Daily Protein Distribution Patterns in Professional and Semi-Professional Male Rugby Union Players

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ABSTRACT

Recent research in healthy adults suggests an even distribution of protein throughout the day may result in greater stimulation of muscle protein synthesis compared to a disproportionate intake, with 0.4g.kg per meal at a minimum of 4 eating occasions proposed to optimise anabolism. In rugby players, this may be of benefit to exercise adaptations, recovery, and performance. In the present study, semi-professional forwards (n=19), semi-professional backs (n=6) and professional (n=10) rugby players recorded dietary intake for seven days. Both absolute (g) and relative to body mass (g.kg) protein intake was calculated across six eating occasions. Relative protein intake at breakfast, AM snack, lunch, PM snack, dinner and evening snack were 0.3, 0.1, 0.4, 0.2, 0.6 and 0.1g.kg, respectively. Total protein intake was significantly different between groups ($p<0.05$). All groups demonstrated differences in protein intake between eating occasions ($p<0.01$). Protein intake was highest at dinner in all athletes, with professionals consuming significantly greater protein than semi-professionals. Rugby players do not appear to meet the recommended per-meal protein dose of 0.4g.kg at a minimum of 4 eating occasions. Consumption of additional protein outside of main eating occasions as snacks may be beneficial to optimise muscle protein synthesis stimulation and thus adaptation, recovery and performance.

Keywords: protein distribution; nutrient timing; rugby players; recovery nutrition; dietary protein for athletes

INTRODUCTION

Rugby Union ("rugby") players are exposed to unique demands during matches and training that can influence energy and nutrient requirements. The sport can be classified as an intermittent team sport, with teams of 15 engaging in repeat-sprints, jumps and collisions (Duthie, Pyne & Hooper, 2003). Additionally, rugby is unique in that large positional variation is observed in both the match demands and body composition of the players (Zemski et al, 2019). It is recommended that rugby players focus on building fat-free soft tissue muscle to meet the demands of the sport and maintaining an appropriate body composition profile is critical for individual players to fulfil their roles on the pitch (Zemski et al, 2019). For example, a greater fat-free mass in the prop position (94.4 ± 7.9 kg) is considered advantageous due to the requirement to exert greater force than the opponent whilst contesting the ball whereas lower fat-free mass in inside back positions (78.8 ± 8.2 kg) can allow for greater agility and mobility (Smart, Hopkins & Gill, 2013). While engaging in high-volume training and competition, rugby players nutritional strategies require careful consideration (Argus et al, 2009).

Rugby players can expect significant physiological, psychological, and endocrine disruption in response to matches (Slimani et al, 2017). The repetitive high-intensity efforts and collisions invokes exercise-induced muscle damage and cellular disruption (Naughton, Miller & Slater, 2018). Metabolic, endocrine, and neuromuscular function may not return to baseline for up to 36 hours following a rugby match. Moreover, mood disturbances are apparent for up to 12 hours post-match, possibly due to competitive stress or fatigue (West et al, 2014). A longer period of disequilibrium as denoted by an impairment of 10m sprint performance, and elevated creatine kinase following a full match was observed in amateur-level rugby players (da Silva et al, 2020). Data from professional players demonstrate the magnitude of muscle damage may be predicted by the number of collisions and high-speed running performance (Jones et al, 2014). With the potential for high training volumes players risk inadequate recovery between matches and training sessions (Argus et al, 2009). As such, ensuring dietary intake is designed to support optimal recovery is of the utmost importance.

Protein intake is an important consideration for athletes to support optimal performance, recovery, and health (Kreider & Campbell, 2007; Phillips, Chevalier & Leidy, 2015). Rugby players engage in activity encompassing both strength and endurance demands, which may require both mitochondrial and myofibrillar adaptations along with preventing amino acid oxidation in response to prolonged and intense activity (Lemon, 1994; Kato et al, 2016). Researchers have sought to quantify protein requirements for athletic populations and various position statements have been published through organisations such as the International Society for Sports Nutrition (ISSN) (Jäger et al, 2017) and the American College of Sports Medicine (ACSM) (Thomas, Erdman & Burke, 2016). These position statements provide a comprehensive and critical review of the literature on protein intake in healthy, exercising individuals to determine requirements. Ranges such as 1.4-2.0g.kg.d and 1.2-1.7g.kg have been proposed as sufficient for most endurance and/or strength-trained individuals within the ISSN and ACSM position statements, respectively. It is important to note that these values are unlikely to consider the unique demands experienced by rugby union athletes, and most of the research in the consensus statements utilised resistance or endurance-training protocols. Nonetheless, rugby athletes appear to consume protein in excess of the recommendations (Jenner et al, 2019) with common intakes above 2.0g.kg.d.

Protein ingestion has the potential to stimulate muscle protein synthesis for two to three hours, after which the process begins to decline (Layman et al, 2015). A positive balance between muscle protein synthesis and breakdown, termed an anabolic response (Kim et al, 2018), is a determinant of protein within a muscle and may be crucial to allow for the repair and re-modelling of damaged muscle tissue following exercise (Tipton et al, 2018). Investigations have reported that ingestion of 20g high-quality protein following leg-based resistance exercise is sufficient to stimulate a positive protein balance greater than no ingestion of protein, however 40g induced similar protein synthesis rates but greater amino acid oxidation (Moore et al, 2009; Witard et al, 2013). Conversely, Macnaughton et al (2016) observed a greater anabolic response in resistance-trained males following full-body resistance training with ingestion of 40g compared to 20g. Collectively, researchers (Morton, McGlory & Phillips, 2015; Schoenfeld & Aragon, 2018) suggest a per-meal relative protein dose of 0.4g.kg may be optimal for anabolic stimulation.

With consideration to the influence of protein ingestion on the anabolic response in the physically-active general population, recent investigations have aimed to identify an optimal daily protein distribution pattern. Over a 12-hour post-exercise period, Areta et al (2013) noted the anabolic response to 80g of protein was greatest when 20g was consumed at 3-hour intervals compared to 10g at 1.5-hour intervals or 40g at 6-hour intervals. When matched for energy and protein, Mamerow et al (2014) demonstrated that an even distribution of protein across three eating occasions (breakfast, lunch, dinner) resulted in a greater muscle protein synthetic response than a skewed protein intake, with the bulk consumed in the evening meal.

The timing of protein and per meal doses throughout the day may be of greater importance to the rugby player than total intake however limited research has explored protein intake and distribution in these athletes. MacKenzie et al (2015) reported that rugby players engaged in 3.8 eating occasions daily wherein 20g or greater protein was consumed. Protein intakes of this amount may not be optimal for the athletes in the study. At a bodyweight of 100.2 ± 13.3kg, this would result in a relative dose of 0.2g.kg which does not reach the current proposed threshold of 0.4g.kg for maximally stimulating muscle protein synthesis (Morton et al, 2015). Mackenzie et al (2015) noted that individual per meal protein target was 30.0 ± 4.0g however it is not known how much protein was consumed at each sitting. The purpose of the present study was to observe and quantify dietary protein distribution patterns across the day in professional and semi-professional rugby athletes. Based on previous research in athletes (Anderson et al, 2017; Gillen et al, 2017) we hypothesised that rugby athletes would consume protein in a disproportionate pattern across the day.

METHODS

Participants

Thirty-five participants were recruited from a semi-professional rugby club in New Zealand. The sample size was based on the availability of players in the team and players were initially approached by the strength and conditioning coach of the club. If interested, participants were briefed further by the lead researcher. Data was granted from a parallel project in professional players due to the current project exploring different parameters. As such, a further ten players from a separate professional club were included in the dataset.

During briefing, the participants were informed that they were required to record their dietary intake for analysis, that their participation in the study was voluntary and that they were able to withdraw at any time without providing a reason. Following briefing of the purpose of the study, participants signed informed consent forms. This study was approved by the University of Waikato Human Research Ethics Committee (HREC(Health)2020#06).

Protocol

Prior to data collection, participants height (Stadiometer, SECA, Hamburg, Germany) and body mass (Electronic Flat Scale, SECA, Hamburg, Germany) were recorded. Data was collected during the 2020 national provincial pre-competition season (August-September).

Dietary intake data was collected over a seven day period for each player using MealLogger (Wellness Foundry, Helsinki, Finland). The application allows for a secure and private connection between the researcher and the participants.

Participants were briefed in person and provided with materials to assist with providing appropriate data for analysis. Participants were asked to take photographs of all food, supplements and fluid consumed. A photograph before and after consumption (if a food or meal was partially consumed) allowed for analysis of the total amount of food consumed. Participants were asked to place a hand or other object next to their plate/bowl as a reference of the size of the meal and to ensure the photograph was from an angle that allows for easy identification of the components and quantity of the meal. The morning after each collection day, participants were contacted by a member of the research team to enquire about any items they may have forgotten to log and to provide further clarification to logged meals if required.

Participants were asked to provide details about the food and/or meals consumed with photo upload. The inclusion of details such as brand labels, measurements, cooking methods and items within meals was encouraged. Participants were asked to weigh food and/or ingredients if possible, to reduce possible measurement error.

Dietary Analysis

Photographs were analysed for nutrient intake using FoodWorks (Version 10, Xyris Software, Brisbane, Australia). The information was entered manually into FoodWorks by a single member of the research team to ensure consistency. Participants' food intake was separated into six main eating occasions throughout the day, as described previously by other groups (Anderson et al, 2017; Gillen et al, 2017). Simply, participants were able to indicate which meal was consumed when uploading photographs with a corresponding timestamp on each photo. The main meals were recorded as 'breakfast' 'lunch' and 'dinner'. Items consumed between 'breakfast' and 'lunch' were recorded as 'AM snack'. Items consumed between 'lunch' and 'dinner' were recorded as 'PM snack'. Finally, items consumed after 'dinner' were recorded as 'evening snack'.

Statistical Analysis

Statistical analysis was performed on SPSS Statistics (Version 26, IBM, Chicago, Illinois, USA). Descriptive statistics are displayed as means ± SD. Total (absolute) and body mass adjusted (relative) values for protein intake were calculated. Significance was set at $p<0.05$. Frequency graphs were created to display distribution of relative protein intake in all participants at each eating occasion. Semi-professional participant data was analysed by position (forwards and backs).

Data was deemed to be non-normally distributed using a Shapiro-Wilk test. As such, non-parametric tests were used for the analysis of data. To analyse protein intake between eating occasions, the Related-Samples Friedman test was applied. In the event of a significant result, post-hoc analysis was applied using Wilcoxon signed-rank test and Bonferroni adjustment for multiple tests. Multiple Independent-Samples Kruskal-Wallis Tests were applied to analyse differences in eating occasions and total protein intake between groups, with post-hoc analysis conducted using Wilcoxon signed-rank test and Bonferroni adjustment for multiple tests.

RESULTS

Participant Characteristics

Of the 35 recruited semi-professional participants, 25 were included with 10 professional rugby union athletes included in the final analysis. Ten participants were excluded for failing to provide adequate photographs and/or descriptions on ≥ three days to allow for analysis of the dietary information. Two semi-professional forwards and one semi-professional back provided six days of dietary analysis. Two professional athletes provided five days of dietary analysis. Participant characteristics are presented in Table 1.

Professional athletes had a greater age than both semi-professional groups ($p<0.01$). Significant differences were observed between all groups for body mass ($p<0.05$). Height was not different between groups.

TABLE 1 HERE

Total Protein Intake

Daily total protein values are displayed in Table 1. For absolute values, semi-professional forwards consumed significantly less protein than professional participants ($p<0.05$). Adjusted for body mass, semi-professional forwards consumed significantly less protein than both semi-professional backs and professional participants ($p<0.05$).

Protein Intake Between Eating Occasions

Combined average protein intake between eating occasions for all participants are displayed in Table 2. Protein intake between the AM snack and PM snack at an absolute and relative level were similar. A significant difference ($p<0.01$) was observed for protein intake between all other meals.

TABLE 2 HERE

Total and body mass adjusted protein intake per meal between semi-professional forwards, semi-professional backs and professionals are displayed in Figure 1 and Figure 2, respectively. When comparing protein intake across eating occasions, lunch and dinner protein intakes were similar in semi-professional forwards and backs, with forwards also consuming similar protein amounts across the AM, PM and evening snack. Protein intake between PM snack – evening snack and breakfast – lunch was similar in professionals. Differences between all other meals were significant (p<0.05). All differences were observed similarly following analysis of absolute and relative intake.

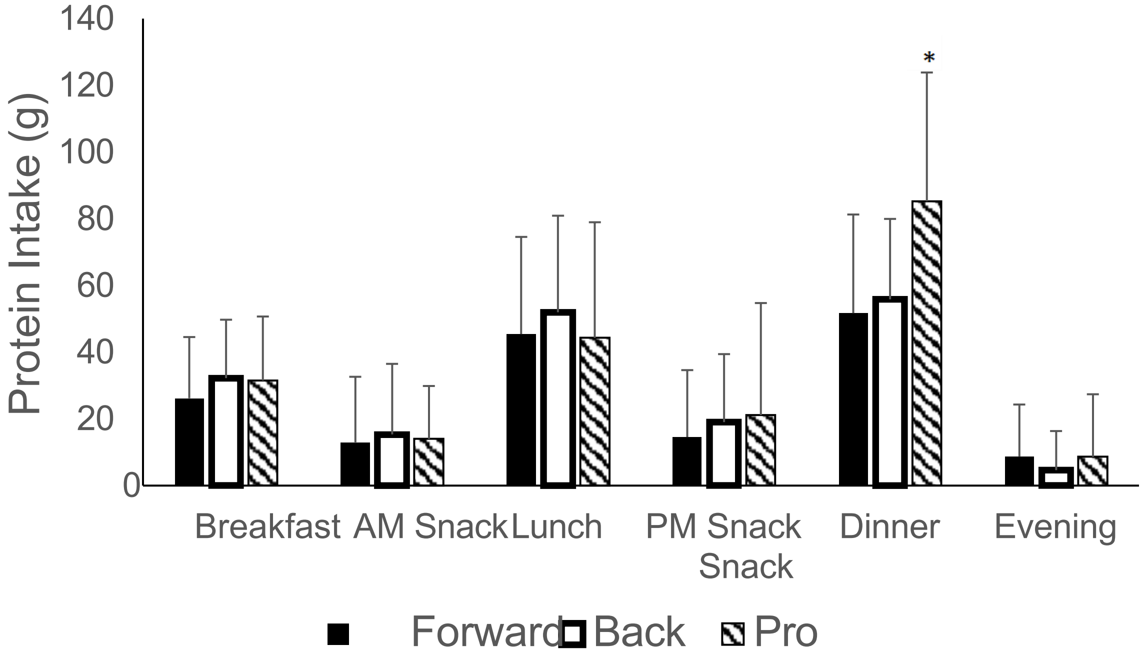

Figure 1. Absolute daily protein distribution. * denotes a significant difference (p<0.05) from both other groups at eating occasion. Values reported as means ± standard deviation.

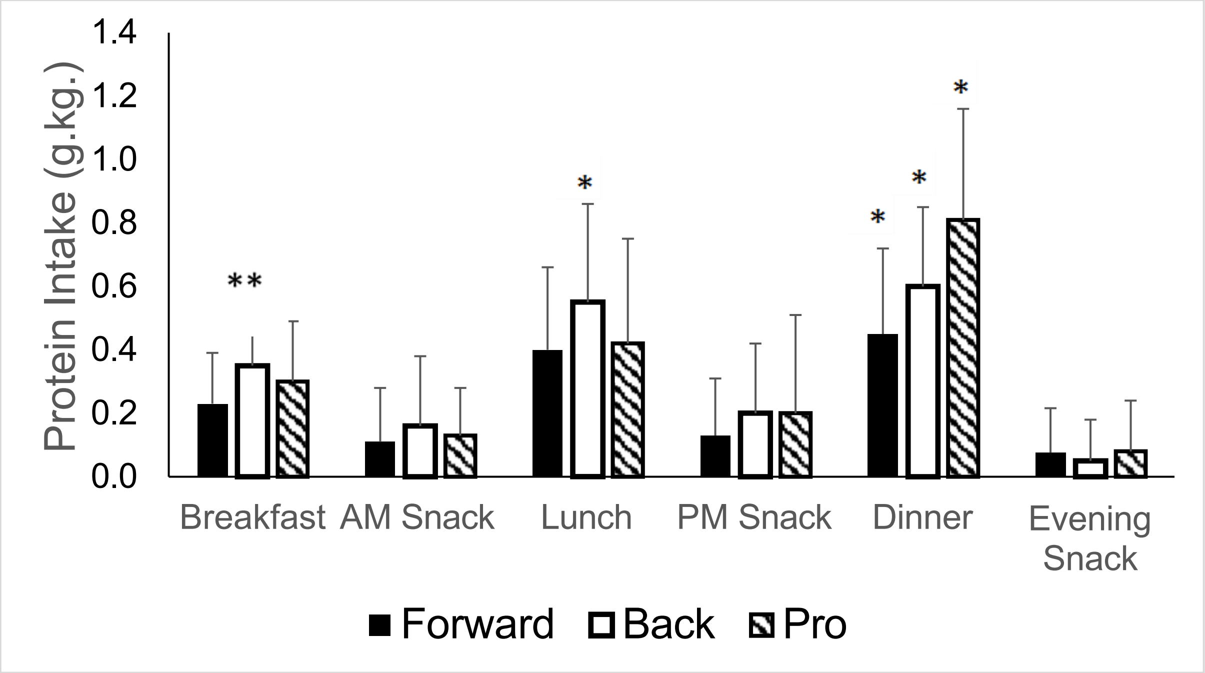

Figure 2. Relative daily protein distribution. * denotes significance ($p<0.05$) from both other groups at eating occasion. ** denotes a significant difference from semi-professional forwards at eating occasion. Values reported as means ± standard deviation.

Frequency graphs are displayed in Supplementary Materials. At breakfast, lunch and dinner, ≥0.4g.kg protein was consumed at 19.2, 52.0 and 70.3% of eating occasions, respectively. No protein was consumed at the AM snack, PM snack and evening snack for 45.9, 41.0 and 59.4% of potential eating occasions, respectively.

Protein Intake Within Eating Occasions

Semi-professional backs consumed significantly greater relative protein intake at lunch than semi-professional forwards or professional participants ($p<0.05$). Differences between relative breakfast protein intake ($p<0.01$) were observed between semi-professional forwards and backs. Additionally, differences in both absolute and relative dinner were observed ($p<0.01$), with professional participants consuming greater absolute protein than either semi-professional group and all groups consuming different amounts of protein relatively.

DISCUSSION

The purpose of this study was to observe and quantify dietary protein distribution patterns across the day in professional and semi-professional rugby athletes. In line with the original hypothesis, all groups consumed protein in a disproportionate pattern, with most protein consumed in the main evening meal compared to earlier in the day. Results from the professional cohort analysed suggest these players eat in a more disproportionate pattern than semi-professional athletes.

Total daily protein intake was lower in semi-professional forwards than professionals for absolute intake and both semi-professional backs and professionals for relative intake. Daily protein intake for semi-professional backs (1.9g.kg.d) and professionals (2.0g.kg.d) was towards the higher end of recommendations (Jäger et al, 2017). At 1.4g.kg.d, protein intake in semi-professional forwards is considerably lower than previously reported in rugby athletes at both professional and semi-professional levels (Jenner et al, 2019). Although 1.4g.kg.d is at the low end of recommendations set forth by ISSN (Jäger et al, 2017) (1.2-2.0g.kg.d) and the ACSM (Thomas, Erdman & Burke, 2016) (1.2-1.7g.kg.d) rugby players in particular may benefit from greater consumption of protein to facilitate recovery from intense exercise (Tipton, 2011) and support lean mass growth to meet the demands of the sport (Smart, Hopkins & Gill, 2013). Additionally, lean mass loss can be offset with a high protein intake (Phillips & Van Loon, 2011) which would be beneficial for athletes seeking body fat reduction, with greater (2.4g.kg.d) requirements for greater energy deficits (Hector & Phillips, 2018).

Semi-professional players consumed similar protein at both lunch and dinner whereas professional players consumed protein in a disproportionate hierarchal fashion (dinner > lunch > breakfast) similarly to other investigations exploring daily protein distribution patterns in athletes (Anderson et al, 2015; Gillen et al, 2017). In the professional group, consumption of protein at dinner was similar to the total Recommended Dietary Allowance for adults (0.8g.kg.d, Phillips, Chevalier & Leidy, 2016) with total and relative protein intakes of 85.6g and 0.81g.kg, respectively. A similar intake of protein at dinner has been observed previously in professional football players (Anderson et al, 2017). This large intake seems to be responsible for the disproportionate pattern of protein ingestion throughout the day as opposed to a compensatory lack of protein at earlier eating occasions. It is unknown whether a per-meal intake of the magnitude seen in the professional cohort is likely to confer additional anabolic benefits. Moore et al. (2009) demonstrated no significant benefit on MPS response following the ingestion of 40g vs. 20g whey protein following a leg-extension exercise session, the demands of which are much different to those of a professional rugby player. When measuring whole-body protein kinetics, Kim et al (2016) found that a meal containing 70g protein increased protein balance over a meal containing 40g. This increase in whole-body protein balance is mainly attributed to a greater reduction in protein breakdown. Greater protein intakes per eating occasion may promote muscle repair, re-modelling and development via reductions in muscle protein breakdown due to protein balance dictating the quantity of proteins in muscle (Tipton et al, 2018).

The frequency graphs indicate that no protein was consumed at 59.4% of evening snack eating occasions. This could be explained in some situations by players simply eating dinner later and possibly not having time or the desire to consume food afterwards or due to intentionally avoiding food after the main evening meal. Nonetheless, consumption of protein pre-sleep may be a useful strategy to optimise skeletal muscle re-modelling and recovery from exercise-induced muscle damage in rugby players. Research has consistently shown a benefit to consumption of post-sleep casein protein on the overnight whole-body protein synthetic response when resistance training was performed (Reis, Loureiro, Roschel & da Costa, 2020) which certainly holds relevance to high level rugby players with congested training schedules. Regarding chronic responses, Snijders et al (2015) found that a daily multi-nutrient supplement (27.5g casein protein + 15g carbohydrates) versus a non-caloric placebo consumed before sleep increased both upper and lower-body strength, quadriceps cross-sectional area and type II fibre size. Consumption of the supplement provided more daily total protein (1.9g.kg vs. 1.3g.kg) which may explain the findings however pre-sleep ingestion of protein is theoretically likely to confer some benefit to athletes. During sleep, muscle protein synthesis rates appear to be low and the body is able to digest and absorb protein efficiently, increasing amino acid availability and thus anabolism (Trommelen & van Loon, 2016). Rugby players may benefit from provision of protein prior to this long period of rest as lean mass levels are predicated by a prolonged positive protein balance (Tipton et al, 2018).

The supplemental frequency graphs indicate a large range of protein intakes at each meal. For example, mean total protein intake at breakfast was adequate to stimulate muscle protein synthesis according to Witard et al (2014) (>20g,) at 28.8g. However, visualization of the frequency graphs indicate many participants did not appear to consume adequate protein at the breakfast occasion according to Morton, McGlory & Phillips (2015) who suggest that a per-dose protein intake of 0.4g.kg is likely to maximally stimulate muscle protein synthesis in young men and 79.9% of potential breakfast eating occasions contained less protein than this threshold. Consuming adequate protein regularly throughout the day may not always be practical for high-level athletes due to various reasons including busy lifestyles and congested training schedules, appetite suppression due to intense exercise and fear of gastrointestinal disturbances (Burke et al, 2003) however this should be encouraged to stimulate and provide substrates for the anabolic processes required for supporting lean mass adaptations (Schoenfeld & Aragon, 2018).

It is important to consider the context of the results in relation to the current research. Enhanced muscle protein anabolism in response to an even distribution of protein throughout the day has been demonstrated in a limited number of studies in populations dissimilar to the one in the present investigation. In a cross-over study, MacKenzie-Shalders et al (2016) aimed to identify whether the provision of protein between main eating occasions would increase lean mass in rugby players. Participants were provided with liquid protein supplements and instructed to consume them either with or between main meals for six weeks. Participants were educated and instructed to consume at least 20g protein as part of their main eating occasions. The authors observed no difference in lean mass gains between groups, despite 5.9 ± 0.7 eating occasions of at least 20g protein in the distributed condition, compared to 4.0 ± 0.8 in the opposite condition. As such, it is currently inconclusive how increased protein distribution throughout the day may influence rugby players in the context of body composition and recovery improvements and further research is required to better understand these.

This is the first study to quantify protein intake per eating occasion relative to body mass in rugby players. This may be especially important as positional differences in rugby can lead to large variations in total and lean body mass, match demands and training volumes. Although 20g of protein is proposed to maximally stimulate muscle protein synthesis when consumed at four equal intervals over a 12-hour period compared to 40g at two intervals (Areta et al, 2013), this amount may not be sufficient for rugby players. When considered on a relative basis, 20g protein does not reach the threshold for young men to experience a maximal anabolic response (0.4g.kg.d)(Morton et al, 2015) in either an 80kg back (0.25g.kg) or a 120kg forward (0.16g.kg). As such, future research should focus on the anabolic response to protein ingestion between individuals of significantly different body compositions.

An acknowledgement of the limitations associated with the present study is warranted. Difficulties with practical research in athletes mean data from a subset of players from one semi-professional and one professional team are presented across a week. As such, the results cannot be generalised to all rugby players or even to the same population at different time-points. Additionally, such difficulties led to six days of dietary analysis being recorded for two semi-professional forwards and one semi-professional back and five days for two professional athletes. As with any dietary analysis study, the practice of collecting dietary intake via self-reported methods is prone to under and misreporting (Capling et al, 2017). Despite the method used for collecting dietary intake information due to its' low burden and favourability in athletic populations (Simpson et al, 2017) it is possible the athletes intentionally or unintentionally omitted food or beverages. There are numerous reasons for this, such as athletes' consuming foods and/or beverages they deem 'unfavourable', not being aware of ingredients in a meal from a restaurant or simply forgetting to log.

CONCLUSION

In conclusion, it has been demonstrated that the pattern of protein intake throughout the day is disproportionate in rugby union athletes at both the semi-professional and professional level. Whilst total protein intake is within ISSN and ACSM recommendations, promotion of an even distribution throughout the day would be beneficial for athletes, particularly those with large training volumes engaging in high-intensity impact sports. Future research should focus on the influence of protein distribution on body composition, performance and recovery in team sport athletes and how differences in body composition may affect the anabolic response to exercise and protein ingestion.

PRACTICAL RECOMMENDATIONS

1. Practitioners working with rugby players should encourage multiple feedings of protein across the day, with four feedings of 0.4g.kg per meal being a minimum target to optimise anabolism and thus recovery and adaptation.
2. Practitioner and athlete awareness of different absolute protein values to meet relative protein requirements is necessary. This will allow for individualised recommendations to be made for appropriate portion sizes.
3. A food first approach to protein intake is recommended as non-protein nutrients

contained within protein-rich whole foods may potentiate the post-exercise utilization of amino acids for anabolic purposes (Burd et al, 2019). Nonetheless, batch-tested dietary protein supplements can assist athletes in meeting both total daily and per-meal protein requirements. Due to the convenience and palatability of supplements they may be preferred following training sessions or during congested schedules.

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REFERENCES

Anderson, L., Naughton, R., Close, G. , Di Michele, R., Morgans, R., Drust, B., & Morton, J. P. (2017). Daily distribution of macronutrient intakes of professional soccer players from the English Premier League. *International Journal of Sport Nutrition and Exercise Metabolism*, 27(6), 491-498. https://doi.org/10.1123/ijsnem.2016-0265

Areta, J., Burke, L., Ross, M., Camera, D., West, D., Broad, E., Jeacocke, N., Moore, D., Stellinwerff, T., Phillips, S. Hawley, J., & Coffey, V. (2013). Timing and distribution of protein ingestion during prolonged recovery from resistance exercise alters myofibrillar protein synthesis. *The Journal of Physiology*, 591(9), 2319-2331. https://doi.org/10.1113/jphysiol.2012.244897

Argus, C., Gill, N., Keogh, J., Hopkins, W., & Beaven, C. (2009). Changes in strength, power, and steroid hormones during a professional rugby union competition. *The Journal of Strength & Conditioning Research*, 23(5), 1583-1592. doi: 10.1519/JSC.0b013e3181a392d9

Black, K. , Hindle, C., McLay-Cooke, R., Brown, R. , Gibson, C., Baker, D., & Smith, B. (2019). Dietary Intakes Differ by Body Composition Goals: An Observational Study of Professional Rugby Union Players in New Zealand. *American Journal of Men's Health*, 13(6), 1557988319891350. https://doi.org/10.1177/1557988319891350

Burd, N., Beals, J., Martinez, I., Salvador, A. and Skinner, S., 2019. Food-first approach to enhance the regulation of post-exercise skeletal muscle protein synthesis and remodeling. *Sports Medicine*, 49(1), 59-68. https://doi.org/10.1007/s40279-018-1009-y

Burke, L., Slater, G., Broad, E., Haukka, J., Modulon, S., & Hopkins, W. (2003). Eating patterns and meal frequency of elite Australian athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, 13(4), 521-538. https://doi.org/10.1123/ijsnem.13.4.521

Capling, L., Beck, K., Gifford, J., Slater, G., Flood, V., & O’Connor, H. (2017). Validity of dietary assessment in athletes: A systematic review. *Nutrients*, 9(12), 1313. https://doi.org/10.3390/nu9121313

da Silva, B., Simim, M., da Silva, R., Mendes, E., Ide, B., Marocolo, M., Martin, J., & Mota, G. (2020). Time Course of Recovery for Performance Attributes and Circulating Markers of Muscle Damage Following a Rugby Union Match in Amateur Athletes. *Sports*, 8(5), 64. https://doi.org/10.3390/sports8050064

Duthie, G., Pyne, D. and Hooper, S., 2003. Applied physiology and game analysis of rugby union. *Sports Medicine*, 33(13), 973-991. https://doi.org/10.2165/00007256-200333130-00003

Gillen, J., Trommelen, J., Wardenaar, F., Brinkmans, N., Versteegen, J., Jonvik, K., Kapp, C., De Vries, J., Van Den Borne., & Van Loon, L. (2017). Dietary protein intake and distribution patterns of well-trained dutch athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, 27(2), 105-114. https://doi.org/10.1123/ijsnem.2016-0154

Hector, A., & Phillips, S. (2018). Protein recommendations for weight loss in elite athletes: A focus on body composition and performance. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(2), 170-177. https://doi.org/10.1123/ijsnem.2017-0273

Jäger, R., Kerksick, C., Campbell, B., Cribb, P., Wells, S., Skwiat, T., Purpura, M., Ziegenfuss, T., Ferrando, A., Arent, S., Smith-Ryan, A., Stout, J., Arciero, P., Ormsbee, M., Taylor, L., Wilborn, C. Kalman, D., Kreider, R., Willoughby, D., Hoffman, J., Krzykowski, J., & Antonio, J. (2017). International society of sports nutrition position stand: protein and exercise. *Journal of the International Society of Sports Nutrition*, 14(1), 1-25. https://doi.org/10.1186/s12970-017-0177-8

Jenner, S. , Buckley, G., Belski, R., Devlin, B., & Forsyth, A. (2019). Dietary intakes of professional and semi-professional team sport athletes do not meet sport nutrition recommendations—a systematic literature review. *Nutrients*, 11(5), 1160. https://doi.org/10.3390/nu11051160

Jones, M., West, D., Harrington, B., Cook, C., Bracken, R., Shearer, D., & Kilduff, L. (2014). Match play performance characteristics that predict post-match creatine kinase responses in professional rugby union players. *BMC Sports Science, Medicine and Rehabilitation*, 6(38) https://doi.org/10.1186/2052-1847-6-38

Kato, H., Suzuki, K., Bannai, M., & Moore, D. (2016). Protein requirements are elevated in endurance athletes after exercise as determined by the indicator amino acid oxidation method. *PloS One*, 11(6), e0157406. https://doi.org/10.1371/journal.pone.0157406

Kim, I.., Deutz, N., & Wolfe, R. (2018). Update on maximal anabolic response to dietary protein. *Clinical Nutrition*, 37(2), 411-418. https://doi.org/10.1016/j.clnu.2017.05.029

Kim, I. , Schutzler, S., Schrader, A., Spencer, H., Azhar, G., Ferrando, A., & Wolfe, R. (2016). The anabolic response to a meal containing different amounts of protein is not limited by the maximal stimulation of protein synthesis in healthy young adults. *American Journal of Physiology-Endocrinology and Metabolism*, 310(1), E73-E80.https://doi.org/10.1152/ajpendo.00365.2015

Kreider, R. , & Campbell, B. (2009). Protein for exercise and recovery. *The Physician and Sports Medicine*, 37(2), 13-21. https://doi.org/10.3810/psm.2009.06.1705

Layman, D., Anthony, T., Rasmussen, B., Adams, S., Lynch, C., Brinkworth, G., & Davis, T. (2015). Defining meal requirements for protein to optimize metabolic roles of amino acids. *The American Journal of Clinical Nutrition*, 101(6), 1330S-1338S. https://doi.org/10.3945/ajcn.114.084053

Lemon, P. (1994). Protein requirements of soccer. *Journal of Sports Sciences*, 12(sup1), S17 - S22. https://doi.org/10.1080/02640414.1994.12059274

MacKenzie, K., Slater, G., King, N., & Byrne, N. (2015). The measurement and interpretation of dietary protein distribution during a rugby preseason. *International Journal of Sport Nutrition and Exercise Metabolism*, 25(4), 353-358. https://doi.org/10.1123/ijsnem.2014-0168

Macnaughton, L., Wardle, S., Witard, O., McGlory, C., Hamilton, D., Jeromson, S., Lawrence, C., Wallis, G., & Tipton, K. (2016). The response of muscle protein synthesis following whole-body resistance exercise is greater following 40 g than 20 g of ingested whey protein. *Physiological Reports*, 4(15). https://doi.org/10.14814/phy2.12893

Mamerow, M., Mettler, J., English, K., Casperson, S., Arentson-Lantz, E., Sheffield-Moore, M., Layman, D., & Paddon-Jones, D. (2014). Dietary protein distribution positively influences 24-h muscle protein synthesis in healthy adults. *The Journal of Nutrition*, 144(6), 876-880. https://doi.org/10.3945/jn.113.185280

Moore, D., Robinson, M., Fry, J., Tang, J., Glover, E., Wilkinson, S., Prior, T., Tarnopolsky, M., & Phillips, S. (2009). Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. *The American Journal of Clinical Nutrition*, 89(1), 161-168. https://doi.org/10.3945/ajcn.2008.26401

Morton, R., McGlory, C., & Phillips, S. (2015). Nutritional interventions to augment resistance training-induced skeletal muscle hypertrophy. *Frontiers in Physiology*, 6, 245. https://doi.org/10.3389/fphys.2015.00245

Naughton, M., Miller, J., & Slater, G. (2018). Impact-induced muscle damage: Performance implications in response to a novel collision simulator and associated timeline of recovery. *Journal of Sports Science & Medicine*, 17(3), 417.

Phillips, S., Chevalier, S., & Leidy, H. (2016). Protein "requirements" beyond the RDA: implications for optimizing health. *Applied Physiology, Nutrition, and Metabolism*, 41(5), 565-572. https://doi.org/10.1139/apnm-2015-0550

Phillips, S., & Van Loon, L. (2011). Dietary protein for athletes: from requirements to optimum adaptation. *Journal of Sports Sciences*, 29(sup1), S29-S38. https://doi.org/10.1080/02640414.2011.619204

Reis, C., Loureiro, L., Roschel, H., & da Costa, T. (2020). Effects of pre-sleep protein consumption on muscle-related outcomes—A systematic review. *Journal of Science and Medicine in Sport*. 24(2), 177-182. https://doi.org/10.1016/j.jsams.2020.07.016

Rodriguez, N., Di Marco, N., Langley, S. (2009). American College of Sports Medicine position stand. Nutrition and athletic performance. *Medicine and Science in Sports and Exercise*, 41(3), 709. doi: 10.1249/MSS.0b013e31890eb86.

Schoenfeld, B., & Aragon, A. (2018). How much protein can the body use in a single meal for muscle-building? Implications for daily protein distribution. *Journal of the International Society of Sports Nutrition*, 15(1), 1-6. https://doi.org/10.1186/s12970-018-0215-1

Simpson, A., Gemming, L., Baker, D., & Braakhuis, A. (2017). Do image-assisted mobile applications improve dietary habits, knowledge, and behaviours in elite athletes? A pilot study. *Sports*, 5(3), 60. https://doi.org/10.3390/sports5030060

Slimani, M., Cheour, F., Moalla, W., & Baker, J. (2017). Hormonal responses to a rugby match: a brief review. *The Journal of Sports Medicine and Physical Fitness.* 58(5). 707-713. https://doi.org/10.23736/S0022-4707.17.07187-0

Smart, D., Hopkins, W. and Gill, N., 2013. Differences and changes in the physical characteristics of professional and amateur rugby union players. *The Journal of Strength & Conditioning Research*, 27(11). .3033-3044. doi: 10.1519/JSC.0b013e31828c26d3

Tipton, K., Hamilton, D., & Gallagher, I. (2018). Assessing the role of muscle protein breakdown in response to nutrition and exercise in humans. *Sports Medicine*, 48(1), 53-64. https://doi.org/10.1007/s40279-017-0845-5

Trommelen, J., & Van Loon, L. (2016). Pre-sleep protein ingestion to improve the skeletal muscle adaptive response to exercise training. *Nutrients*, 8(12), 763. https://doi.org/10.3390/nu8120763

West, D., Finn, C., Cunningham, D., Shearer, D., Jones, M., Harrington, B., Crewther,B., Cook, C., & Kilduff, L. (2014). Neuromuscular function, hormonal, and mood responses to a professional rugby union match. *The Journal of Strength & Conditioning Research*, 28(1), 194-200. doi: 10.1519/JSC.0b013e318291b726

Witard, O., Jackman, S., Breen, L., Smith, K., Selby, A., & Tipton, K. (2014). Myofibrillar muscle protein synthesis rates subsequent to a meal in response to increasing doses of whey protein at rest and after resistance exercise. *The American Journal of Clinical Nutrition*, 99(1), 86-95. https://doi.org/10.3945/ajcn.112.055517

Zemski, A., Keating, S., Broad, E., & Slater, G. (2019). Longitudinal changes in body composition assessed using DXA and surface anthropometry show good agreement in elite rugby union athletes. International Journal of Sport Nutrition and Exercise Metabolism, 29(1), 24-31. https://doi.org/10.1123/ijsnem.2018-0019

Table 1: Participant characteristics

	n	Age (years)	Height (cm)	Weight (kg)	Total protein intake (grams.day)	Total protein intake (grams.kg.day)
Semi-professional						
Forward	19	24.2 ± 3.5	186.8 ± 7.9	114.3 ± 8.2*	151.5 ± 64.6**	1.4 ± 0.5*
Back	6	24.4 ± 4.7	185.5 ± 6.8	93.8 ± 6.2*	178.7 ± 47.3	1.9 ± 0.5
Professional	10	31.4 ± 3.0*	187.2 ± 9.3	104.9 ± 12.0*	203.7 ± 68.1	2.0 ± 0.6

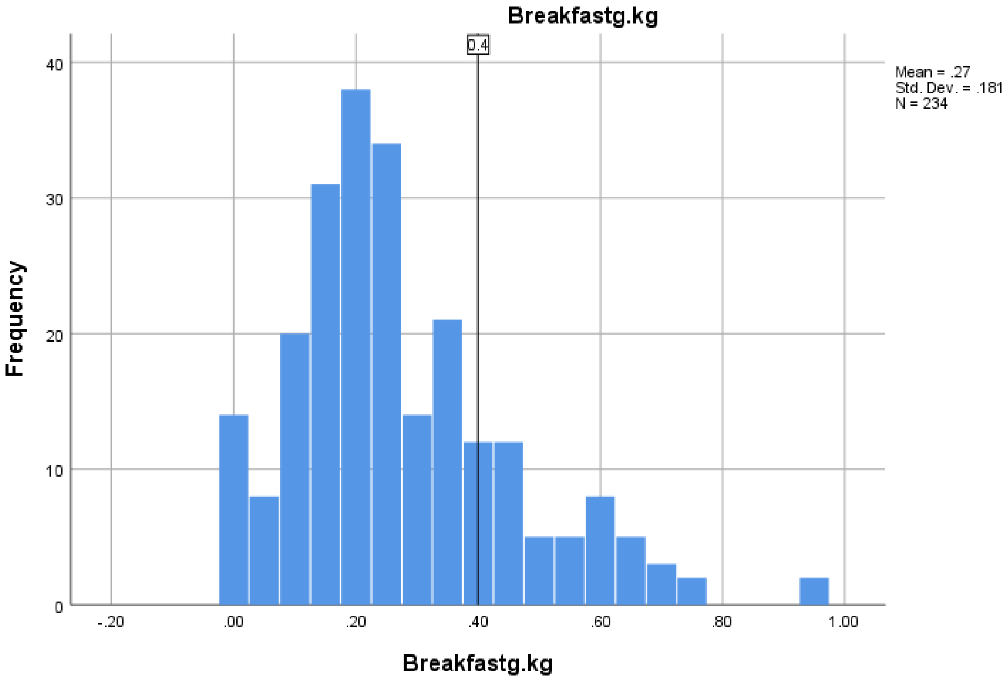
*Denotes significant difference from both other groups ($p<0.05$) **Denotes significant difference from professionals only ($p<0.05$)

Table 2: Per-meal protein intake in semi-professional and professional rugby players

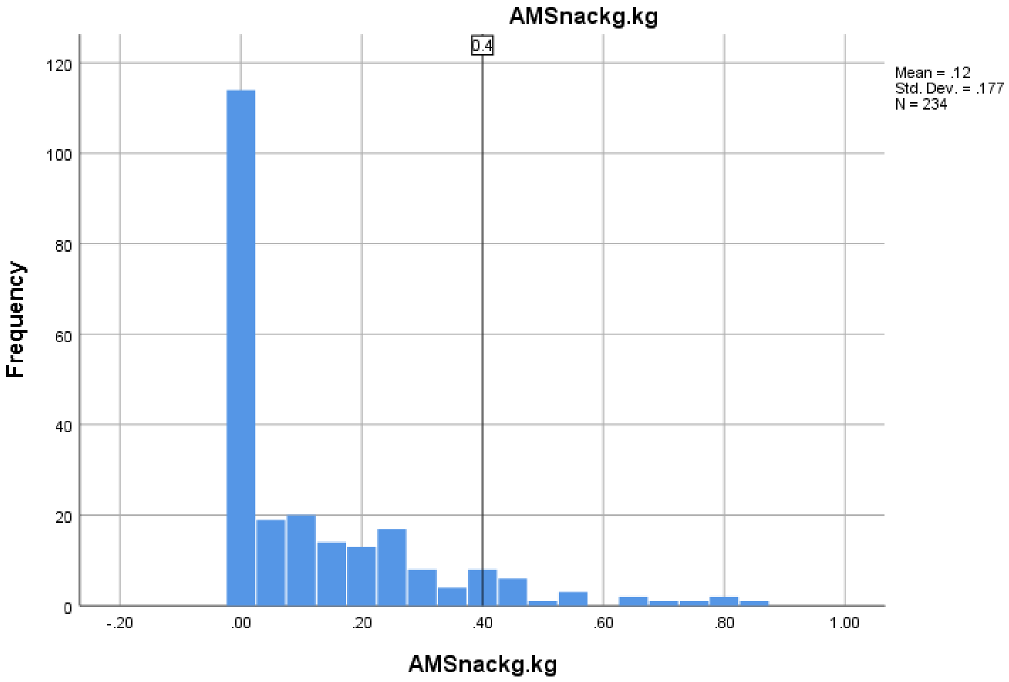
	Breakfast	AM Snack	Lunch	PM Snack	Dinner	Evening Snack
Absolute protein intake (grams)	28.8 ± 18.6	13.6 ± 19.0	46.3 ± 30.7	17.1 ± 24.7	61.7 ± 34.7	7.9 ± 15.9
Relative protein intake (grams.kg)	0.27 ± 1.8	0.13 ± 0.18	0.43 ± 0.29	0.16 ± 0.23	0.58 ± 0.33	0.07 ± 0.14

SUPPLEMENTARY MATERIALS

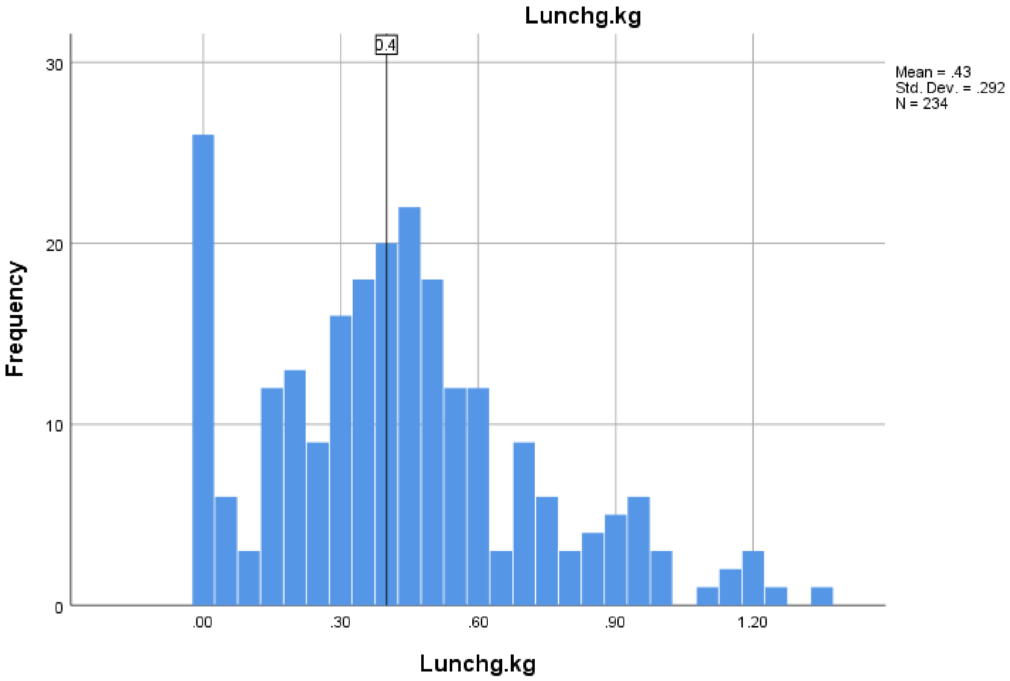
The frequency graphs below display the total number of eating occasions (y axis) that contained the relative to body mass dietary protein (x axis). N=234 indicates the total number of eating occasions for the meal. Reference lines on each graph highlight 0.4g.kg as a recommended per-meal protein dose (Schoenfeld & Aragon, 2018).



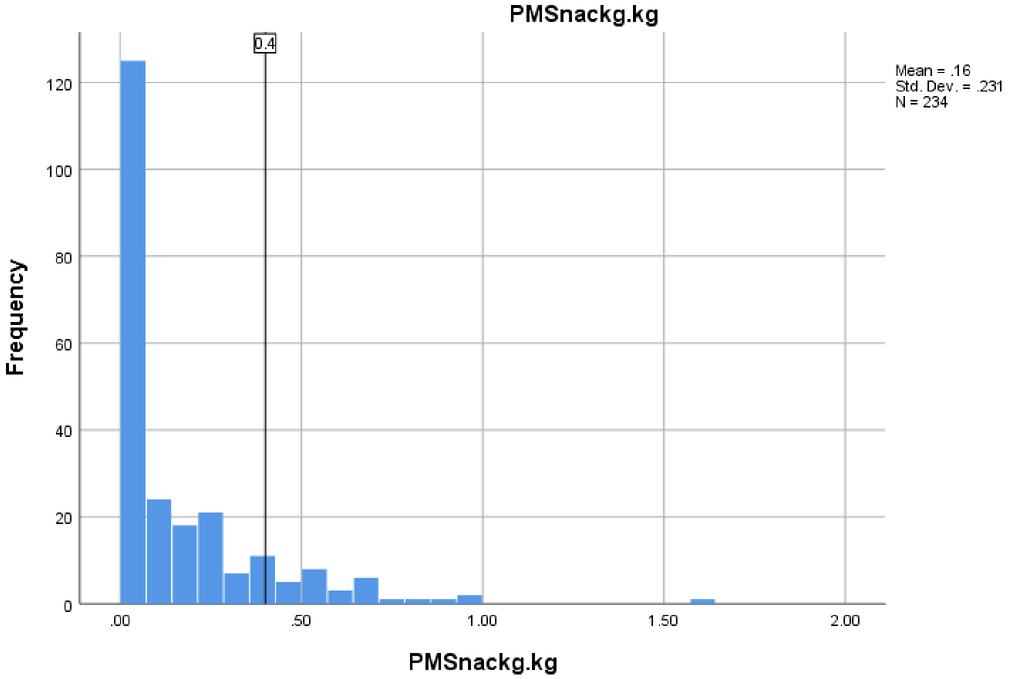
S1. Frequency of relative breakfast protein consumption (g.kg) across all eating occasions



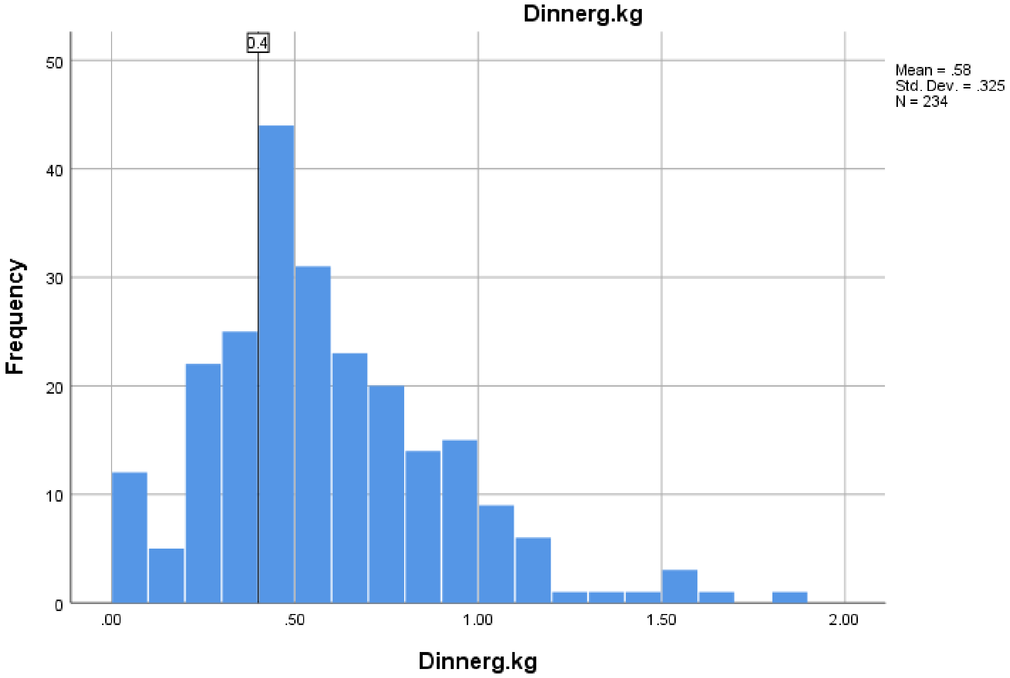
S2. Frequency of relative AM snack protein consumption (g.kg) across all eating occasions



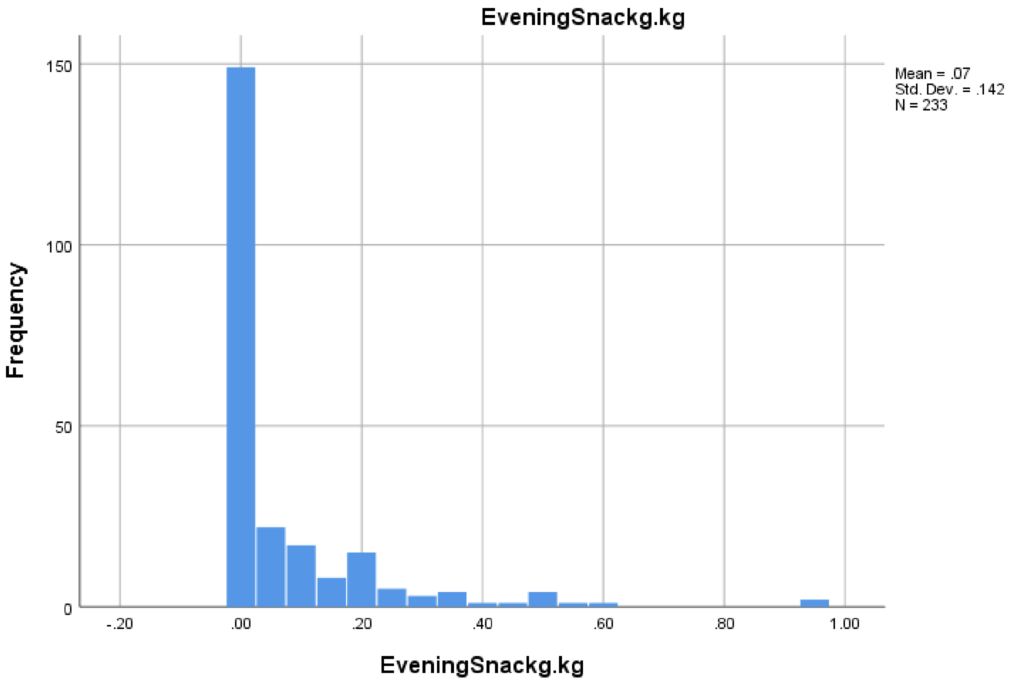
S3. Frequency of relative lunch protein consumption (g.kg) across all eating occasions



S4. Frequency of relative PM snack protein consumption (g.kg) across all eating occasions



S5. Frequency of relative dinner protein consumption (g.kg) across all eating occasions



S1. Frequency of relative evening snack protein consumption (g.kg) across all eating occasions