

Season-long changes in the body composition profiles of competitive female Rugby Union players assessed via Dual Energy X-ray Absorptiometry

CURTIS, C, ARJOMANDKHAH, N, COOKE, C, RANCHORDAS, Mayur <<http://orcid.org/0000-0001-7995-9115>> and RUSSELL, M

Available from Sheffield Hallam University Research Archive (SHURA) at:

<http://shura.shu.ac.uk/28158/>

This document is the author deposited version. You are advised to consult the publisher's version if you wish to cite from it.

Published version

CURTIS, C, ARJOMANDKHAH, N, COOKE, C, RANCHORDAS, Mayur and RUSSELL, M (2021). Season-long changes in the body composition profiles of competitive female Rugby Union players assessed via Dual Energy X-ray Absorptiometry. *Research Quarterly for Exercise and Sport*.

Copyright and re-use policy

See <http://shura.shu.ac.uk/information.html>

Section: Original Research

Article Title: Season-long changes in the body composition profiles of competitive female Rugby Union players assessed via Dual Energy X-ray Absorptiometry

Authors: Curtis, C.^{a,b,*}, Arjomandkhah, N.^a, Cooke, C.^a, Ranchordas, M.K.^c, Russell, M.^a

Affiliations: ^aSchool of Social and Health Sciences, Leeds Trinity University, Leeds, LS18 5HD, United Kingdom. ^bLondon Sports Institute, Middlesex University, London, NW4 4BT, United Kingdom. ^cAcademy of Sport & Physical Activity, Sheffield Hallam University, Sheffield, S1 1WB, United Kingdom

Running Head: Body Composition Changes in Female Rugby Union

Journal: *Research Quarterly for Exercise and Sport*

Corresponding Author: Christopher Curtis, London Sport Institute, Middlesex University, Hendon, London, NW4 4BT. Telephone: (+44) 20 8411 4491 Email: c.curtis@mdx.ac.uk

Abstract: 231

Word Count: 2,751

Number of Figures: 0

Number of Tables: 1

ABSTRACT:

1 **Background:** Reference data for the body composition values of female athletes are
2 limited to very few sports, with female Rugby Union players having mostly been
3 omitted from such analyses.

4 **Methods:** Using dual energy X-ray absorptiometry (DXA) scans, this study assessed
5 the body composition profiles (body mass, bone mineral content; BMC, fat mass;
6 FM, lean mass; LM, bone mineral density; BMD) of 15 competitive female Rugby
7 Union players before and after the 2018/19 competitive season. Total competitive
8 match-play minutes were also recorded for each player.

9 **Results:** Body mass (73.7 ± 9.6 kg vs 74.9 ± 10.2 kg, $p \leq 0.05$, $d = 0.13$) and BMC
10 (3.2 ± 0.4 kg vs 3.3 ± 0.4 kg, $p \leq 0.05$, $d = 0.15$) increased pre- to post-season for all
11 players. Conversely, FM (21.0 ± 8.8 kg), LM (50.7 ± 3.9 kg), and BMD (1.31 ± 0.06 g·cm⁻²)
12 were similar between time-points (all $p > 0.05$). Accounting for position, body mass
13 ($r_{\text{partial}(12)} = 0.196$), FM ($r_{\text{partial}(12)} = -0.013$), LM ($r_{\text{partial}(12)} = 0.351$), BMD ($r_{\text{partial}(12)} =$
14 0.168) and BMC ($r_{\text{partial}(12)} = -0.204$) showed no correlation (all $p > 0.05$) against
15 match-play minutes.

16 **Conclusion:** The demands of the competitive season influenced specific body
17 composition indices (i.e., body mass, BMC) in female Rugby Union players; a finding
18 which was unrelated to the number of minutes played in matches. While the causes
19 of such differences remain unclear, practitioners should be cognisant of the body
20 composition changes occurring throughout a female Rugby Union competitive
21 season and, where necessary, consider modifying variables associated with
22 adaptation and recovery accordingly.

23

24 **Key Words:** Dual Energy X-ray Absorptiometry, female athlete, team sport, bone
25 mineral density

26 1. INTRODUCTION:

27 Rugby Union (RU) is a field-based contact team sport characterized by repeated
28 brief bouts of high-intensity exercise (i.e., running, sprinting, tackling, scrummaging,
29 rucking, and mauling) interspersed with periods of low to moderate intensity activities
30 (i.e., standing, walking, and jogging) ¹. In recent years, the popularity of female rugby
31 has increased significantly ²; now being played in over 100 countries ¹. Both males
32 and females (15-a-side) play for 80 min under the same rules and with the same
33 equipment. However, in contrast to their male counterparts ^{3,4,5} data pertaining to the
34 match-play demands of 15-a-side female RU is limited ^{1,6}.

35 Body composition is often assessed to provide an indication of an athlete's fitness
36 and health status ⁷. Traditionally, body composition is estimated using two- (e.g.,
37 skinfolds; SF, bioelectrical impedance; BIA, air displacement plethysmography; ADP)
38 and more recently, three- (e.g., BIA, dual-energy X-ray absorptiometry; DXA)
39 compartment models to calculate fat-free mass (FFM), lean mass (LM), fat mass
40 (FM), and in the case of DXA, bone mineral content (BMC) ^{7,8,9}. Anthropometric
41 measurement techniques provide an accurate measure of body composition, and
42 tracking changes in such indices can be useful for evaluating the effectiveness of
43 dietary and/or conditioning interventions. Furthermore, increases in LM within RU
44 have benefitted performance ^{10,11}. Notably, increased LM may positively influence
45 the power-to-weight ratios of players during match-play and improve key success
46 predictors such as; momentum, strength, power, and speed ^{11,12}. It is therefore
47 beneficial to have accurate information concerning measures of body composition in
48 athletes for both health and performance purposes.

49 When compared to other methodologies of measuring body composition, DXA is
50 widely regarded as the gold standard non-invasive method of measuring FM, FFM
51 and separating FFM in to LM and bone ¹³. Likewise, the method has also shown
52 greater accuracy when ascertaining body composition measures relative to ADP ¹⁴,
53 BIA ¹⁵ and SF ¹⁶ analyses, with DXA being highly correlated with both magnetic
54 resonance imaging and computed tomography when measuring muscle mass ¹⁷. By
55 accounting for the variability in bone density that often exists in this population, DXA
56 may also be a superior methodology for use with athletic females ⁷. However, current
57 reference values for the body composition of females when assessed by DXA are

58 limited to a small number of sports such as soccer ¹⁸, track and field ^{19, 20}, basketball
59 ²¹ and softball ²².

60 While physical and body composition data exists for elite female Rugby League (RL)
61 players ²³, with significant differences in body mass, LM, FM and body fat percentage
62 existing between forwards and backs, body composition values assessed by DXA for
63 the 15-a-side format of female RU are scarce. Santos *et al.*, ²⁴ collated body
64 composition data from both SF and DXA scans in 21 different sports (including both
65 males and females), but no information was presented for female RU players ²⁴.
66 Notably, Harty *et al.* ²⁵ published body composition data of female collegiate RU
67 players via DXA and reported significant differences between forwards and backs in
68 all measured variables; findings which disagree with those of elite Scottish female
69 RU players when measured via ADP ²⁶. Such contrasts may be associated with ADP
70 being a two-component model of body composition which demonstrates a higher
71 error (up to 13%) compared to DXA ¹⁴. Acknowledging such equivocal findings, the
72 aim of this study was to assess seasonal changes in the body composition of female
73 RU players. Furthermore, to provide novel insight, we sought to also investigate
74 whether changes in such values occurred as a result of involvement in a competitive
75 playing season.

76

77 2. METHODS:

78 2.1 Experimental Approach to the Problem:

79 Using an observational approach, body composition was measured via DXA scan
80 within competitive female RU players in both the pre-season (i.e., August 2018) and
81 immediately post-season (i.e., March 2019) periods of the 2018/19 competitive cal-
82 endar. Body composition variables of body mass, FM, LM, bone mineral density
83 (BMD) and BMC were collected via DXA scans during pre-season. Measurements
84 were repeated at the end of the same competitive season. Notably, DXA technology
85 offers high precision and reliability when compared to other body composition meth-
86 ods such as BIA and anthropometry ^{17,27}, and all scans were performed by the same
87 qualified technician on each occasion. Throughout the duration of the competitive
88 season, dietary intake was administered as per the club nutritionist's direction. Play-
89 ers were recommended to adopt diets in a periodized manner adhering to 1.2 - 2.0
90 g·kg⁻¹·BM·d⁻¹ protein, ~5 g·kg⁻¹·BM·d⁻¹ carbohydrate and 20-35% of daily energy in-
91 take from fats.

92

93 2.2 Participants:

94 All participants (n=15, age: 27±5 years, height: 169±5 cm, weight: 73.7±9.6 kg) were
95 recruited from a team competing in the highest tier of female RU in the United
96 Kingdom (i.e., Women's Premiership League). Six of the participants were
97 professional, international players (International caps: 26±23). The study obtained
98 institutional ethical approval and informed consent was sought from participants prior
99 to study involvement.

100

101 2.3 Dual-energy X-ray absorptiometry (DXA):

102 For each measurement, participants were asked to attend the laboratory in a rested
103 state and having fasted overnight. This was to eliminate changes in lean and total
104 mass that corresponded to a volume of food/drink consumed prior to scanning ²⁸.
105 Before measurements were taken, participants were screened for any existing
106 injuries and/or pregnancy that may have precluded them from the scan. Stature was

107 measured via portable stadiometer (Seca, Hamburg, Germany) to the nearest 1 mm
108 and body mass was measured via calibrated weighing scales (Seca, Hamburg,
109 Germany) to the nearest 0.1 kg. These data were inputted into the DXA computer for
110 initial participant characteristics. DXA scans (DPX-L Lunar Prodigy, GE Medical
111 Systems, Lunar Madison, Wisconsin, USA) assessed FM, LM, BMD and BMC
112 through tissue X-ray absorption from two X-ray energy peaks ¹⁷ (enCORE 2008,
113 version 12.30.008 software). Within the DXA procedure, participants were exposed
114 to low levels of ionizing radiation (0.4 µGy per 1 full-body scan); thus posing minimal
115 risk to health with exposures being comparable to that of everyday activity over a 24
116 h period at sea level ^{19,28}. During the scans, participants were required to lay supine
117 on the DXA bed, with their hands in a pronated position by their sides (as per
118 manufacturer instructions) and to wear minimal clothing to improve the accuracy of
119 scan results as per the methods of Nana *et al.* ²⁷. These processes were repeated
120 for the follow-up measures during the post-season period taken within four days of
121 final playing encounter.

122

123 **2.4 Match-Play Analysis:**

124 Total match-play minutes were recorded over the 2018/19 competitive season from
125 official match reports. A total of twenty competitive regular season women's RU
126 matches were recorded; an average of one match played per week between
127 September 2018 – March 2019, plus two additional play-off fixtures played between
128 March 2019 – April 2019 (a maximum total of 160 min match-play minutes).

129

130 **2.5 Statistical Analysis:**

131 All data are presented as mean ± standard deviation. In the case of whole group
132 changes between pre and post-season values, data were analyzed via SPSS (IBM
133 Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY:
134 IBM Corp). Normality was assessed via Shapiro-Wilks test. A multivariate analysis of
135 variance (MANOVA) was conducted to identify interaction and main effects. Where
136 significant main effects were identified, Tukey's post hoc analysis and within-player
137 paired t-tests were performed. Delta values of differences between pre- and post-

138 season measures of body mass, FM, LM, BMD and BMC were calculated, and
139 controlling for position, a Pearson's partial correlation was used to determine total
140 playing minutes against these variables. Effect sizes (ES) were calculated in
141 accordance with Cohen's *d* ES principles (0 < ES < 0.2 = trivial, 0.2 < ES < 0.5 =
142 small, 0.5 < ES < 0.8 = medium, > 0.8 = large) ²⁹. An alpha level of $p \leq 0.05$ denoted
143 significance. For the purposes of benchmarking positional data, and in the absence
144 of inferential statistics due to insufficient statistical power, descriptive statistics are
145 presented for each variable according to playing position (i.e., forwards vs backs).

146

147 **3. RESULTS:**

148 Body composition data can be seen in Table 1. Interaction effects were non-
149 significant for all variables (all $p > 0.05$). Significant time effects were observed across
150 variables ($F_{(4,10)} = 4.734$, $p \leq 0.05$, partial $\eta^2 = 0.654$). Specifically, body mass (Body
151 mass_{Pre}: 73.7 ± 9.6 kg, Body mass_{Post}: 74.9 ± 10.2 kg, $p \leq 0.05$, $d = 0.13$) and BMC
152 (BMC_{Pre}: 3.23 ± 0.35 kg, BMC_{Post}: 3.28 ± 0.36 kg, $p \leq 0.05$, $d = 0.15$) increased from pre-
153 to post-season. Mean FM (20.1 ± 8.3 vs 21.0 ± 8.8 kg, $d = 0.11$), LM (50.2 ± 3.6 vs
154 50.7 ± 3.9 kg, $d = 0.14$) and BMD (1.30 ± 0.07 g·cm⁻² vs 1.31 ± 0.06 g·cm⁻², $d = 0.16$)
155 showed no differences between pre- and post-season measures (all $p > 0.05$).

156 Mean average match-play durations for all participants ($n = 15$) across the competitive
157 season was 902 ± 330 min. No differences were observed between positions for total
158 match-play durations (Forwards: 790 ± 298 min, Backs: 1030 ± 338 min, $p > 0.05$,
159 $d = 0.81$) or total full-game equivalents (Forwards: 10 ± 4 , Backs: 13 ± 4 , $p > 0.05$,
160 $d = 0.81$). The relationships between match-play minutes and all DXA variables were
161 not significant (Body mass: $r_{\text{partial}(12)} = 0.196$, $p \geq 0.05$, FM: $r_{\text{partial}(12)} = -0.013$, $p \geq 0.05$,
162 LM: $r_{\text{partial}(12)} = 0.351$, $p \geq 0.05$, BMD: $r_{\text{partial}(12)} = 0.168$, $p \geq 0.05$ and BMC: $r_{\text{partial}(12)} = -$
163 0.204 , $p \geq 0.05$).

164

165 *******INSERT TABLE 1 NEAR HERE*******

166

167

168 4. DISCUSSION:

169 The primary objective of this study was to profile the body composition profiles of
170 female RU players before and after a competitive season. Secondly, via correlational
171 analyses, we sought to also investigate whether changes in body composition values
172 were related to the number of match-play minutes played. Although significant
173 changes in body mass and BMC occurred over the course of a competitive season,
174 ES analyses deemed these trivial. To the author's knowledge, this is the first study to
175 investigate DXA-derived body composition changes of competitive female RU
176 players throughout the course of a domestic season. Therefore, insight is offered into
177 the benchmarks of body composition data of female RU players; findings which may
178 have application to practitioners working with this specific sporting population.

179 Body mass increased by ~1.2 kg post-season relative to pre-season values; findings
180 which despite being statistically significant were trivial as per ES analyses. Notably,
181 the significant changes in body mass seen here support those observed previously
182 in female Rugby Sevens³⁰ and female 15-a-side RU players^{25,31}. The congruent
183 changes in BMC also reported at post-season are unlikely to explain such responses
184 given the differences in magnitude (i.e., Δ body mass: ~1.2 kg, ES: 0.13; Δ BMC:
185 ~0.05 kg, ES: 0.15). Although non-significant, contributions from LM and FM are
186 therefore more likely. In support of this, despite a lack of statistical significance,
187 increased FM and LM occurred between pre- and post-season (equivalent to trivial
188 ES of 0.11 and 0.14, respectively). While it is unclear as to the practical significance
189 of, and the exact reasoning underpinning such observations, reductions in training
190 loads have previously been attributed to increases in FM towards the end of a
191 season in male, elite RU players³² and may offer insight to explain such changes in
192 female RU players. Likewise, increased LM occurred in both male elite RU and
193 Australian football which was attributed to exposure to resistance training throughout
194 the pre- and competitive season respectively^{11,32}, and may help explain the LM
195 findings in the present study. Speculatively, and acknowledging that correlations to
196 match-play minutes were non-significant, differences in body mass over the season
197 may be attributed to specific match-play characteristics that RU players undertake³⁰.
198 For example, as body mass is correlated with increased scrum force³³ and larger
199 force magnitudes³⁴, it may be suggested that larger athletes are either talent-
200 identified or self-select to play in forward positions during their development, or that

201 specific interventions have led to larger body masses versus backs ³⁰. Nevertheless,
202 irrespective of the origins of such differences, the findings in this present study
203 highlight that practitioners may also need to consider the effects of a competitive
204 season on specific indices of body composition.

205 Increased BMC was also observed throughout the domestic season, but it must be
206 noted that ES analyses deemed these trivial changes. These observations, both in
207 terms of magnitude and direction, are supported by findings from female basketball
208 (Baseline: 3.25 ± 0.04 kg, Follow-Up: 3.30 ± 0.04 kg; ¹⁹). Training that consists of
209 weight-bearing exercise, high-impact exercises ³⁴ and associated RU-specific
210 training and match-play, have previously been found to stimulate bone accretion
211 ^{12,35}. Notably, bone mineral accrual mechanisms have been attributable to excess
212 loading above accustomed levels during weight-bearing exercises ^{36,37}. Similarly,
213 several modes of resistance exercise have been investigated in relation to BMD, with
214 training involving high-intensity actions increasing BMD ³⁵. Such training modalities
215 are commonplace in RU ³⁸, and reflect the activities undertaken by the players in the
216 present study.

217 Our BMD findings were comparable with that of female basketball players ¹⁹ and
218 higher than observed in female soccer ¹⁹. However, while specific body composition
219 indices may need consideration when seeking to optimize performance in female
220 RU, differences between pre- and post-season measures did not correlate against
221 total match-play minutes. Collectively, these findings indicate that total match-play
222 minutes alone have limited relationship to body composition when assessed in
223 competitive female RU players. That said, ascertaining the potential role of other
224 factors (e.g., training volume, match-play characteristics, dietary intake etc.) on
225 markers of body composition remains to be investigated and presents itself as a
226 future research opportunity.

227 Whilst a lack of statistical power precluded an inferential statistical approach to
228 position-specific data analyses, the dearth of literature presently available presents
229 an opportunity to provide practitioners with descriptive statistics regarding position-
230 specific body composition findings (Table 1). Using the method of ADP, Nyberg &
231 Penpraze ²⁶ observed no between-position differences in anthropometric data in elite
232 Scottish female RU players. More recently, reporting of position-specific DXA-

233 derived anthropometric data in female collegiate RU players observed greater body
234 mass, FM, FFM, BMD and BMC in forwards compared to backs ²⁵. In the case of the
235 latter, and despite comparable assessment methodologies to those reported in the
236 present study (i.e., DXA), the length of the assessment period (i.e., one season in
237 the present study versus a more prolonged 3-year period) and its influence on the
238 realization of adaptive responses resulting from accumulated training volumes
239 should be considered. That said, despite a lack of statistical analysis for between-
240 position differences, meaningful benchmark data is presented from a high-level
241 competitive cohort of female RU players. Future research opportunities therefore
242 exist to substantiate such findings in comparable populations.

243 Despite DXA being widely deemed a gold standard method for body composition
244 analyses due to its accuracy and repeatability ^{39,40}, the method is not without its
245 limitations. Firstly, our findings suggest the possible role that increased FM may
246 have had over the course of the competitive season. Research indicates that with
247 increasing fat mass comes increased risk of error via DXA ^{39,41}. Also, the potential
248 effects of the menstrual cycle on indices of body composition were not considered
249 within this study. Although the effects of such changes on the accuracy of body
250 composition measures via DXA scan are not fully understood ²⁸, the influence of
251 menses on the reliability of body composition estimates appears minimal in a cohort
252 of pre-menopausal females ⁴²; whether this is true for female RU players remains to
253 be investigated. Within these limitations, is the fact that DXA manufacturers' body
254 composition estimation algorithms are not developed from athletic populations –
255 meaning that reference values are compared against 'general' cohorts ²⁷. Therefore,
256 refining algorithms to better reflect the characteristics of athletic populations (both
257 male and female) may increase the resolution and accuracy of future research.

258 In summary, although trivial from an ES perspective, changes in specific indices of
259 body composition were observed in competitive female RU players and such
260 responses occurred throughout a domestic season (i.e., increased body mass and
261 BMC). No significant changes were observed across the season in FM, LM and
262 BMD, findings which were supported with trivial ES analyses. Therefore, given the
263 limited literature available, further research into the body composition changes (both
264 regional and total), involving longitudinal studies with a larger sample size of
265 intermittent female team sports players within applied settings, are warranted.

266 Additionally, these findings provide insight into position-specific benchmark data and
267 thus also highlight future opportunities for research in this respect.

268 This novel study provides data from a sample of competitive female RU players
269 competing in the highest playing standard in the United Kingdom. Both body mass
270 and BMC differed across the course of a competitive season. Because of the
271 position-specific demands of RU, body composition changes need to be considered
272 by sports science practitioners and where appropriate, an appropriate intervention
273 implemented. Such considerations can help practitioners maximize performance
274 over the course of a competitive season. Practitioners should therefore consider
275 strength and conditioning and nutritional strategies to optimize changes in body
276 composition for the sake of enhanced performance.

277

278 **ACKNOWLEDGEMENTS:**

279 The authors would like to thank the participants for their involvement in the study and
280 to the club support staff for their cooperation throughout.

281

282 **AUTHOR CONTRIBUTIONS:**

283 The study was designed by CCu and MR; data was collected and analyzed by CCu;
284 data interpretation and manuscript preparation were undertaken by CCu, MR, MKR,
285 NA and CCo. All authors approved the final version of the paper.

286

287 **FUNDING DETAILS:**

288 The author(s) received no specific funding for this work.

289

290 **COMPETING INTERESTS:**

291 The authors declare that they have no competing interests.

292

293 **REFERENCES:**

- 294 1. Suarez-Arrones L, Portillo J, Pareja-Blanco F, de Villereal ES, Sanchez-
295 Medina L, Munguia-Izquierdo D. Match-play activity profile in elite women's
296 rugby union players. *J Strength Cond Res.* 2014;28(2): 452–458
- 297 2. Gabbett TJ. Physiological and anthropometric characteristics of elite women
298 rugby league players. *J Strength Cond Res.* 2007;21: 875–881
- 299 3. Campbell PG, Peake JM, Minett GM. (2018) The specificity of rugby union
300 training sessions in preparation for match demands. *Int J Sport Physiol.*
301 2018;13(4): 496–503
- 302 4. Pollard BT, Turner AN, Eager R, Cunningham DJ, Cook CJ, Hogben P,
303 Kilduff, LP. The ball in play demands of international rugby union. *J Sci Sport*
304 *Med.* 2018;21(10): 1090–1094
- 305 5. Quarrie KL, Hopkins WG, Anthony MJ, Gill ND. Positional demands of inter-
306 national rugby union: evaluation of player actions and movements. *J Sci Sport*
307 *Med.* 2013;16(4): 353–359
- 308 6. Virr JL, Game A, Bell GJ, Syrotuik D. (2014). Physiological demands of wom-
309 en's rugby union: time-motion analysis and heart rate response. *J Sport Sci.*
310 2014;32(3): 239–247
- 311 7. Warner ER, Fornetti WC, Jallo JJ, Pivarnik, JM (2004) A skinfold model to
312 predict fat-free mass in female athletes. *J Athl Train.* 2004;39(3): 259–262
- 313 8. Marks P, Van Meel M., Robinson J, Robinson C. Body composition differ-
314 ences by assessment methods such as DEXA, hydrostatic, bio-impedance
315 and skin fold. *Int J Exerc Sci Conf Proc.* 2015;8(3): 39.
- 316 9. von Hurst PR, Walsh DCI, Conlon CA, Ingram M, Kruger R, Stonehouse W.
317 Validity and reliability of bioelectrical impedance analysis to estimate body fat
318 percentage against air displacement plethysmography and dual-energy X-ray
319 absorptiometry. *Nutr Diet.* 2016;73(2): 197–204
- 320 10. Bilsborough JC, Greenway K, Livingstone S, Cordy J, Coutts, A. Changes in
321 anthropometry, upper-body strength, and nutrient intake in professional Aus-

- 322 australian football players during a season. *Int J Sport Physiol.* 2016:11(3): 290–
323 300. doi: 10.1123/ijsp. 2014-0447
- 324 11.Zemski AJ, Keating SE, Broad EM, Marsh DJ, Hind K, Slater GJ. Preseason
325 body composition adaptations in elite white and Polynesian rugby union
326 athletes. *Int J Sport Nutr Exe.* 2019:4: 1-9. doi: 10.1123/ijsnem.2018-0059
- 327 12.Bell W, Evans WD, Cobner DM, Eston RG. Regional placement of bone min-
328 eral mass, fat mass, and lean soft tissue mass in young adult rugby union
329 players. *Ergonomics.* 2005:48: 1462–1472. doi: 10.1080/00140130500101007
- 330 13.Tewari N, Awad S, Macdonald IA, Lobo DN. A comparison of three methods
331 to assess body composition. *Nutrition.* 2018:47: 1-5. doi:
332 10.1016/j.nut.2017.09.005
- 333 14.Lowry DA, Tomiyama JA. Air displacement plethysmography versus dual-
334 energy x-ray absorptiometry in underweight, normal-weight, and over-
335 weight/obese individuals. *PLoS ONE.* 2015:10(1):e011508
- 336 15.Rockamann RA, Dalton EK, Arabas JL, Jorn L, Mayhew JL. Validity of arm-to-
337 arm BIA devices compared to DXA for estimating % fat in college men and
338 women. *Int J Exerc Sci.* 2017:10(7): 977-988
- 339 16.Zemski AJ, Broad EM, Slater GJ. Skinfold prediction equations fail to provide
340 an accurate estimate of body composition in elite rugby union athletes of
341 Caucasian and Polynesian ethnicity. *Int J Sport Nutr Exe.* 2018:28(1): 90-99.
342 doi: 10.1123/ijsnem.2017-0251
- 343 17.Erlandson MC, Lorbergs AL, Mathur S, Cheung AM. Muscle analysis using
344 pQCT, DXA and MRI. *Eur J Radiol.* 2016:85(8): 1505-1511. doi:
345 10.1016/j.ejrad.2016.03.001
- 346 18.Minett MM, Binkley TB, Weidauer LA, Specker BL. Changes in body composi-
347 tion and bone of female collegiate soccer players through the competitive
348 season and off-season. *J Musculoskel Neuron.* 2017: 17(1): 386-398
- 349 19.Stanforth D, Lu T, Stults-Kolehmainen MA, Crim BN, Stanforth PR. Bone min-
350 eral content and density among female NCAA Division I athletes across the

- 351 competitive season and over a multi-year time frame. *J Strength Cond Res.*
352 2016:30(10): 2828 – 2838. doi: 10.1519/JSC.0000000000000785
- 353 20. Stanforth PR, Crim BN, Stanforth D, Stults-Kolehmainen MA. Body composi-
354 tion changes among female NCAA division 1 athletes across the competitive
355 season and over a multiyear time frame. *J Strength Cond Res.* 2014; 28(2):
356 300-307.
- 357 21. Raymond-Pope CJ, Solfest AL, Carbuhn A, Stanforth PR, Oliver JM, Ransone
358 JW, Bosch TA, Dengel DR. Total and regional body composition of NCAA Di-
359 vision I collegiate basketball athletes. *Int J Sports Med.* 2020; 41(4): 242-247.
- 360 22. Czeck MA, Raymond-Pope CJ, Stanforth PR, Carbuhn A, Bosch TA, Bach
361 CW, Oliver JM, Dengel DR. Total and regional body composition of NCAA Di-
362 vision I collegiate female softball athletes. *Int J Sports Med.* 2019; 40(7): 645-
363 649.
- 364 23. Jones B, Emmonds S, Hind K., Nicholson G, Rutherford Z., Till K. Physical
365 qualities of international female rugby league players by playing position. *J*
366 *Strength Cond Res.* 2016:30 (5): 1333-1340
- 367 24. Santos DA, Dawson JA, Matias CN, et al. (2014) Reference values for body
368 composition and anthropometric measurements in athletes. *PLoS ONE.*
369 2014:9(5): e97846
- 370 25. Harty PS, Zabriskie HA, Stecker RA. Position-specific body composition val-
371 ues in female collegiate rugby union athletes. *J Strength Cond Res.*
372 2019:[Epub ahead of print]
- 373 26. Nyberg CC, Penpraze V. Determination of anthropometric and physiological
374 performance measures in elite Scottish female rugby union players. *Int J Res*
375 *Ex Phys.* 2016:12(1): 10–16
- 376 27. Nana A., Slater GJ, Stewart AD, Burke LM. Methodology Review: Using dual-
377 energy x-ray absorptiometry (DXA) for the assessment of body composition in
378 athletes and active people. *Int J Sport Nutr Exe.* 2015:25(2): 198–215

- 379 28. Nana A, Slater GJ, Hopkins WG, Burke LM. Effects of daily activities on DXA
380 measurements of body composition in active people. *Med Sci Sports Exerc.*
381 2012;44(1): 180–189. doi: 10.1249/MSS.0b013e318228b60e
- 382 29. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for
383 studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009:
384 41(1): 3–13. doi: 10.1249/MSS.0b013e31818cb278
- 385 30. Agar-Newman DJ, Goodale TL, Klimstra MD. Anthropometric and physical
386 qualities of international level female rugby sevens athletes based on playing
387 position. *J Strength Cond Res.* 2017;31(5): 1346–1352. doi:
388 10.1519/JSC.0000000000001167
- 389 31. Hene NM, Bassett SH, Andrews BS. Physical fitness profiles of elite women's
390 rugby union players. *Afr. J. Phys. Health Edu. Recreat. Dance.* 2011:(Suppl):
391 1–8
- 392 32. Johnston RD, Black GM, Harrison PW, Murray NB, Austin DJ. (2018) Applied
393 sport science of Australian football: A systematic review. *Sports Med.*
394 2018;48(7): 1673–1694. doi: 10.1007/s40279-018-0919-z
- 395 33. Quarrie K, Wilson B. Force production in the rugby union scrum. *J Sport Sci.*
396 2000;18(4): 237–246
- 397 34. Green A, Dafkin C, Kerr S, McKinnon W. Combined individual scrummaging ki-
398 netics and muscular power predict competitive team scrum success. *Eur J*
399 *Sport Sci.* 2017;17(8): 994–1003. doi: 10.1080/17461391.2017.1343387
- 400 35. Guadalupe-Grau, A., Fuentes, T., Guerra, B., Calbet, J.A. Exercise and bone
401 mass in adults. *Sports Med.* 2009;39(6): 439–468
- 402 36. Frost HM. Skeletal structural adaptations to mechanical usage (SATMU): 1.
403 Redefining Wolff's law: the bone modelling problem. *Anat Rec.* 1990;226(4):
404 403–413
- 405 37. Ha AS, Ng JYY. Rope skipping increases bone mineral density at calcanei of
406 pubertal girls in Hong Kong: A quasi-experimental investigation. *PLoS ONE.*
407 2017;2(12): e0189085. doi: 10.1371/journal.pone.0189085.

- 408 38. Jones TW, Smith A, Macnaughton LS, French DN. Strength and Conditioning
 409 and concurrent training practices in elite rugby union. *J Strength Cond Res.*
 410 2016;30(12): 3354 – 3366
- 411 39. Demmer DL, Beilin LJ, Hands B, et al. Dual energy x-ray absorptiometry
 412 compared with anthropometry in relation to cardio-metabolic risk factors in a
 413 young adult population: Is the “gold standard” tarnished? *PLoS ONE.*
 414 2016;11(9): e0162164.
- 415 40. Toombs RJ, Ducher G, Shepherd JA, De Souza MJ. The impact of recent
 416 technological advances on the trueness and precision of DXA to assess body
 417 composition. *Obesity.* 201;20(1): 30–39
- 418 41. Buckinx F, Landi F, Cesari M. et al. Pitfalls in the measurement of muscle
 419 mass: a need for a reference standard. *J. Cachexia Sarcopenia Muscle.*
 420 2018;9(2): 269–278
- 421 42. Hicks CS, McLester CN, Esmat TA, McLester JR. A comparison of body com-
 422 position across two phases of the menstrual cycle utilizing dual-energy x-ray
 423 absorptiometry, air displacement plethysmography, and bioelectrical imped-
 424 ance analysis. *Int J Exerc Sci.* 2017;10(8): 1235–1249
- 425

426 **LEGENDS:**

Table 1: Comparisons between pre- and post-season Dual Energy X-ray Absorptiometry scan measures of body mass (BM), fat mass (FM), lean mass (LM) bone mineral content (BMC) (all kg) and bone mineral density (BMD) ($\text{g}\cdot\text{cm}^{-2}$) of competitive female rugby union players. * within-variable difference relative to the pre-season value at $p\leq 0.05$ level. Position-specific data is not subject to inferential statistical analyses but is presented for descriptive purposes.

Table 1: Comparisons between pre- and post-season Dual Energy X-ray Absorptiometry scan measures of body mass (BM), fat mass (FM), lean mass (LM) bone mineral content (BMC) (all kg) and bone mineral density (BMD) ($\text{g}\cdot\text{cm}^{-2}$) of competitive female rugby union players. * within-variable difference relative to the pre-season value at $p\leq 0.05$ level. Position-specific data is not subject to inferential statistical analyses but is presented for descriptive purposes.

Time	Group	DXA Variable				
		BM (kg)	FM (kg)	LM (kg)	BMD ($\text{g}\cdot\text{cm}^{-2}$)	BMC (kg)
Pre-season	All (n=15)	73.7 \pm 9.6	20.1 \pm 8.3	50.2 \pm 3.6	1.30 \pm 0.07	3.24 \pm 0.40
	Forwards (n=8)	77.2 \pm 12.1	23.1 \pm 10.1	50.5 \pm 4.7	1.32 \pm 0.04	3.40 \pm 0.30
	Backs (n=7)	69.9 \pm 3.0	16.6 \pm 3.9	49.7 \pm 2.0	1.28 \pm 0.08	3.04 \pm 0.30
Post-Season	All (n=15)	74.9 \pm 10.2*	21.0 \pm 8.8	50.7 \pm 3.9	1.31 \pm 0.06	3.28 \pm 0.36*
	Forwards (n=8)	78.9 \pm 12.8	24.0 \pm 10.8	51.5 \pm 4.9	1.33 \pm 0.04	3.50 \pm 0.40
	Backs (n=7)	70.4 \pm 2.9	17.6 \pm 4.32	49.7 \pm 2.34	1.28 \pm 0.08	3.10 \pm 0.30