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1 **Three-compartment body composition changes in professional rugby union players over**
2 **one competitive season: a team and individualised approach**

3

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7

8 Matthew J. Lees*¹, Brian Oldroyd¹, Ben Jones¹, Amy Brightmore¹, John P. O’Hara¹, Matthew J.
9 Barlow¹, Kevin Till¹ and Karen Hind¹

10

11 ¹ *Institute for Sport, Physical Activity and Leisure, Leeds Beckett University,*
12 *Leeds, West Yorkshire, United Kingdom*

13

14 Corresponding Author

15 Mr Matthew Lees,

16 Room 227, Fairfax Hall,

17 Headingley Campus, Leeds Beckett University,

18 Leeds, West Yorkshire, LS6 3QS.

19 Tel: (+44) 0113 812 3353

20 Email: m.lees@leedsbeckett.ac.uk

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27

1 **Abstract**

2 The purpose of this study was to investigate longitudinal body composition of professional rugby
3 union players over one competitive season. Given the potential for variability in changes, and as the
4 first to do so, we conducted individual analysis in addition to analysis of group means. Thirty-five
5 professional rugby union players from one English Premiership team (forwards: $n=20$, age: 25.5 ± 4.7
6 years; backs: $n=15$, age: 26.1 ± 4.5 years) received one total-body dual-energy X-ray absorptiometry
7 (DXA) scan at preseason (August), midseason (January) and endseason (May), enabling
8 quantification of body mass, total and regional fat mass, lean mass, percentage tissue fat mass
9 (%TFM) and bone mineral content (BMC). Individual analysis was conducted by applying least
10 significant change (LSC), derived from our previously published precision data and in accordance
11 with International Society for Clinical Densitometry (ISCD) guidelines. Mean body mass remained
12 stable throughout the season ($p>0.05$), but total fat mass and %TFM increased from pre to endseason,
13 and mid to endseason ($p<0.05$). There were also statistically significant increases in total-body BMC
14 across the season ($p<0.05$). In both groups, there was a loss of lean mass between mid and endseason
15 ($p<0.018$). Individual evaluation using LSC and Bland-Altman analysis revealed a meaningful loss of
16 lean mass in 17 players and a gain of fat mass in 21 players from pre to endseason. Twelve players
17 had no change and there were no differences by playing position. There were individual gains or no
18 net changes in BMC across the season for 10 and 24 players, respectively. This study highlights the
19 advantages of an individualised approach to DXA body composition monitoring and this can be
20 achieved through application of derived LSC.

21

22 **Keywords:** team sport; fat mass; lean mass; bone mineral content; imaging

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1 **Introduction**

2 Rugby union is a field-based contact sport, contested by two teams of 15 players over 80 minutes of
3 match play ^[1]. The Premiership constitutes the highest level of professional rugby union in England,
4 comprising of 12 teams that compete from September to May. In addition to 22 league fixtures, teams
5 also compete in both domestic and international cup competitions. Successful performance in rugby
6 union requires players to possess high levels of muscular power, strength and speed, in addition to a
7 high aerobic and anaerobic capacity ^[1-3]. To meet the physical demands of the game, an optimal
8 power-to-weight ratio is desired through lean mass and the avoidance of unfavourably high levels of
9 fat mass. This assists players in maximising their aerobic and anaerobic capacity ^[4, 5].

10 In rugby union, distinct physical differences exist between forwards and backs - forwards are
11 taller, heavier and possess greater fat, lean and bone mass than backs ^[6, 7]. These differences are
12 indicative of the discrete demands placed upon each positional group, whereby forwards typically
13 spend more time engaging in static tasks such as rucking, mauling and scrummaging, and backs tend
14 to cover greater total distances and perform more high-intensity running activity ^[3, 8, 9]. Hence, it is
15 clear that divergent body composition profiles are required with regards to player position and these
16 should be considered when assessing body composition.

17 Cross-sectional body composition data have been reported for academy and professional
18 rugby players using skinfold assessment ^[10, 11] and dual-energy X-ray absorptiometry (DXA) ^[6, 7, 12, 13].
19 Although skinfold analysis is practical for field-based measurements, DXA provides more of an in-
20 depth analysis, establishing individual levels of fat mass, lean mass and bone mineral content (BMC)
21 and is recognised as a criterion method for the measurement of total ^[14, 15] and regional ^[16, 17] body
22 composition.

23 In rugby union, the professional season is preceded by a preseason period before weekly
24 competition begins ^[10]. During this time, increased lean mass and decreased fat mass are primary
25 objectives for most players ^[2, 10]. The maintenance of this profile throughout the competitive season
26 may be beneficial for performance and health, given the ergolytic effects of excess body fat on energy
27 expenditure and movement economy ^[1], and that lean mass may attenuate the risk of contact injury
28 ^[18]. However, seasonal changes in three-compartment body composition of rugby league players, but

1 not rugby union players, have been reported elsewhere ^[19, 20]. Previous studies of athlete body
2 composition change have also not evaluated data at the individual level, and hence rely solely on
3 group differences that reach statistical significance. Interpretation of group means alone will not
4 enable the capture of important information on potential heterogeneity in player response to exercise
5 and recovery. Individual longitudinal change in body composition can be evaluated by applying least
6 significant change (LSC) as determined from precision error for the specific group ^[21, 22]. The purpose
7 of this study was to investigate both team and individual DXA-derived body composition changes
8 across one competitive season in professional rugby union players.

9

10 **Methods**

11 *Study design*

12 The present study followed players from an English Premiership rugby union team over a period of
13 ten months using an observational, longitudinal research design.

14

15 *Participants*

16 Thirty-seven professional male rugby union players from one English Premiership rugby union club
17 were recruited for participation in the study, constituting the entire senior playing staff. Two players
18 (forwards) were excluded due to experiencing an injury which kept them from normal training and
19 inclusion in games. The final sample consisted of 35 players (forwards: $n=20$, age: 25.8 ± 4.7 years,
20 height: 186.0 ± 7.1 cm; backs: $n=15$, age: 26.1 ± 4.5 years, height: 183.3 ± 4.0 cm), with all players
21 successfully completing the study. There were no instances of missing data or players lost to follow-
22 up after beginning the study. Positional forwards consisted of six props, five hookers, two locks, and
23 seven back-row forwards, and positional backs consisted of three centres, three scrum-halves, three
24 fly-halves, three wingers and three fullbacks. By ethnic group, there were 17 Caucasian, one Black
25 and two Polynesian forwards and 12 Caucasian, one Black and two Polynesian backs. Prior to testing,
26 all participants provided signed, informed consent and the study was approved by the University
27 Faculty Research Ethics Committee.

28

1 *Physical measurements*

2 For all tests, players wore shorts without buckles or catches and removed all jewellery. Height was
3 measured using a stadiometer (SECA Alpha, Birmingham, UK) to the nearest millimetre and body
4 mass was measured using calibrated electronic scales (SECA Alpha 770, Birmingham, UK) to the
5 nearest gram. Players received one total-body DXA scan (Lunar iDXA, GE Healthcare, UK) at the
6 end of preseason (August), midseason (January) and endseason (May) in a euhydrated state (urine
7 osmolality $<700 \text{ mOsmol}\cdot\text{kg}^{-1}$)^[23] to ensure that lean mass was not affected by hydration status^[17].
8 Participants were positioned supine on the scanning table with arms situated to their side and ankles
9 supported using the Lunar ankle strap. The standard mode scans took approximately 6.5 minutes,
10 whereas heavier participants (those above 100 kg in body mass) necessitated the use of the thick mode
11 scan, of which the duration was approximately 12.5 minutes. For consistency the scan mode and
12 position selected for the preseason measurement was used for the mid and endseason measurements.
13 From each scan, total and regional fat mass, lean mass, percentage tissue fat mass (%TFM) and BMC
14 values were obtained. These values were determined from the ratio of soft tissue attenuation of 2 X-
15 ray energy beams for each pixel containing a minimal amount of soft tissue but no significant bone
16^[24]. All scanning and analysis procedures were completed by the same trained operator using the
17 Lunar Encore software package (Version 15.0), with subsequent interpretation by a Certified Clinical
18 Densitometrist. The machine was calibrated and checked on a daily basis in accordance with the
19 manufacturer's recommendations.

20 The published *in-vivo* short-term precision (root-mean-square standard deviation (RMS-SD)
21 and coefficient of variation (%CV)) and corresponding LSC in professional rugby players using the
22 same Lunar iDXA^[21] are provided in Table 1.

23

24

insert Table 1 about here

25

26 Data were collected on the type and number of training sessions completed during the competitive
27 season (both gym and field-based sessions) in addition to the number of fixtures completed each week
28 (see supplementary material). The total number of games played by the team was 36 competitive

1 games, which included both league and cup fixtures. The mean number of matches played was as
2 follows: forwards 15±10; backs 17±9.

3

4 *Statistical analyses*

5 All statistical analysis procedures were completed using SPSS (Version 22.0, IBM Corp., Armonk,
6 NY). Prior to analysis, assumptions of normality in the data were made using the Shapiro-Wilk test
7 and visualisation of normality plots. In the event that a variable was not normally distributed (total fat
8 mass, arm lean mass, leg lean mass, leg BMC, trunk fat, trunk BMC), log transformation was
9 performed prior to conducting parametric analysis. Changes in seasonal body composition for each
10 positional group were analysed using mixed-model analysis of variance (ANOVA), with the testing
11 phase as the within-subject factor and playing position as the between-subject factor. Significant
12 overall effects were subsequently explored using Bonferroni *post hoc* tests for multiple comparisons.
13 Sphericity of the data were assessed using Mauchly's test; for instances in which sphericity was
14 violated, the Greenhouse-Geisser correction was applied. Data are presented as mean ± standard
15 deviation (SD) with statistical significance for all analyses defined as $p \leq 0.05$.

16 Individual changes were evaluated through the application of LSC derived from our precision
17 data using repeated (i.e., re-positioned) DXA measurements of 45 professional male rugby players ^[21].
18 Precision error was calculated as root-mean-square standard deviation (RMS-SD), with LSC
19 subsequently derived as RMS-SD x 2.77 (95% CI). Individual values at each time point were then
20 plotted and visually interpreted using Bland-Altman analysis.

21

22 **Results**

23 *Positional descriptives*

24 Body mass, fat mass, lean mass, %TFM and BMC were greater in forwards than backs at all testing
25 phases ($p < 0.001 - 0.010$) (Table 2). For regional body composition, forwards demonstrated
26 significantly greater values for all variables ($p \leq 0.004$) at all testing phases except for arm and leg
27 BMC, which did not significantly differ ($p > 0.05$). No significant interaction effects were observed
28 between time and playing position.

1 *Changes in total and regional body composition*

2 Seasonal changes in total and regional body composition characteristics by playing position are
3 presented in Table 2. Significant main effects of time were found for fat mass ($F = 5.545$; $p < 0.001$),
4 lean mass ($F = 8.899$; $p < 0.001$), %TFM ($F = 13.172$; $p < 0.001$), and BMC ($F = 15.714$; $p < 0.001$).
5 No significant change in body mass was observed during the competitive season ($F = 3.070$; $p =$
6 0.053).

7 In forwards, endseason fat mass ($p = 0.041$) and %TFM ($p = 0.008$) were significantly higher
8 than preseason. There was also a concomitant decrease in lean mass from mid to endseason ($p =$
9 0.018). BMC was higher at midseason ($p = 0.001$) and endseason ($p < 0.001$) compared to preseason.
10 In backs, endseason fat mass and %TFM were significantly higher than preseason ($p = 0.009$; $p =$
11 0.008) and midseason ($p = 0.024$; $p = 0.013$). A loss of lean mass from mid to endseason ($p = 0.003$)
12 was also observed. BMC was higher at endseason compared to preseason ($p = 0.005$).

13

14 ****insert Table 2 about here****

15

16 For regional body composition, significant main effects of time were found for arm fat mass
17 ($F = 12.571$; $p < 0.001$), arm lean mass ($F = 3.386$; $p = 0.040$), arm BMC ($F = 11.346$; $p < 0.001$), leg
18 fat mass ($F = 7.370$; $p = 0.001$), leg BMC ($F = 8.213$; $p = 0.001$), trunk fat mass ($F = 9.108$; $p <$
19 0.001), trunk lean mass ($F = 6.143$; $p = 0.004$) and trunk BMC ($F = 4.559$; $p = 0.014$).

20 In forwards, fat mass significantly increased in all regions from pre to endseason ($p \leq 0.017$).
21 In the arms, a significant decrease in lean mass was observed from mid to endseason ($p = 0.022$). Arm
22 BMC increased from pre to midseason ($p < 0.001$) and decreased from mid to endseason ($p = 0.001$).
23 Trunk BMC significantly increased between pre and endseason ($p = 0.010$). In backs, arm fat mass
24 increased from pre to endseason ($p = 0.002$). Trunk lean mass reduced from pre to endseason ($p =$
25 0.024) and pre to midseason ($p = 0.004$). Arm BMC increased from pre to midseason ($p = 0.004$).

26

27 *Individual player changes by LSC*

1 Utilising LSC from our recent precision study in rugby players^[21], individual changes in total lean mass
2 and fat mass are shown in Figures 1 and 2. Seven players lost lean mass (exceeding LSC) pre-
3 midseason, 17 players, mid-endseason, and 3 players lost lean mass during *both* pre-mid and mid-end
4 season. Ten players did not lose lean mass at anytime during the season, and 6 players gained lean mass.
5 Eighteen players gained fat mass pre-midseason, 19, mid-endseason, and 8 players gained fat mass
6 during *both* pre-mid and mid-endseason. Three players did not gain fat mass at anytime during the
7 season. Only one player, a forward, completed the season without any significant changes in lean or fat
8 mass. Twelve players gained BMC pre-midseason and 7 players had a reduction in BMC mid-
9 endseason. Over the course of the season (pre to end), only one player demonstrated a loss of BMC that
10 was outside of the LSC range. There were no differences in baseline characteristics (age, height, body
11 mass, percentage tissue fat mass) or playing position between players who did or did not have changes
12 in body composition through the season.

13

14 ***insert Figures 1, 2 and 3 about here***

15

16 **Discussion**

17 This study is the first to apply an individualised approach to analysis of longitudinal body
18 composition change in athletes. In doing so, we were able to capture individual heterogeneity in body
19 composition shifts at different time points over the course of the 10 month competitive season.
20 Further, to our knowledge, this is the first study reporting seasonal changes in three-compartment
21 body composition of professional male rugby union players. Statistically, fat mass increased over the
22 competitive season; these changes were accompanied by a decrease in lean mass from mid to
23 endseason in backs and preseason to endseason in forwards, respectively. Importantly however,
24 individual analysis revealed that loss of lean mass was more common mid-endseason regardless of
25 playing position. Fat mass gains were equally prevalent pre-mid and mid-endseason, suggesting that a
26 gain of fat mass may precede loss of lean mass. Further, few players had a *continuous* loss of lean
27 mass ($n = 3$) or gain in fat mass ($n = 8$) over the season. Statistically significant seasonal increases in
28 regional fat mass among both groups were also observed. At all time points, forwards were heavier

1 and possessed greater amounts of total fat and lean mass in addition to BMC. By region, similar
2 trends were observed for fat and lean mass at the arms, legs and trunk.

3 Concurrent with previous investigations of seasonal body composition changes in
4 professional rugby league players^[19, 20], body mass did not significantly alter during the season.
5 However, body composition shifts were evident - backs and forwards demonstrated an increase in
6 total fat mass and %TFM over the season, with a loss of lean mass in both groups. Importantly,
7 further insights were gained by applying individual analysis. The loss of lean mass was more
8 prevalent between mid-endseason ($n = 17$), in contrast with pre-midseason ($n = 7$), whereas fat mass
9 gains were comparatively similar between both phases. Moreover, this would suggest that fat mass
10 gains preceded losses in lean mass. The decreased duration of gym-based training sessions and
11 reduced competitive demands (see supplementary material) towards the end of the season, in contrast
12 with the beginning, serves as a potential rationale. The development and maintenance of lean mass
13 has been related to an attenuated risk of contact injury, thus posing practical considerations for player
14 health^[18], although further research is required. Increases in fat mass could theoretically attenuate
15 force production according to Newton's second law of motion ($a = F/m$), whereby increases in fat
16 mass (m) without a corresponding increase in muscle force (F) will reduce acceleration (a)^[2, 6]. This
17 is noteworthy given the crucial role of momentum in determining the outcome of a tackle contest^[25].
18 As such, the maintenance of a body composition profile preserving lean mass should be considered by
19 practitioners during periods of competition. In terms of regional body composition, fat mass increases
20 were relatively spread equally across regions in forwards, and in the arms for backs. The explanation
21 for these differences may lie in the fact that forwards engage in more static activity such as rucking,
22 mauling and scrummaging whereas backs tend to cover greater total distances and engage in more
23 high-intensity running in open play^[3, 9].

24 Similar to the study by Harley et al.^[19], there were significant seasonal increases in total
25 BMC among forwards and backs. Individual analysis provided greater insights, with a meaningful
26 increase in BMC in 12 players from pre-midseason and a loss of BMC in 7 players from mid-
27 endseason. Most players maintained BMC, and the gain of bone mass in 12 players pre-midseason
28 might suggest an osteogenic response of bone to a change in loading with the onset of competition in

1 these players ^[26]. The loss of BMC in 7 players from mid-endseason warrants further exploration with
2 assessment of bone metabolism markers to inform on a potential consolidation effect on bone
3 turnover ^[26].

4 Unlike existing studies of body composition change, we utilised LSC from our earlier
5 precision study in rugby players in order to obtain a greater insight into the data. In doing so,
6 meaningful gains in fat mass and losses in lean mass were observed for at least half of the sample.
7 However, not all players demonstrated unfavourable changes, thus highlighting the need for an
8 individualised approach to evaluating changes in body composition in sports science research and
9 practice. A similar proportion of forwards and backs demonstrated meaningful losses of lean mass
10 from mid to endseason and pre to endseason (Figure 1), concurrent with increases in fat mass (Figure
11 2). Additionally, the changes observed from pre to endseason can be misleading in that players may
12 have significant increases/decreases in lean or fat mass over the time periods (pre to mid and mid to
13 endseason) which result in a statistically non-significant change over the pre to endseason time period.
14 Determining the precision error of DXA at a given Centre, specific to the population of interest, can
15 enable the interpretation of true change by application of LSC ^[16, 21, 22, 27] and is recommended by the
16 International Society for Clinical Densitometry ^[28]. In this study, individual analysis using LSC was
17 particularly insightful for all body compartments.

18 Our study is limited in that we could only group players according to their primary positional
19 group (i.e., forwards and backs). A larger sample would have facilitated the further classification of
20 forwards (prop, hooker, second-row and loose forward) and backs (full-back, winger, centre and half
21 back). This would be desirable given the unique and disparate roles of each position within the team ^{[9,}
22 ^{12]}. Future studies would also benefit from investigating body composition changes across multiple
23 professional clubs to reduce any potential recruitment bias. Finally, our results should not be
24 generalised given the potential disparities in training, competitive demands and recovery between
25 clubs and levels.

26 To conclude, consistent body mass across the season in professional rugby union players does
27 not reflect an unchanged body composition. We have reported both team and individual significant
28 changes in fat, lean and bone mass. Rugby union players may benefit from maintaining their pre-season

1 body composition profile for the duration of the competitive season, adopting a highly individualised
2 approach on the part of coaches and conditioning professionals. We recommend that DXA-monitoring
3 of body composition in groups should also include an individualised approach, using the same protocol
4 as reported in this study. Future work exploring interactions between body composition, bone
5 metabolism, performance, and injury/ health over the course of a competitive season, with a larger
6 sample group, would also be of value.

7
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11 12 **References**

- 13 1. Duthie G, Pyne D, Hooper S. 2003 Applied physiology and game analysis of rugby union. *Sports*
14 *Med.* 33: 973-991.
- 15 2. Duthie GM. 2006 A framework for the physical development of elite rugby union players. *Int J*
16 *Sports Physiol Perform.* 1: 2-13.
- 17 3. Roberts SP, Trewartha G, Higgitt RJ, El-Abd J, Stokes KA. 2008 The physical demands of elite
18 English rugby union. *J Sports Sci.* 26: 825-833.
- 19 4. Duthie GM, Pyne DB, Hopkins WG, Livingstone S, Hooper SL. 2006 Anthropometry profiles of
20 elite rugby players: quantifying changes in lean mass. *Br J Sports Med.* 40: 202-207.
- 21 5. Darrall-Jones JD, Jones B, Till K. 2015 Anthropometric and Physical Profiles of English Academy
22 Rugby Union Players. *J Strength Cond Res.* 29: 2086-2096.
- 23 6. Higham DG, Pyne DB, Anson JM, Dziedzic CE, Slater GJ. 2014 Distribution of fat, non-osseous
24 lean and bone mineral mass in international Rugby Union and Rugby Sevens players. *Int J Sports*
25 *Med.* 35: 575-582.
- 26 7. Zemski AJ, Slater GJ, Broad EM. 2015 Body composition characteristics of elite Australian rugby
27 union athletes according to playing position and ethnicity. *J Sports Sci.* 33: 970-978.
- 28 8. Deutsch MU, Kearney GA, Rehrer NJ. 2007 Time - motion analysis of professional rugby union
29 players during match-play. *J Sports Sci.* 25: 461-472.
- 30 9. Cahill N, Lamb K, Worsfold P, Headey R, Murray S. 2013 The movement characteristics of
31 English Premiership rugby union players. *J Sports Sci.* 31: 229-237.
- 32 10. Argus CK, Gill N, Keogh J, Hopkins WG, Beaven CM. 2010 Effects of a short-term pre-season
33 training programme on the body composition and anaerobic performance of professional rugby union
34 players. *J Sports Sci.* 28: 679-686.
- 35 11. Darrall-Jones J, Roe G, Carney S, et al. 2015 The Effect of Body Mass on the 30-15 Intermittent
36 Fitness Test in Rugby Union Players. *Int J Sports Physiol Perform.* doi: 10.1123/ijssp.2015-0231.
- 37 12. Jones B, Till K, Barlow M, Lees M, O'Hara JP, Hind K. 2015 Anthropometric and Three-
38 Compartment Body Composition Differences between Super League and Championship Rugby
39 League Players: Considerations for the 2015 Season and Beyond. *PLoS One.* 10: e0133188.
- 40 13. Till K, Jones B, O'Hara J, et al. 2015 Three-compartment Body Composition in Academy and
41 Senior Rugby League Players. *Int J Sports Physiol Perform.* doi: 10.1123/ijssp.2015-0048.
- 42 14. Van der Ploeg GE, Withers RT, Laforgia J. 2003 Percent body fat via DEXA: comparison with a
43 four-compartment model. *J Appl Physiol.* 94: 499-506.

- 1 15. Harley JA, Hind K, O'Hara J, Gross A. 2009 Validation of the skinfold thickness method and air
2 displacement plethysmography with dual-energy X-ray absorptiometry, for the estimation of % body
3 fat in professional male rugby football league players. *Int J Body Comp Res.* 7: 7-14.
- 4 16. Hind K, Oldroyd B, Truscott JG. 2011 In vivo precision of the GE Lunar iDXA densitometer for
5 the measurement of total body composition and fat distribution in adults. *Eur J Clin Nutr.* 65: 140-
6 142.
- 7 17. Nana A, Slater GJ, Hopkins WG, Burke LM. 2012 Effects of daily activities on dual-energy X-ray
8 absorptiometry measurements of body composition in active people. *Med Sci Sports Exerc.* 44: 180-
9 189.
- 10 18. Gabbett TJ, Ullah S, Finch CF. 2012 Identifying risk factors for contact injury in professional
11 rugby league players – application of a frailty model for recurrent injury. *J Sci Med Sport.* 15: 496-
12 504.
- 13 19. Harley JA, Hind K, O'Hara JP. 2011 Three-compartment body composition changes in elite rugby
14 league players during a super league season, measured by dual-energy X-ray absorptiometry. *J*
15 *Strength Cond Res.* 25: 1024-1029.
- 16 20. Georgeson EC, Weeks BK, McLellen C, Beck BR. 2012 Seasonal change in bone, muscle and fat
17 in professional rugby league players and its relationship to injury: a cohort study. *BMJ Open.* doi:
18 10.1136/bmjopen-2012-001400.
- 19 21. Barlow MJ, Oldroyd B, Smith D, et al. 2015 Precision error in dual-energy X-ray absorptiometry
20 body composition measurements in elite male rugby league players. *J Clin Densitom.* 18: 546-550.
- 21 22. Hopkins SJ. 2015 Response to 'Precision Error in Dual-Energy X-Ray Absorptiometry Body
22 Composition Measurements in Elite Male Rugby League Players'. *J Clin Densitom.* 18: 449-450.
- 23 23. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. 2007 American
24 College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc.* 39:
25 377-390.
- 26 24. Mazess RB, Barden HS, Bisek JP, Hansen J. 1990 Dual-energy x-ray absorptiometry for total-
27 body and regional bone mineral and soft-tissue composition. *Am J Clin Nutr.* 51: 1106-1112.
- 28 25. Hendricks S, Karpul D, Lambert M. 2014 Momentum and kinetic energy before the tackle in
29 rugby union. *J Sports Sci Med.* 13: 557-563.
- 30 26. Frost HM. 1987 Bone "mass" and the "mechanostat": a proposal. *Anat Rec.* 219: 1-9.
- 31 27. Rothney MP, Martin FP, Xia Y, et al. 2012 Precision of GE Lunar iDXA for the measurement of
32 total and regional body composition in nonobese adults. *J Clin Densitom.* 15: 399-404.
- 33 28. Kendler DL, Borges JL, Fielding RA, et al. 2013 The Official Positions of the International
34 Society for Clinical Densitometry: Indications of Use and Reporting of DXA for Body Composition. *J*
35 *Clin Densitom.* 16: 496-507.

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1 **Figure Legends**

2

3 **Figure 1.** Individual rugby union player seasonal changes in total lean mass by least significant
4 change (LSC) as determined by Barlow et al ^[21].

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6 **Figure 2.** Individual rugby union player seasonal changes in total fat mass by least significant change
7 (LSC) as determined by Barlow et al ^[21].

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9 **Figure 3.** Individual rugby union player seasonal changes in total bone mineral content (BMC) by
10 least significant change (LSC) as determined by Barlow et al ^[21]. *TBBMC*, total-body bone mineral
11 content.

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1 **Table 1.** The *in-vivo* short-term precision and corresponding least significant change in professional
 2 rugby players using the same Lunar iDXA ^[21].

	LSC – 95%CI			
	RMS - SD	%CV	RMS - SD	%CV
Total-Body				
Fat mass (g)	280	2.3	775	6.4
Lean mass (g)	321	1.6	888	4.5
%TFM	0.32	2.3	0.89	6.4
BMC (g)	24	1.7	65	4.6
Regional				
<i>Arms</i>				
Fat mass (g)	63	4.2	175	11.5
Lean mass (g)	137	2.4	380	6.7
BMC (g)	4.7	2.1	13	5.7
<i>Legs</i>				
Fat mass (g)	145	3.1	403	8.7
Lean mass (g)	369	2.1	1023	6.0
BMC (g)	9.5	1.7	22.6	4.6
<i>Trunk</i>				
Fat mass (g)	299	4.1	828	11.5
Lean mass (g)	402	2.0	1115	5.5
BMC (g)	16.3	2.0	45.3	5.6

3 *Notes:* %TFM, percentage tissue fat mass; BMC, bone mineral content; CV, coefficient of variation;

4 LSC, least significant change; RMS-SD, root-mean-square standard-deviation

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1 **Table 2.** Differences in total and regional (arms, legs and trunk) body composition characteristics over the course of one competitive season in professional
 2 rugby union forwards ($n = 20$) and backs ($n = 15$). Data reported as mean \pm standard deviation.

	Preseason	Midseason	Endseason
<u>Total-Body</u>			
<i>Forwards</i>			
Body mass (kg)	110.6 \pm 7.6	111.7 \pm 7.8	111.5 \pm 7.5
Fat mass (g)	20640 \pm 4935	21524 \pm 5096	22199 \pm 5443 ^a
Lean mass (g)	85386 \pm 5376	85554 \pm 5503	84663 \pm 5358 ^b
%TFM	19.3 \pm 3.8	20.0 \pm 3.9	20.6 \pm 4.3 ^a
BMC (g)*	4564 \pm 383	4632 \pm 395 ^a	4616 \pm 391 ^a
<i>Backs</i>			
Body mass (kg)	92.5 \pm 6.3	93.3 \pm 7.4	92.9 \pm 7.5
Fat mass (g)	13473 \pm 3276	14045 \pm 3920	14959 \pm 4090 ^{a, b}
Lean mass (g)	74774 \pm 5755	74993 \pm 5680	73735 \pm 5479 ^b
%TFM	15.3 \pm 3.5	15.7 \pm 3.9	16.7 \pm 3.9 ^{a, b}
BMC (g)*	4212 \pm 362	4260 \pm 385	4256 \pm 367 ^a

Regional***Forwards****Arms*

Fat mass (g)	1988 ± 463	2073 ± 479	2134 ± 479 ^a
Lean mass (g)	11202 ± 937	11325 ± 893	11055 ± 922 ^b
BMC (g)*	653 ± 86	666 ± 84 ^a	653 ± 87 ^b

Legs

Fat mass (g)	7070 ± 1425	7351 ± 1758	7507 ± 1641 ^a
Lean mass (g)	30739 ± 2572	30987 ± 2516	30575 ± 2704
BMC (g)	1772 ± 206	1784 ± 215	1790 ± 215

Trunk

Fat mass (g)	10675 ± 3682	11172 ± 3586	11638 ± 3917 ^a
Lean mass (g)	39982 ± 2639	39717 ± 2780	39529 ± 2567
BMC (g)	1583 ± 172	1612 ± 184	1618 ± 171 ^a

Backs*Arms*

Fat mass (g)	1352 ± 330	1424 ± 390	1543 ± 385 ^a
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Lean mass (g)	9978 ± 1238	10038 ± 1165	9920 ± 1250
BMC (g)*	598 ± 63	608 ± 63 ^a	605 ± 63
<i>Legs</i>			
Fat mass (g)	4595 ± 1081	4626 ± 1185	4955 ± 1271
Lean mass (g)	26034 ± 2853	26128 ± 2735	25841 ± 2593
BMC (g)	1648 ± 169	1660 ± 164	1664 ± 157
<i>Trunk</i>			
Fat mass (g)	6604 ± 2117	7068 ± 2577	7523 ± 2641
Lean mass (g)	35229 ± 2147	35283 ± 2198	34400 ± 2052 ^{a, b}
BMC (g)	1369 ± 110	1386 ± 138	1380 ± 132

1 *Notes: %TFM, percentage tissue fat mass; BMC, bone mineral content; *Greenhouse-Geisser correction applied; ^asignificantly different from preseason ($p <$*
2 *0.05); ^bsignificantly different from midseason ($p < 0.05$).*

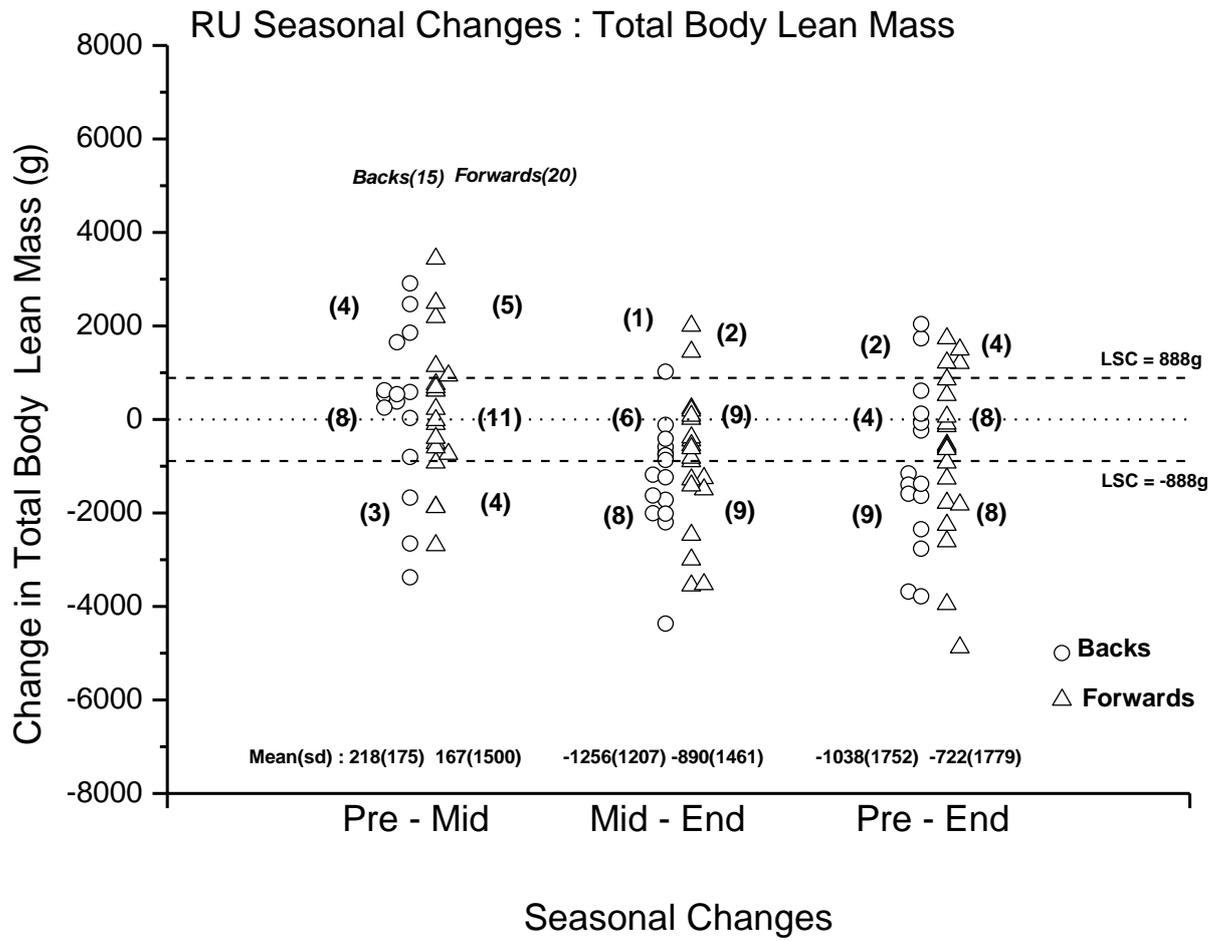
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1 **Table S1.** The training and competition schedule of the 36-week professional season, grouped into cycles of 4 weeks. Data represent the range and mean
 2 duration of training sessions in addition to matches completed each week.

Training Cycle	1	2	3	4	5	6	7	8	9
Gym-based sessions									
Frequency	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2
Duration (min)	73.1 ± 3.8	75.0 ± 0	75.0 ± 0	69.4 ± 3.8	63.8 ± 4.3	65.6 ± 7.2	65.6 ± 3.8	61.9 ± 3.8	60.0 ± 0
Field-based sessions									
Frequency	3-4	3-4	3-4	4	3-4	3-4	3	3	2-3
Duration (min)	70.6 ± 0.7	71.9 ± 2.2	70.6 ± 0.7	67.5 ± 0	68.8 ± 1.4	68.8 ± 1.4	75.0 ± 4.1	66.9 ± 4.7	67.5 ± 5.0
Matches/week	1	1	1	1	0-1	1	1	0-1	0-1

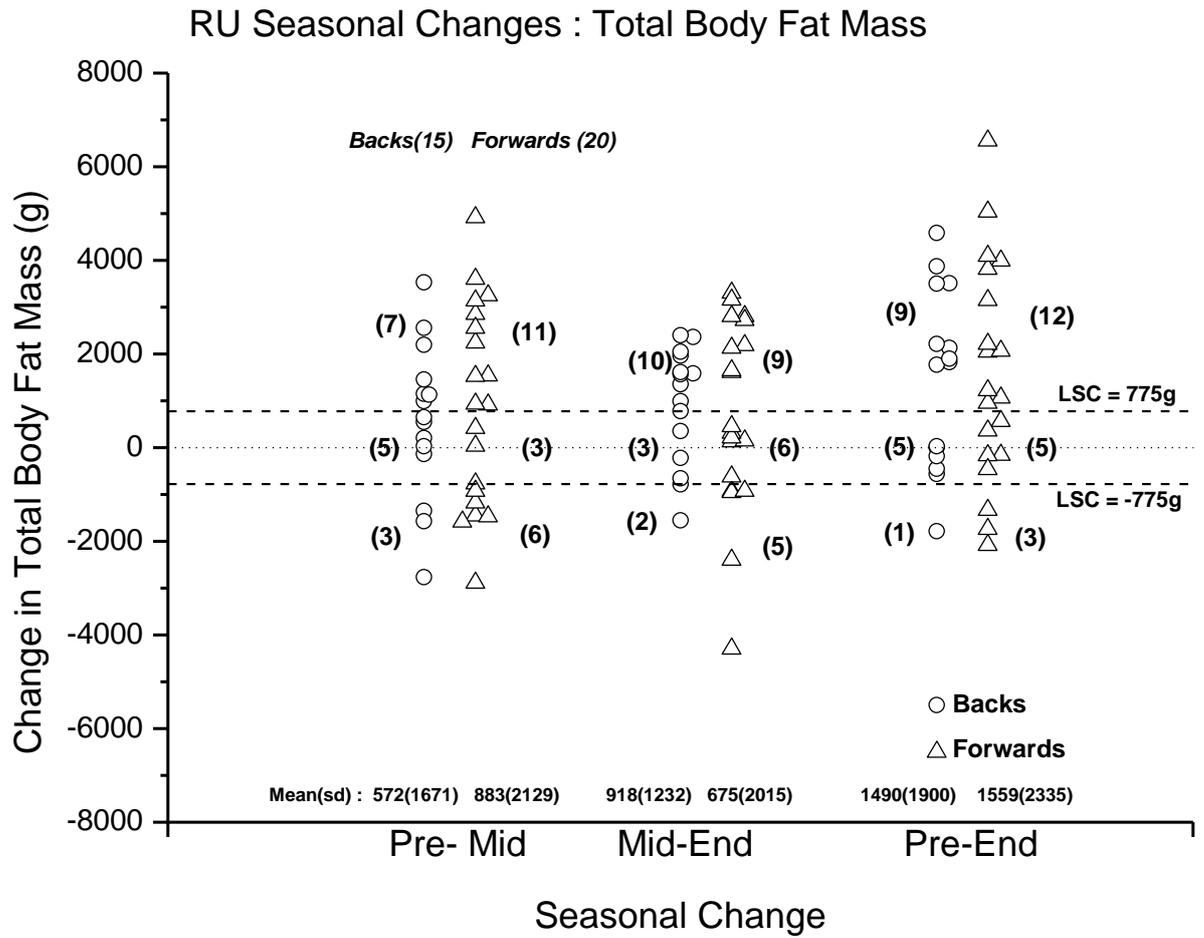
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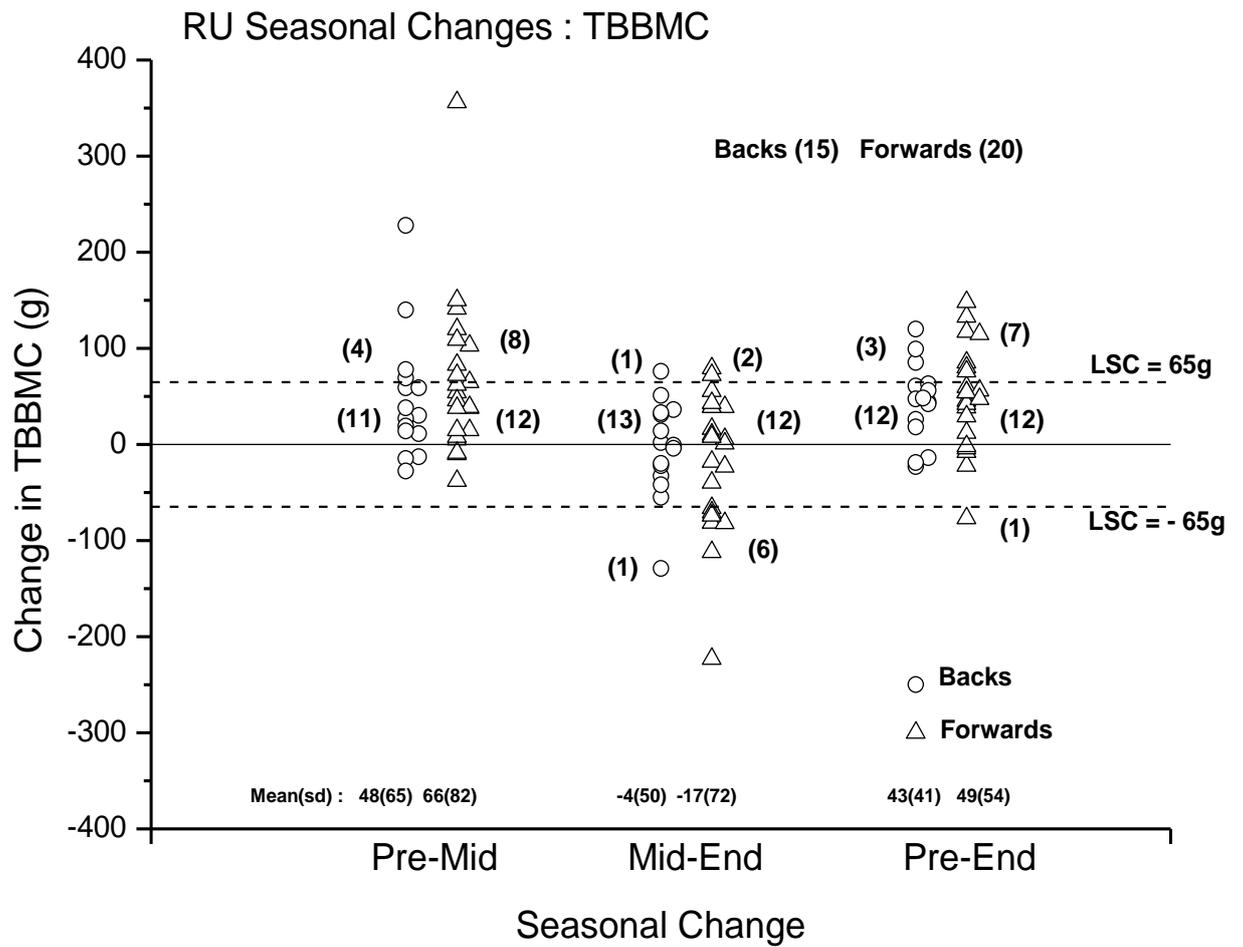
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Figure 1. Individual rugby union player seasonal changes in total lean mass by least significant change (LSC) as determined by Barlow et al [21].



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Figure 2. Individual rugby union player seasonal changes in total fat mass by least significant change (LSC) as determined by Barlow et al ^[21].



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Figure 3. Individual rugby union player seasonal changes in total bone mineral content (BMC) by least significant change (LSC) as determined by Barlow et al ^[21]. *TBBMC*, total-body bone mineral content.