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

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

102

103 **Abstract**

104

105 During pre-season training, rugby union (RU) athletes endeavour to enhance physical
106 performance characteristics that are aligned with on-field success. Specific physique
107 traits are associated with performance, therefore body composition assessment is
108 routinely undertaken in elite environments. This study aimed to quantify pre-season
109 physique changes in elite RU athletes with unique morphology and divergent
110 ethnicity. Twenty-two Caucasian and Polynesian professional RU athletes received
111 dual-energy X-ray absorptiometry (DXA) assessments at the beginning and
112 conclusion of an 11-week pre-season. Interactions between on-field playing position
113 and ethnicity in body composition adaptations were explored, and the least significant
114 change (LSC) model was used to evaluate variations at the individual level. There
115 were no combined interaction effects with the variables position and ethnicity, and
116 any body composition measure. After accounting for baseline body composition,
117 Caucasians gained more lean mass during the pre-season than Polynesians ($2425 \pm$
118 1303 g vs 1115 ± 1169 g; $F=5.4$, $p=0.03$). Significant main effects of time were found
119 for whole body and all regional measures with fat mass decreasing ($F=31.1-52.0$,
120 $p<0.01$), and lean mass increasing ($F=12.0-40.4$, $p<0.01$). Seventeen athletes (9
121 Caucasian, 8 Polynesian) had a reduction in fat mass, and 8 athletes (6 Caucasian, 2
122 Polynesian) increased lean mass. This study describes significant and meaningful
123 physique changes in elite RU athletes during a pre-season period. Given the
124 individualised approach applied to athletes in regards to nutrition and conditioning

125 interventions, a similar approach to that used in this study is recommended to assess
126 physique changes in this population.

127

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

129

130 **Introduction**

131

132 Professional rugby union (RU) athletes may compete in several different competitions
133 and tournaments throughout a calendar year. Following a period of rest (off-season),
134 athletes typically embark on a high volume pre-season training program of increasing
135 intensity that incorporates multifaceted aspects of physical conditioning (Argus et al.,
136 2009; Bradley et al., 2015). The physical goals of pre-season are to increase aerobic
137 and anaerobic fitness, speed, strength and power (Argus et al., 2010), in conjunction
138 with undertaking rugby specific technical and tactical training. Adjustments in body
139 composition, such as increases in lean mass (LM), are associated with favourable
140 changes in a number of performance traits (Bilsborough et al., 2016; Crewther et al.,
141 2013). Therefore, being able to accurately quantify pre-season physique changes is of
142 value to sport science practitioners and coaches to facilitate further personalisation of
143 training and/or dietary interventions.

144

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

150 (FM) has negative implications for thermoregulation (Selkirk & McLellan, 2001), and
151 concurrently increases energy expenditure during exercise, both of which may limit
152 an athlete's ability to perform at a high intensity for the duration of a match (Duthie,
153 2006). Additionally, an increase in FM has the potential to attenuate force production
154 according to Newton's second law of motion ($a = F/m$), whereby increases in FM (m)
155 without a corresponding increase in muscle force (F) will reduce acceleration (a)
156 (Duthie, 2006; Lees et al., 2017).

157

158 Pre-season increases in LM and decreases in FM have previously been reported in
159 elite RU athletes using surface anthropometry (Argus et al., 2010; Bradley et al.,
160 2015). However, there are limits to relying on anthropometric measures for estimating
161 body composition in athletes, given the regression equations haven't been validated
162 for use in RU, or to track changes in body composition (Silva et al., 2009; Zemski et
163 al., 2017). Over recent years, the use of dual-energy X-ray absorptiometry (DXA) for
164 body composition assessment in elite RU has increased (Lees et al., 2017; Zemski et
165 al., 2015). This technology provides an in-depth analysis of whole body and regional
166 bone mineral content (BMC), FM and LM, and is recognised as a valid and precise
167 body composition assessment tool (Harley et al., 2009; Van der Ploeg et al., 2003)
168 when client presentation is standardised in accordance with best practice guidelines
169 (Nana et al., 2015).

170

171 In recent years there has been a surge in the number of Polynesian athletes securing
172 professional RU contracts. One study has investigated three-compartment body
173 composition in Polynesian RU players and reported different distributions of regional
174 FM and LM (Zemski et al., 2015). In non-athletes, large differences in physique have

175 been reported between Caucasian and Polynesian individuals, with Polynesians
176 having more LM and greater LM:FM ratios (Rush et al., 2004; Swinburn et al., 1996;
177 Swinburn et al 1999). To date, no study has explored differences in physique
178 adaptations to training by ethnicity in RU. Therefore, the aim of this study was to
179 investigate pre-season team and individual athlete DXA body composition
180 adaptations in elite RU athletes, with sub-group analysis to compare changes between
181 Polynesian and Caucasian individuals.

182

183 **Methods**

184

185 *Participants*

186

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

192

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

199

200 *Study design*

201

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

208

209 *Body composition assessment*

210

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

215

216 A standardised scanning protocol was implemented to maximise technical reliability
217 and minimise error. This protocol has been described in detail elsewhere (Nana et al.,
218 2015). Specifically, athletes were scanned first thing in the morning (between 5:00 am
219 and 8:30 am) prior to food and fluid ingestion, or exercise. The athletes were
220 requested to remain well hydrated the day before, and to consume their normal
221 prescribed training diet the day before the assessment. They were scanned wearing
222 sports shorts, and those taller than the 196 cm scanning boundary undertook two scans,
223 the first of which captured the body from the menton (the inferior point of the
224 mandible) down whilst the head was positioned in the Frankfort plane. The athletes

225 were then repositioned on the scanner, with the subsequent scan capturing from the
226 menton up to the vertex of the head. The results of the two scans were combined
227 during the analysis process to yield whole body composition (Evans et al., 2005).
228 None of the athletes in this study were too broad for the scanning area. To ensure
229 consistency, the same experienced and qualified technician performed all
230 measurements and post-scan analysis, including the manual adjustment of all regions
231 of interest. Fat-Free Mass Index (FFMI) was calculated using the equation fat-free
232 mass (kg) divided by stature (m) squared (Vanltallie et al., 1990).

233

234 *Pre-season training program*

235

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

249 individualised dietary plans aimed at supporting training adaptations throughout the
250 pre-season period.

251

252 *Statistical analysis*

253

254 Statistical analyses were completed using SPSS (Version 22.0, IBM Corp., Armonk,
255 NY) and Microsoft Excel 2011 (Microsoft, Redmond, WA, USA). Before analysis,
256 assumptions of normality in the data were made using visualisations of normality
257 plots and the Shapiro-Wilk test. Changes in body composition over the pre-season
258 period were analysed using mixed-model analysis of variance (ANOVA), with the
259 pre-season period acting as the within-subject factor, and playing position and
260 ethnicity as the between subject factors. Additionally, a two-way analysis of
261 covariance (ANCOVA) was conducted using both position and ethnicity as
262 independent variables, and the start of pre-season as covariate, to test for interactions
263 between position and ethnicity controlled for baseline values. Significant effects were
264 subsequently explored using Bonferroni post hoc tests to counteract multiple
265 comparisons. Sphericity of the data was assessed using the Mauchly test, assumptions
266 of homogeneity of variance using Levene's test of equality of error variances, and
267 Box's test of equality of covariance matrices were conducted. Between subject-effects
268 were evaluated using the partial eta squared (η_p^2) rankings of small (> 0.01), medium
269 (> 0.09) and large (> 0.25). Data are presented as mean \pm standard deviation (SD)
270 with statistical significance for all analyses defined as $p \leq 0.05$.

271

272 The short term precision root-mean-square-standard deviation (RMS-SD), percent
273 coefficient of variation (%CV), and corresponding least significant change (LSC) was

274 calculated using standardised protocols as recommended by the International Society
275 for Clinical Densitometry (Hangartner et al., 2013). This was done in a population of
276 resistance trained athletes using the same Hologic Discovery A scanner used in this
277 study (Zemski et al., 2018). Precision errors from same day scans (technical error) for
278 whole body BMC, LM and FM, were 21.1 g, 238.4 g, and 222.7 g respectively.
279 Precision error from consecutive day scans (technical error and biological variation)
280 was calculated as the root-mean-square standard deviation (RMS–SD), with LSC
281 subsequently derived as $\text{RMS–SD} \times 2.77$ (95% confidence interval [95% CI]), and is
282 presented in Table 1. Meaningful changes in individual athletes were identified if they
283 exceeded the LSC as described elsewhere (Lees et al., 2017).

284

285 **Results**

286

287 *Descriptive characteristics*

288

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

295

296 *Team changes in whole and regional body composition*

297

298 Pre-season body composition changes are presented in Table 2. There were no
299 combined interaction effects between the variables position and ethnicity, with any
300 body composition measure. After accounting for baseline body composition,
301 Caucasians gained more LM during the pre-season than Polynesians (2425 ± 1303 g
302 vs 1115 ± 1169 g; $F = 5.4$, $p = 0.03$). Significant main effects of time were found for
303 whole body and all regional measures with FM decreasing (whole body $F = 52.0$, $p <$
304 0.01 ; arms $F = 31.1$, $p < 0.01$; trunk $F = 44.8$, $p < 0.01$; legs $F = 39.5$, $p < 0.01$), LM
305 increasing (whole body $F = 40.4$, $p < 0.01$; arms $F = 33.7$, $p < 0.01$; trunk $F = 14.8$, p
306 < 0.01 ; legs $F = 12.0$, $p < 0.01$), and trunk BMC increasing ($F = 5.1$, $p = 0.04$).
307 Between-subject effects were found based on position for all variables ($F = 3.8$ – 13.2 ;
308 $p = 0.01$ – 0.03 ; $\eta_p^2 = 0.39$ – 0.69 [large effect]).

309

310 *Individual player body composition changes*

311

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

320

321 **Discussion**

322

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

331

332 Significant changes in body composition during pre-season training have been
333 reported in as little as 4-weeks in a similar population of professional RU athletes
334 (Argus et al., 2010). However, given that body composition changes were inferred via
335 a surface anthropometry derived regression equation, the validity of such a marked
336 increase in LM (2.0 ± 0.6 kg) in such a short time period is questionable (Silva et al.,
337 2009). Indeed, only 8 athletes in the present investigation observed similar gains in
338 LM, despite an 11-week pre-season period. FM losses in this study were slightly
339 larger than in the aforementioned study (1.4 ± 0.4 kg), although this would be
340 expected given the duration of the pre-season was considerably longer. Pre-season
341 increases in LM and decreases in FM of a similar magnitude to those observed in this
342 study have also been reported in professional Australian rules footballers (AFL) using
343 DXA (Bilsborough et al, 2017), corroborating that the pre-season period in
344 professional sport is a time of noteworthy body composition change.

345

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

348 For example, although statistically significant gains in LM were observed in the
349 current investigation, only one-third of athletes had meaningful increases in LM based
350 on LSC analysis (>2083 g). This may be a result of the challenges associated with
351 increasing LM once high levels of muscularity are reached (Abe et al., 2018). Indeed,
352 the rate of LM accumulation has been reported to decline in American football (NFL)
353 athletes when BM exceeds ~114 kg (forwards in this study 112.5 ± 7.6 kg) (Bosch et
354 al., 2014), and an upper limit in FFMI of 25 kg/m^2 has been suggested in non-steroid
355 using males (Kouri et al., 1995). However, the validity of this FFMI cut-off has been
356 questioned in athletic populations (Trexler et al., 2017). Specifically, professional RU
357 forwards routinely exceed this threshold (Zemski et al., 2015), including all 11 of the
358 forwards in the present study ($26.1 \pm 1.2 \text{ kg/m}^2$; range 25.5 – 29.0 kg/m^2).

359 Characterising athletes and measuring adaptations at the group level may not tell the
360 whole story, as was the case with LM adaptations in this study. Therefore, being able to
361 evaluate changes in body composition at the individual level provides practitioners
362 the opportunity to appreciate more deeply individual adaptations, which may provide
363 benefits in program personalisation and performance optimisation.

364

365 Polynesians have consistently been shown to display higher LM and lower FM
366 compared to Caucasians (Rush et al., 2004; Rush et al, 2009; Swinburn et al., 1996;
367 Swinburn et al., 1999); however, longitudinal adaptations have not previously been
368 investigated. More Caucasian athletes increased LM than Polynesians (6 athletes vs 2
369 athletes) particularly in the trunk region (3 athletes vs 0 athletes), and a statistically
370 significant group main effect based on ethnicity was found. Future investigations
371 incorporating ethnicity differentiated within and between season measures may
372 provide further insight into the role ethnicity plays in training adaptations not only

373 during the season, but also post-season in the absence of the training stimulus, where
374 previously significant compromises in body composition have been noted in other
375 elite contact team-sport populations (Bilsborough et al., 2017).

376

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

385

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

397

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

422

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

431

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439

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446

447 **References**

448

449 Abe, T., Buckner, S. L., Dankel, S. J., Jessee, M. B., Mattocks, K. T., Mouser, J. G.,
450 & Loenneke, J. P. (2018). Skeletal muscle mass in human athletes: What is the upper
451 limit? *American Journal of Human Biology*. Epub ahead of print.

452

453 Argus, C. K., Gill, N., Keogh, J., Hopkins, W. G., & Beaven, C. M. (2010). Effects of
454 a short-term pre-season training programme on the body composition and anaerobic
455 performance of professional rugby union players. *Journal of Sports Sciences*, 28, 679-
456 686.

457

458 Argus, C. K., Gill, N. D., Keogh, J. W., Hopkins, W. G., & Beaven, C. M. (2009).
459 Changes in strength, power, and steroid hormones during a professional rugby union
460 competition. *Journal of Strength and Conditioning Research*, 23, 1583-1592.

461

462 Bell, W., Evans, W. D., Cobner, D. M., & Eston, R. G. (2005). Regional placement of
463 bone mineral mass, fat mass, and lean soft tissue mass in young adult rugby union
464 players. *Ergonomics*, 48, 1462-1472.

465

466 Bilsborough, J. C., Kempton, T., Greenway, K., Cordy, J., & Coutts, A. J. (2017).
467 Longitudinal changes and seasonal variation in body composition in professional
468 Australian football players. *International Journal of Sports Physiology and*
469 *Performance*, 12, 10-17.

470

471 Bilsborough, J. C., Greenway, K., Livingstone, S., Cordy, J., & Coutts, A. J. (2016).
472 Changes in anthropometry, upper-body strength, and nutrient intake in professional

473 Australian football players during a season. *International Journal of Sports*
474 *Physiology and Performance*, 11, 290-300.

475

476 Bosch, T. A., Burrell, T. P., Weir, N. L., Fielding, K. A., Engel, B. E., Weston, T. D.,
477 & Dengel, D. R. (2014). Abdominal body composition differences in NFL football
478 players. *Journal of Strength and Conditioning Research*, 28, 3313-3319.

479

480 Bradley, W. J., Cavanagh, B. P., Douglas, W., Donovan, T. F., Morton, J. P., & Close,
481 G. L. (2015). Quantification of training load, energy intake, and physiological
482 adaptations during a rugby preseason: a case study from an elite European rugby
483 union squad. *Journal of Strength and Conditioning Research*, 29, 534-544.

484

485 Crewther, B. T., Heke, T. L., & Keogh, J. W. (2013). The effects of a resistance-
486 training program on strength, body composition and baseline hormones in male
487 athletes training concurrently for rugby union 7's. *Journal of Sports Medicine and*
488 *Physical Fitness*, 53, 34-41.

489

490 Drenowatz, C., & Eisenmann, J. C. (2011). Validation of the SenseWear Armband at
491 high intensity exercise. *European Journal of Applied Physiology*, 111, 883-887.

492

493 Duthie, G. M. (2006). A framework for the physical development of elite rugby union
494 players. *International Journal of Sports Physiology and Performance*, 1, 2-13.

495

496 Evans, E. M., Prior, B. M., & Modlesky, C. M. (2005). A mathematical method to
497 estimate body composition in tall individuals using DXA. *Medicine and Science in*
498 *Sports and Exercise*, 37, 1211-1215.

499

500 Hangartner, T. N., Warner, S., Braillon, P., Jankowski, L., & Shepherd, J. (2013). The
501 official positions of the international society for clinical densitometry: acquisition of
502 dual-energy x-ray absorptiometry body composition and considerations regarding
503 analysis and repeatability of measures. *Journal of Clinical Densitometry*, 16, 520-536.

504

505 Harley, J. A., Hind, K., O'Hara, J., & Gross, A. (2009). Validation of the skin-fold
506 thickness method and air displacement plethysmography with dual energy X-ray
507 absorptiometry for the estimation of % body fat in professional male rugby football
508 league players. *International Journal of Body Composition Research*, 7, 7-14.

509

510 Kouri, E. M., Pope, H., G., Katz, D. L., & Oliva P. (1995). Fat-free mass index in
511 users and nonusers of anabolic-androgenic steroids. *Clinical Journal of Sports*
512 *Medicine*, 5, 223-228.

513

514 Lees, M. J., Oldroyd, B., Jones, B., Brightmore, A., O'Hara, J. P., Barlow, M. J., Till,
515 K., & Hind, K. (2017). Three-compartment body composition changes in professional
516 rugby union players over one competitive season: A team and individual approach.
517 *Journal of Clinical Densitometry*, 20, 50-57.

518

519 Magkos, F., & Yannakoulia, M. (2003). Methodology of dietary assessment in
520 athletes: concepts and pitfalls. *Current Opinion in Clinical Nutrition and Metabolic*
521 *Care*, 6, 539-549.

522

523 Nana, A., Salter, G. J., Stewart, A. D., & Burke, L. M. (2015). Methodology review:
524 using dual-energy X-ray absorptiometry (DXA) for the assessment of body
525 composition in athletes and active people. *International Journal of Sport Nutrition*
526 *and Exercise Metabolism*, 25, 198-215.

527

528 Olds, T. (2001) The evolution of physique in male rugby union players in the
529 twentieth century. *Journal of Sports Sciences*, 19, 253-262.

530

531 Quarrie, K. L., & Hopkins, W. G. (2007). Changes in player characteristics and match
532 activities in Bledisloe Cup rugby union from 1972 to 2004. *Journal of Sports Sciences*,
533 25, 895-903.

534

535 Roberts, S. P., Trewartha, G., Higgitt, R. J., El-Abd, J., & Stokes, K. A. (2008). The
536 physical demands of elite English rugby union. *Journal of Sports Sciences*, 26, 825-
537 833.

538

539 Rush, E. C., Freitas, I., & Plank, L. D. (2009). Body size, body composition and fat
540 distribution: comparative analysis of European, Maori, Pacific Island and Asian
541 Indian adults. *British Journal of Nutrition*, 102, 632-641.

542

543 Rush, E., Plank, L., Chandu, V., Lualaba, M., Simmons, D., Swinburn, B., & Yajnik, C.
544 (2004). Body size, body composition, and fat distribution: a comparison of young
545 New Zealand men of European, Pacific Island, and Asian Indian ethnicities. *New*
546 *Zealand Medical Journal*, 117, U1203.

547

548 Selkirk, G. A., & McLellan, T. M. (2001). Influence of aerobic fitness and body
549 fatness on tolerance to uncompensable heat stress. *Journal of Applied Physiology*
550 (1985), 91, 2055-2063.

551

552 Silva, A. M., Fields, D. A., Quiterio, A. L., & Sardinha, L. B. (2009). Are skinfold-
553 based models accurate and suitable for assessing changes in body composition in
554 highly trained athletes? *Journal of Strength and Conditioning Research*, 23, 1688-
555 1696.

556

557 Swinburn, B. A., Craig, P. L., Daniel, R., Dent, D. P., & Strauss, B. J. (1996). Body
558 composition differences between Polynesians and Caucasians assessed by
559 bioelectrical impedance. *International Journal of Obesity and Related Metabolic*
560 *Disorders*, 20, 889-894.

561

562 Swinburn, B. A., Ley, S. J., Carmichael, H. E., & Plank, L. D. (1999). Body size and
563 composition in Polynesians. *International Journal of Obesity and Related Metabolic*
564 *Disorders*, 23, 1178-1183.

565

566 Trexler, E. T., Smith-Ryan, A. E., Blue, M. N. M., Schumacher, R. M., Mayhew, J. L.,
567 Mann, J. B., ... & Mock, M. G. (2017). Fat-free mass index in NCAA Division I and

568 II collegiate American football players. *Journal of Strength and Conditioning*
569 *Research*, 31, 2719-2727.

570

571 Vanltallie, T. B., Yang, M. U., Heymsfield, S. B., Funk, R. C., & Boileau, R. A.
572 (1990). Height-normalized indices of the body's fat-free mass and fat mass:
573 potentially useful indicators of nutritional status. *American Journal of Clinical*
574 *Nutrition*, 52, 953-959.

575

576 Van Der Ploeg, G. E., Withers, R. T., & Laforgia, J. (2003). Percent body fat via
577 DEXA: comparison with a four-compartment model. *Journal of Applied Physiology*,
578 94, 499-506.

579

580 Zemski, A. J., Broad, E. M., & Slater, G. J. (2017). Skinfold prediction equations fail
581 to provide an accurate estimate of body composition in elite rugby union athletes of
582 Caucasian and Polynesian ethnicity. *International Journal of Sport Nutrition and*
583 *Exercise Metabolism*, 16, 1-23.

584

585 Zemski, A. J., Hind, K., Keating, S. E., Broad, E. M., Marsh, D. J., & Slater., G. J.
586 (2018). Precision error of the Hologic Discovery A densitometer for the measurement
587 of body composition in resistance trained athletes. *European Journal of Clinical*
588 *Nutrition*. In review.

589

590 Zemski, A. J., Slater, G. J., & Broad, E. M. (2015). Body composition characteristics
591 of elite Australian rugby union athletes according to playing position and ethnicity.
592 *Journal of Sports Sciences*, 33, 970-978.

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

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

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

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

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

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

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

^a Significant interaction between time and ethnicity

^b Significant main effect for time

^c Significant difference between forwards and backs

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

		All	Position		Ethnicity	
		(n=22)	(n=22)		(n=22)	
			Forwards	Backs	Caucasians	Polynesians
			(n=11)	(n=11)	(n=11)	(n=11)
↑ Bone Mineral Content	Arms	1 (5%)	1 (9%)	0 (0%)	1 (9%)	0 (0%)
	Trunk^a	9 (41%)	6 (55%)	3 (27%)	3 (27%)	6 (55%)
	Legs^b	5 (23%)	2 (18%)	3 (27%)	3 (27%)	2 (18%)
	WB^c	4 (18%)	2 (18%)	2 (18%)	3 (27%)	1 (9%)
↓ Fat Mass	Arms	10 (45%)	6 (55%)	4 (36%)	3 (27%)	7 (64%)
	Trunk	17 (77%)	9 (82%)	8 (73%)	9 (82%)	8 (73%)
	Legs	14 (64%)	8 (73%)	6 (55%)	8 (73%)	6 (55%)
	WB	17 (77%)	9 (82%)	8 (73%)	9 (82%)	8 (73%)
↑ Lean Mass	Arms	11 (50%)	6 (55%)	5 (45%)	6 (55%)	5 (45%)
	Trunk	3 (14%)	3 (27%)	0 (0%)	3 (27%)	0 (0%)
	Legs	2 (9%)	0 (0%)	2 (18%)	1 (9%)	1 (9%)
	WB	8 (36%)	4 (36%)	4 (36%)	6 (55%)	2 (18%)
Data shown as – number of athletes (% of athletes)						
WB = whole body						
^a 2 athletes lost BMC in their trunk (Caucasian forward, Polynesian back)						
^b 2 athletes lost BMC in their legs (Caucasian forward, Polynesian back)						
^c 1 athlete lost BMC in their whole body (Caucasian forward)						

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

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

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