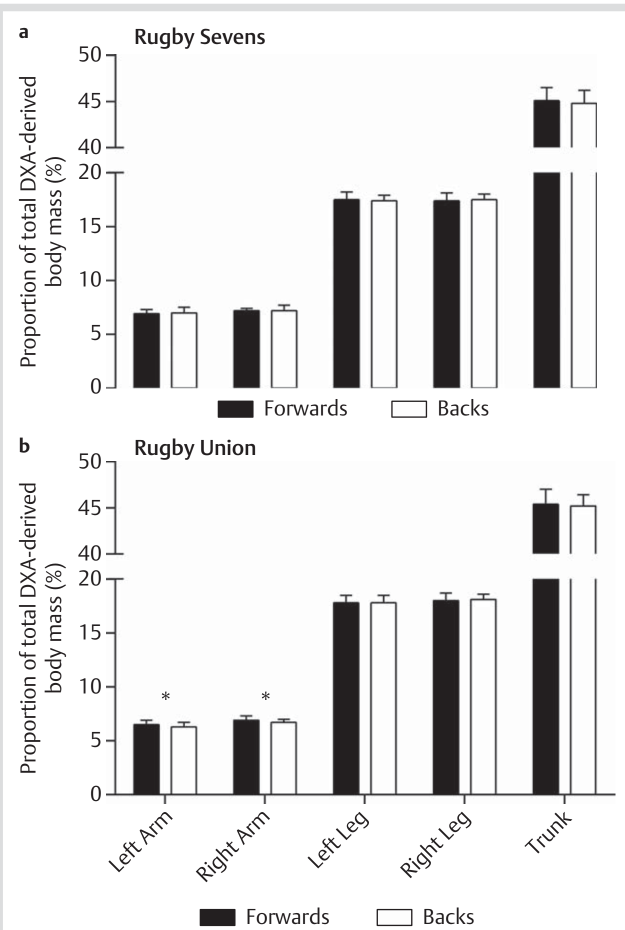

Fig. 1 Regional mass of Rugby Sevens **a** and Rugby Union **b** backs and forwards as a proportion of DXA-derived whole-body mass (mean + SD). *Greater relative regional mass in forwards than backs (small standardized difference).

tissue component characterized a trunk-upper limb contrast, while the second component demonstrated an upper body-lower body contrast. The first bone mineral mass component contrasted the trunk and legs with the arms, while the second component characterized a trunk-extremity contrast.

There was substantial variation in principal component scores by squad and positional group for fat (▶ **Fig. 2a**), non-osseous lean (▶ **Fig. 2b**) and bone mineral (▶ **Fig. 2c**) mass. Substantial differences between Rugby Union and Rugby Sevens players were observed for both fat components (first component very large standardized difference; second component small difference), both non-osseous lean components (first component very large difference; second component small difference) and the first bone mineral component (moderate difference). In other words, compared with Rugby Union players, Rugby Sevens players had greater fat deposition in the trunk than limbs and in the lower rather than upper limbs, stored greater lean soft-tissue mass in the arms than trunk, and stored more bone mineral mass in their trunk and legs than arms.

The combined forwards were moderately higher than backs in the first bone mineral component indicating that, relative to backs, forwards deposited more bone in the arms than trunk and legs. Forwards were also lower than backs by a small magnitude in the second components of fat and bone mineral mass, indicating that, relative to backs, forwards deposited more fat in the legs than arms and more bone in the trunk than limbs. Positional group differences were unclear for non-osseous lean mass distribution.

Compared with all other players, Rugby Union backs carried relatively more fat in the arms than legs (▶ **Fig. 2a**; moderate differences with other groups) and greater lean soft tissue in the trunk than arms (▶ **Fig. 2b**; small to very large differences). In contrast, Rugby Union forwards deposited relatively greater bone mineral mass in the arms than trunk and legs compared to all other players (▶ **Fig. 2c**; moderate to large differences). Rugby Union forwards also had more non-osseous lean mass in the trunk than arms compared with Rugby Sevens players (large

Table 3 Principal components of combined relative regional fat, non-osseous lean and bone mineral mass.

	Fat mass		Non-osseous lean mass		Bone mineral mass	
	Component 1	Component 2	Component 1	Component 2	Component 1	Component 2
left arm	0.81	0.54	0.92	−0.32	0.78	0.38
right arm	0.83	0.52	0.93	−0.24	0.86	0.21
left leg	0.82	−0.53	0.12	0.93	−0.35	0.86
right leg	0.84	−0.51	0.11	0.91	−0.44	0.80
trunk	−0.98	0.01	−0.92	−0.33	−0.46	−0.39
eigenvalue	3.69	1.09	2.58	1.97	1.87	1.72
variance (%)	74	22	52	39	37	34
distribution contrast	trunk-extremity	lower limb-upper limb	trunk-upper limb	lower body-upper body	trunk/lower limb-upper limb	trunk-extremity

differences), but less than Rugby Union backs (small difference) (▶ **Fig. 2b**).

Discussion

Knowledge of the body size and composition characteristics of elite-level Rugby players is important for monitoring adaptations to training and diet, as well as informing the selection of players in apposite positions and/or Rugby formats. This is the first study to compare the regional composition and distribution of mass between backs and forwards in international-level Rugby Union and Rugby Sevens. The findings offer insight into the quantity and distribution of tissue mass of internationally-competitive players in regard to playing position and game format. Given the international standard of the players in this study, the results provide reference values useful for talent identification and transfer purposes. Forwards are characterized by a higher whole-body mass, as well as greater fat, lean and bone mass compared with backs, although to a lesser extent in Rugby Sevens. In addition, the anatomical distribution of tissue varies between positional groups and Rugby formats.

Positional group differences in tissue mass

Forwards have a greater body mass than backs in both Rugby Union and Rugby Sevens, which is not surprising given differences in positional roles during competition. The primary objective of forwards is to contest possession in set-piece plays as well as rucks and mauls, while backs use possession to gain territory and score points. Whole-body mass differences between positions derive from forwards having more adipose, non-osseous lean and bone tissue. Although the positional group differences are consistent between Rugby Union and Rugby Sevens, the magnitude of difference between forwards and backs was greater in Union players. Smaller positional group differences in Rugby Sevens players in absolute tissue masses are consistent with previous findings of relatively uniform anthropometric, physiological and performance characteristics [12].

Linear momentum is the product of mass and velocity. When other attributes remain constant, a higher body mass produces a higher momentum regardless of the type of tissue of the additional mass. Greater momentum is beneficial during contests for the ball and when effecting or breaking a tackle. However, applying Newton's second law of motion ($F = m \cdot a$) suggests that additional mass (m) in the form of non-functional adipose tissue will be detrimental to a player's ability to accelerate (a) without a corresponding increase in the muscle force (F) applied. Despite this, there has been a progressive increase in the body mass of Rugby players of all positions in recent decades as players attempt to gain a physical advantage over opponents [23,25,31]. Increasing whole-body mass through excess energy intake alone typically results in greater proportional gains in fat than fat-free mass [16], as optimizing muscle hypertrophy is a multifactorial process [30]. The comparative complexity of increasing lean rather than fat mass may partially explain the higher absolute and relative fat mass in Rugby Union forwards compared with backs in the same squad.

Forwards in Rugby Union sprint less [1,7,27] and have more contacts [34] than backs during competition. It is likely an increase in fat mass has less of an effect on the movement profile of a forward compared with a back. However, given the higher requirements for speed and endurance [11] and smaller differences in the activity profiles of forwards and backs in Rugby Sevens competition [13] the greater homogeneity of regional tissue mass proportions observed in this study was not unexpected. Although positional differences in Rugby Sevens players were unclear when tissue mass was expressed as a proportion of total regional mass, differences between backs and forwards followed the trends observed in the Rugby Union players. In other words, forwards tended to have slightly greater relative fat mass, lower relative non-osseous lean mass and similar or lower relative bone mineral mass than backs across all regions. The greater fat mass in forwards may attenuate the high forces transferred during contact [3]. Despite the purported role of fat mass as a physical buffer, there is little evidence the quantity or distribution of adipose tissue offers such protection [24]. Longitudinal research utilizing large numbers of players of different positions is needed to elucidate relationships between physique characteristics and risk of injury.

A compromise between a player's size and mobility may be necessary for fully meeting the position-specific demands of training and competition. The ideal physique characteristics most likely to positively influence locomotion and movement patterns typical of Rugby competition, including the translation of force during contact, require further investigation. Although the technical skill components of Rugby-specific tasks must be acknowledged, additional research is needed to examine associations between the quantity and distribution of tissue in Rugby players and functional measures, such as power, agility, running speed and scrummaging force.

Distribution of mass

Quantifying the regional distribution of mass may be useful in highlighting priorities for the physical development of players. The combined mass of the legs expressed as a proportion of whole-body DXA-derived mass of players in this study (~35–36%) was similar to lower-level Rugby Union players and their recreationally active controls matched for body mass index

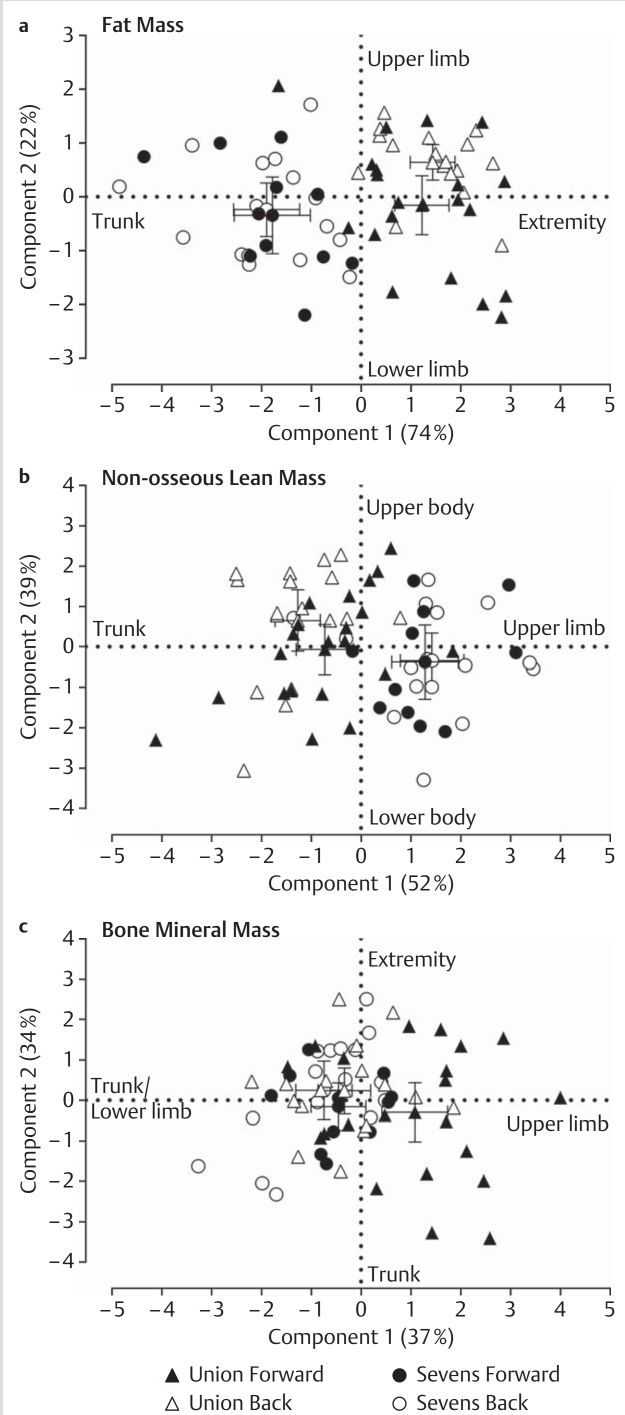

Fig. 2 Principal component scores of Rugby Union and Rugby Sevens backs and forwards for fat **a**, non-osseous lean **b** and bone mineral **c** mass distribution. Mean ± 95 % confidence interval is shown for each group.

(~35 %) [4], but less than U.S. Army Rangers candidates (~39 %) [22]. Trunk mass comprised ~45 % of whole-body DXA mass, which was greater than U.S. Army Rangers candidates (~43 %) [22], but less than lower-level Rugby Union players and controls (~48 %) [4]. Combined arm mass accounted for ~13–14 % of DXA-derived mass, higher than both U.S. Army Rangers candidates (~12 %) [22] and lower-level Rugby Union players (~12 %) [4]. The arms are important for many Rugby-specific skills. With the exception of passing, many of these skills relate to contact situations, such as fending, lifting, tackling, grappling and turning opposition players, and binding during scrums, rucks and mauls. The relatively high proportional arm mass in international-level players indicates the importance of supporting these skills by increasing arm mass, primarily through the development of lean tissue. Rugby Union forwards had a greater proportion of total mass in the arms compared with Rugby Union backs, again highlighting the importance of mass in the upper limbs for contact-related skills.

The lower body of Rugby players contributes to performance through power produced during skills such as rucking, mauling, scrummaging, jumping during line-outs, and running. The trunk is also an important constituent of a player's physique, creating a stable framework for generating and transfering force during contact [18]. It is apparent that a strong trunk and legs are essential elements in optimizing a player's performance. The trunk contains a high proportion of non-osseous lean mass from organs, whereas the soft-tissue lean mass of limbs is composed almost entirely of skeletal muscle tissue. Although non-osseous lean tissue is not a substitute for muscle tissue, a higher proportional lean mass is likely to improve a player's ability to produce force and power. Given variations in competition demands, the optimal total mass and ratio of regional lean and fat mass differ substantially between positions and between Rugby Union and Rugby Sevens. Specialized training and dietary interventions may be necessary for optimizing a player's physique specific to his position and game format.

Distribution of fat

The first principal component of fat distribution characterized a trunk-extremity contrast, consistent with previous observations in athletes and non-athletes [2, 17, 19]. This pattern of fat deposition is consistent across ethnic groups and reflects a masculine characteristic associated with sex-hormone levels [2]. Explanations for substantial differences in fat distribution between Rugby Union and Rugby Sevens players regardless of position, and a small difference between forwards and backs in lower limb-upper limb fat distribution regardless of squad, require further study. Although sport participation and specialized training for competition have a larger effect on absolute body-fat levels than fat distribution [17], other lifestyle and biological factors may influence differences in fat deposition. For example, testosterone is an important regulator of the distribution of central and peripheral adipose tissue in men [5]. Anatomical fat distribution is also influenced by ethnicity [2, 17]. Eight players in each squad (backs and forwards) were of Polynesian, Melanesian or Aboriginal Australian ethnicity. Although the distribution of tissue mass appears to be largely biological with relatively little influence of competing in sport, the interaction of genetic and environmental factors influencing tissue distribution requires further examination.

Distribution of non-osseous lean mass

Magnitudes of difference between the squads in non-osseous lean mass distribution were concordant with differences in fat distribution. Rugby Union backs and forwards had trunk-upper limb distribution contrasts that were not only distinct from Rugby Sevens players, but also from one another. However, differences in distribution between backs and forwards regardless of the Rugby format they played were unclear. A previous study of non-osseous lean tissue distribution in lower-level Rugby Union players concluded that the arms and legs contribute equally to playing performance based on similar principal component loadings at these sites [4]. Our investigation of international-level players produced different results, showing a primary trunk-arm contrast explaining 52% of variance in distribution. The legs had a high positive loading in the second non-osseous lean mass component, but as with fat and bone mass, the second component scores were closer to zero than the first component in all groups, indicating less contrast between the lower and upper body. The observed distribution patterns highlight the importance of lean mass development in the upper body for top-level players.

Distribution of bone mineral mass

The two components of bone mineral mass explained a similar proportion of the variance in distribution. Differences between squads and between positional groups in the first component were moderate. However, a small difference was present between backs and forwards in the second component regardless of their squad, while the difference between Rugby Sevens and Rugby Union was unclear. The distribution of bone mineral mass was distinct for Rugby Union forwards by their propensity to store a greater proportion of mass in the arms than all other groups. Enhanced appendicular skeletal mass accretion in the arms of Rugby Union forwards is likely the result of adaptation to bone deformations due to vibration and strain induced by muscle contractions and a high frequency of impacts [8,9]. The higher body mass and frequency of engagement of forwards in contact situations, including pushing in scrums and jumping and supporting in line-outs, increase the osteogenic mechanical stimuli compared with backs. As with the other tissues, higher bone mineral mass in forwards than backs may be explained by the combination of selection of playing position based on genetic predisposition and adaptation to the specific role requirements of competition.

Conclusion

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While forwards have a greater quantity of fat, lean and bone mass than backs in both Rugby Union and Rugby Sevens, the magnitude of difference between the positional groups is greater in Rugby Union players. These differences likely represent variation in the physical demands of competition between positional groups in each Rugby format. When regional tissue mass is expressed as a proportion of total regional mass, positional group differences persist in Rugby Union players, but become predominantly unclear in Rugby Sevens players. It appears the advantage of higher body mass gained through an increase in absolute fat mass and proportional decrease in non-osseous lean mass in international Rugby Union forwards is greater than any potential detriment to physical performance and work capacity. Achieving the ideal ratio of fat and lean mass in each anatomical region should contribute to optimal physical performance. The most effective absolute and relative tissue masses vary between Rugby formats, positions and individuals. Competing at the international level in Rugby Union or Rugby Sevens characterizes the distribution of fat and non-osseous lean mass to a greater extent than a player's positional group. However, the distribution of bone mineral mass is associated more with a player's position than the Rugby format in which he competes.

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