

CASE STUDY

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# Energy requirements of injured soccer players: a doubly labelled water case series from the English Premier League

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## Abstract

Accurate estimation of energy requirements is essential for optimising nutritional strategies during injury rehabilitation in professional soccer. This case series examined total daily energy expenditure (TDEE) via doubly labelled water (DLW), energy intake (EI), and body composition across two rehabilitation phases in English Premier League (EPL) players. Case Study 1 (22 years-old, 193 cm, 93.7 kg) involved early-stage hamstring rehabilitation, while Case Study 2 (21 years-old, 186 cm, 88.7 kg) captured the transition from partial (PWB) to full weight-bearing (FWB) during rectus femoris rehabilitation. EI was measured via remote food photography method and 24-hour recalls on two non-consecutive days per case. Body composition was measured via dual-energy X-ray absorptiometry in Case Study 1 at baseline and Day 14. In Case Study 1, TDEE increased by 1013 kcal·day<sup>-1</sup> (Week 1: 3143 kcal·day<sup>-1</sup>; Week 2: 4156 kcal·day<sup>-1</sup>), accompanied with an increased DLW-estimated EI (Week 1: 2911 kcal·day<sup>-1</sup>; Week 2: 4343 kcal·day<sup>-1</sup>). Body mass (BM) remained stable (+0.10 kg), but fat-free soft-tissue mass (FFSTM) decreased (-0.50 kg), primarily in the trunk and non-injured leg, while FFSTM in the injured leg was preserved (+0.07 kg). In Case Study 2, TDEE increased by 538 kcal·day<sup>-1</sup> (PWB: 3175 kcal·day<sup>-1</sup>; FWB: 3713 kcal·day<sup>-1</sup>) but remained below pre-injury levels (4546 kcal·day<sup>-1</sup>). BM reduced in both PWB (-0.3 kg) and FWB phases (-1.2 kg). DLW-estimated EI indicated energy deficits in both phases (PWB: 139 kcal·day<sup>-1</sup>; FWB: 557 kcal·day<sup>-1</sup>). These findings highlight that energy requirements of EPL players fluctuate across rehabilitation phases, emphasising the importance of individualised nutritional support during rehabilitation.

**Keywords** Soccer, Doubly labelled water, Energy expenditure, Rehabilitation, Injury

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## Introduction

Soccer is a high intensity, intermittent sport characterised by repeated explosive actions including sprinting, tackling, jumping and rapid changes of direction, interspersed by lower intensity activity like walking [1]. The physical demands of the sport predispose players to injuries, predominantly the lower extremities, with an incidence rate of 6.8 per 1000 h of exposure [2]. Elite European soccer teams experience an average of ~50 injuries per season [3] and injury rates are projected to increase due to increasingly congested fixtures [4]. Notably, the incidence of hamstring injuries has doubled over the past two decades among elite professional soccer players [5]. Injuries have substantial implications on performance, with lower injury rates being strongly associated with better league rankings, higher point totals and increased win rates [6]. Financially, English Premier League (EPL) teams are estimated to lose an average of £45 million each season due to injury-related performance declines [7]. Given the practical and financial implications of player injuries, implementing effective rehabilitation strategies to support a timely return to play is paramount for elite soccer teams [8].

Sports nutrition is a fundamental component of the multidisciplinary strategies employed to support recovery and improve rehabilitation outcomes in injured players [9–12]. During the early phases of rehabilitation, joint immobilisation is commonly required to protect the injured area. However, this often restricts full weight bearing (FWB) and voluntary muscle contractions, resulting in periods of muscle disuse [9]. Short term muscle disuse has been shown to significantly suppress myofibrillar protein synthesis, contributing a state of anabolic resistance despite protein ingestion [13, 14]. This physiological response can lead to rapid muscle atrophy, with reductions in fat-free soft tissue mass (FFSTM) observed after as little as 5 days (-1.4%) and 14 days (-3.1%) of immobilisation [15]. Preserving FFSTM during this period is therefore critical to support functional recovery and expedite return to play [16].

Understanding energy requirements during rehabilitation is therefore the basis for formulating effective nutritional interventions; however, research in this area remains limited [17]. To date, only one study has quantified total daily energy expenditure (TDEE) in a professional soccer player during rehabilitation using the doubly labelled water (DLW) method, reporting a value of 3178 kcal·day<sup>-1</sup> six weeks after anterior cruciate ligament (ACL) injury [18]. Despite this, energy requirements during other phases of rehabilitation remain largely unexplored. Notably, it has been suggested that TDEE may not decrease as substantially as commonly assumed during early rehabilitation phase, as the physiological demands of tissue healing can elevate energy

expenditure by 15–50%, depending on the type and severity of the injury [19]. Furthermore, the energetic cost of ambulation with crutches is two- or three-fold greater when compared to normal walking [20], indicating that TDEE during partial or non-weight bearing phases may not decline as markedly as often assumed if the player maintains a relatively high level of movement during rehabilitation [21]. Nonetheless, these assumptions remain speculative, as no studies have directly assessed TDEE across different rehabilitation phases in professional soccer players using the DLW method.

With this in mind, the aim of this case series was to evaluate TDEE in professional soccer players during rehabilitation. Specifically, two case studies were conducted on players from the EPL. The first investigated TDEE, energy intake (EI) and changes in body composition over the initial two weeks of rehabilitation following a hamstring injury. The second case evaluated TDEE and EI over a 15-day period in a EPL player recovering from rectus femoris surgery, during which the player progressed from partial to full weight bearing between the third and fourth postoperative weeks. Findings aim to inform evidence-based nutritional strategies to support optimal recovery during rehabilitation in elite soccer.

## Materials and methods

### Presentation of the participants

Players 1 and 2 were both internationally capped male EPL players. Their physical characteristics are summarised in Table 1. Both players had been full time professional since age 18. Their training regime prior to injury included periodised field-based sessions, two resistance training sessions per week (upper and lower limbs) and 1–2 competitive matches per week. Player 1 suffered a grade 3c proximal intramuscular tendon injury to the right bicep femoris, occurred during a sprinting action in a match. Player 2 suffered a grade 4c retracted tear of the conjoint tendon and proximal musculotendinous junction of the left rectus femoris, occurred during a goal shooting action in training. Following consultation with a specialist, surgery was performed four days after the injury. Player 2 was partially weight bearing (PWB) on the injured limb using elbow crutches for three weeks post-surgery.

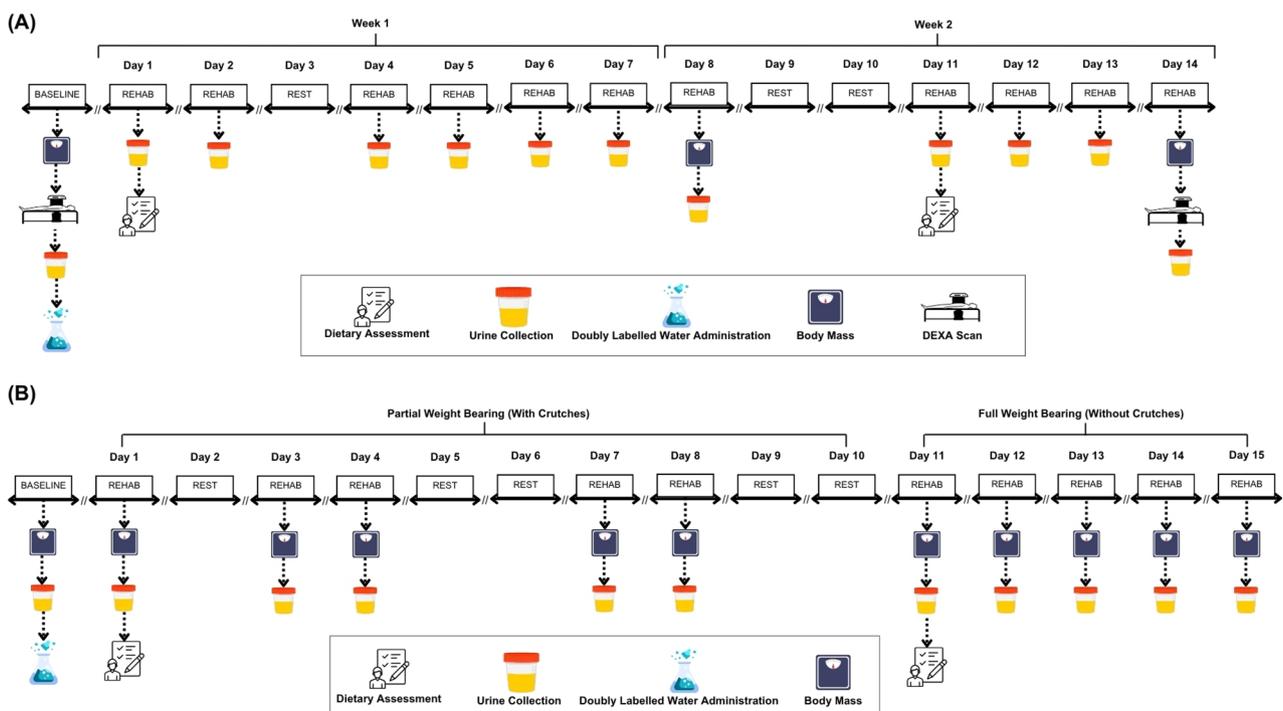
### Study design

#### Player 1

An overview of the study design is presented in Fig. 1A. Baseline body mass (BM) and urine samples were collected on the morning of Day 0 of the data collection period (23 days after the onset of injury), followed by DLW dosing. Subsequent BM assessments were conducted on Days 8 and 14, while urine samples were collected on Days 1, 2, 4, 5, 6, 7, 8, 11, 12, 13 and 14 (in line

**Table 1** Physical characteristics of players 1 and 2

Position	Player 1	Player 2
Age	22	21
Height (cm)	193	186
Body Mass (kg)	93.7	88.7
English Premier League appearances	39	52
Injury history	One left hamstring injury	Three left hamstring and one quadricep injury
Daily nutritional supplementation protocol	<ul style="list-style-type: none"> <li>• During physiotherapy: 25 g whey protein isolate, 5 g creatine monohydrate</li> <li>• Supplementation: 30 ml of Montmorency Tart Cherry Juice, 2 g omega-3 fatty acids (1000 mg Eicosapentaenoic Acid [EPA], 400 mg Docosahexaenoic Acid [DHA]) and 500 mg curcumin</li> </ul>	<ul style="list-style-type: none"> <li>• During physiotherapy: 15 g hydrolysed collagen, 25 g whey protein isolate, 5 g creatine monohydrate</li> <li>• Supplementation: 30 ml of Montmorency Tart Cherry Juice, 2 g omega-3 fatty acids (1000 mg Eicosapentaenoic Acid [EPA], 400 mg Docosahexaenoic Acid [DHA]), 500 mg Curcumin and 500 mg Vitamin C</li> </ul>



**Fig. 1** Overview of study design for Player 1 (A) and Player 2 (B)

with logistical constraint). Energy and macronutrient intakes were assessed on Days 1 and 11 using the remote food photography method (RFPM) [22] with 24-hour dietary recalls conducted on the following days (Days 2 and 12) to ensure the player did not omit any foods/drinks. EI was also calculated using the DLW method by adjusting TDEE for changes in energy stores over Days 0–14 [23]:

$$EI \text{ (kcal day}^{-1}\text{)} = TDEE \text{ (kcal day}^{-1}\text{)} + \text{changes in energy stores (kcal in grams of fat mass)} + \text{kcal in grams of FFSTM changes)}$$

Given that tissue energy density differs according to the direction of BM change, values of 9 kcal·g<sup>-1</sup> of fat mass and 1 kcal·g<sup>-1</sup> of FFSTM were applied during periods of BM loss whereas corresponding values of 13.2 kcal·g<sup>-1</sup> and 2.2 kcal·g<sup>-1</sup>, respectively, were used to characterise BM gain [24]. Body composition was assessed via Dual-energy X-ray Absorptiometry (DXA) (Lunar iDXA. GE Healthcare, Madison, USA) at baseline and on Day 14. All scans were performed at the same time of day (~ 1 h within waking) [25]. The player was fasted overnight and presented to the scanner with the bladder voided and had not undertaken in any strenuous exercise 18 h before the scanning. He was asked to wear minimal clothing (e.g. underwear) and remove all jewelry and metal objects. Both scans were performed and analysed

by the same trained technician with more than five years of experience, with a special emphasis on the consistency in the positioning of the player on the scanning bed. Specifically, the player was centrally aligned with hands mid prone to maintain a constant distance between palms and trunk. The lower limb was stabilised in full extension and in zero degrees of internal rotation using Velcro straps to immobilise the limbs. The scans were analysed automatically by the software. Due to the club's scanning schedule, repeat DXA assessments could not be performed and thus device-specific precision errors could not be established. Consequently, precision errors were drawn from published research using the same DXA iLunar model in athletic population [26]. Reported root mean squared standard deviations (RMS-SD) of DXA iLunar was 0.32 kg for total FFSTM, 0.40 kg for trunk FFSTM, 0.37 kg for legs FFSTM and 0.14 kg for arms FFSTM. Corresponding RMS-SD values for fat mass were 0.28 kg (total), 0.30 kg (trunk), 0.15 kg (legs) and 0.06 kg (arms) [26]. TDEE of Week 1 was compared to Week 2.

### Player 2

An overview of the study design is presented in Fig. 1B. Baseline BM and urine samples were collected on the morning of Day 0 (three days after the onset of injury), followed by dosing with DLW. BM and urine sampling then occurred on Days 1, 3, 4, 7, 8, 11, 12, 13, 14 and 15 (in line with logistical constraint). Player 2 spent Days 1–10 in the PWB phase with crutches and transitioned to FWB from Days 11–15. Energy and macronutrient intakes were assessed on Days 1 (PWB) and 11 (FWB) using the RFPM with 24-hour dietary recalls conducted on the following days (Days 2 and 12) to ensure the player did not omit any foods/drinks. EI was also estimated using the DLW method described above [23]. As DXA scans were not performed on Player 2, the changes in energy stores were estimated with the assumption that  $\frac{2}{3}$  of change in BM was metabolic and  $\frac{1}{3}$  was water and that  $\frac{3}{4}$  of the change in metabolic weight was fat mass and  $\frac{1}{4}$  was FFSTM [23]. This was measured from Day 0 up until the final day (Day 15). TDEE during PWB and FWB phases was compared to the player's TDEE when fully fit, as reported in a separate study [27].

### Measurement of TDEE via DLW

TDEE was measured via the DLW method, previously applied in elite soccer players [27]. Baseline urine samples were collected in a 20-mL tube. Following collection of baseline samples, players were orally administered a single bolus dose of DLW containing isotopes deuterium

( $^2\text{H}$ ) and oxygen-18 ( $^{18}\text{O}$ ) in the form of water ( $^2\text{H}_2^{18}\text{O}$ ) with a desired enrichment of 10%  $^{18}\text{O}$  and 5%  $^2\text{H}_2$  using the calculation:

$$\text{Dose (mL)} = 0.65 (\text{BM, g}) \times \text{DIE/IE}$$

Where 0.65 is the approximate proportion of the body comprised of water, DIE is the desired initial enrichment in the body ( $\text{DIE} = 618.923 \times \text{BM (kg)}^{-0.305}$ ) and IE is the initial dose enrichment (10%) 100,000 parts per million dosed according to BM [28]. To ensure the whole dose was administered, both players were observed consuming each bolus dose and each glass vial was refilled with additional water which players were asked to consume. Time of dosing was recorded. Isotopes were purchased from Sercon (Cheshire, UK). For the DLW analysis, urine was encapsulated into capillaries, which were then vacuum distilled [29] and water from the resulting distillate was used. This water was analysed using a liquid water analyser (Los Gatos Research) [30]. Samples were run alongside three laboratory standards for each isotope and three International standards (Standard Light Arctic Precipitate-2, Standard Mean Ocean Water-2 and Greenland Summit Precipitation) [31, 32] to account for machine day to day variation and correct delta values to parts per million. Daily isotope enrichments were  $\log_e$  converted and the elimination constants ( $k_o$  and  $k_d$ ) were calculated by fitting a least squares regression model against sample time. The back extrapolated intercept was used to calculate the isotope dilution spaces ( $N_o$  and  $N_d$ ). Isotope elimination rates and dilution spaces were converted to TDEE using an updated two-pool model Eq. (28) and a mean calculated food quotient of  $0.85 \pm 0.2$ .

### Nutritional supplementation protocols

Table 1 summarises the supplementation strategies provided to both players. During physiotherapy, whey protein ( $25 \text{ g}\cdot\text{day}^{-1}$ ) and creatine monohydrate ( $5 \text{ g}\cdot\text{day}^{-1}$ ) were provided to support myofibrillar protein synthesis [33] and help preserve FFSTM during rehabilitation [34]. Player 2 also received collagen supplementation ( $15 \text{ g}\cdot\text{day}^{-1}$ ) and vitamin C ( $500 \text{ mg}\cdot\text{day}^{-1}$ ) to facilitate collagen synthesis [35, 36]. In addition, omega 3 fatty acids ( $2 \text{ g}\cdot\text{day}^{-1}$ ) [11] and curcumin ( $500 \text{ mg}\cdot\text{day}^{-1}$ ) [37] were provided to both players to aid in modulating inflammation.

### Rehabilitation exercise programme

Table 2 outlines the rehabilitation exercise programme for Player 1 in Weeks 1 and 2. In Week 1, the player engaged in upper body strength training, upper body cardiovascular exercise and lower body exercises. In Week 2, lower body strength and cardiovascular exercises were introduced alongside the progression of the prior activities, in line with standard club rehabilitation protocols.

**Table 2** Dietary intake and exercise program performed by player 1 during the data collection period

		Week 1	Week 2
Dietary Intake	Energy	2617 kcal (28.2 kcal·kg BM <sup>-1</sup> )	3121 kcal (33.3 kcal·kg BM <sup>-1</sup> )
	Carbohydrate	229 g (2.4 g·kg BM <sup>-1</sup> )	304 g (3.2 g·kg BM <sup>-1</sup> )
	Protein	250 g (2.7 g·kg BM <sup>-1</sup> )	262 g (2.8 g·kg BM <sup>-1</sup> )
	Fat	78 g (0.8 g·kg BM <sup>-1</sup> )	95 g (1.0 g·kg BM <sup>-1</sup> )
Exercise Program	Lower Body Exercise		
	Aim	Lumbo-pelvic control, hamstring isometrics, pool running mechanics	Daily hamstring loading, functional movement circuit, accessory lower body strength, running mechanics, run in pool
	Frequency/Week	5x	5x
	Repetition Range	5–10	5–8
	Sets/Session	30	46
	Exercise Selection	6x mobility & lumbo-pelvic exercise (3 sets, 10 reps) 4x isometrics hamstring exercise (3 sets, 5 reps, 8 s) Hydrotherapy (20 min functional movement and low intensity running drills)	8x mobility & lumbo-pelvic exercises (2 sets, 8 reps) 4x glute activation exercises (2 sets, 8 reps) 5x functional movement exercises (2 sets, 8 reps) 4x isometrics hamstring exercise (3 sets, 5 reps, 8 s) Hydrotherapy (30 min running drills and pool run)
	Upper Body Strength		
	Aim	Strength	Strength
	Frequency/Week	1x	2x
	Repetition Range	8	6–8
	Sets/Session	18	26
	Exercise Selection	Lat pull down, bench press, row, shoulder press, hammer curl, chest fly	Lat pull down, medicine ball slam, bench press, supine medicine ball press, hammer curl, chest fly
	Cardiovascular		
	Aim	Cardiovascular fitness	Cardiovascular fitness
	Frequency/Week	1x	3x
	Duration	30 min per session	20 min per session
	Exercise Selection	Battle ropes, assault bike, seated ski ergometer	Spin bike
	Lower Body Strength		
	Aim		Strength
	Frequency/Week		2x
Duration		8	
Exercise Selection		20–25 X2 concentric hamstring exercises X2 eccentric hamstring exercises Adductor cable, calf raise, leg extension	

Table 3 outlines the rehabilitation exercise program during PWB and FWB phases for Player 2. During the PWB phase, the player performed lower body exercises and upper body strength training. In the FWB phase, upper body cardiovascular exercises were introduced alongside the progression of prior activities as part of normal club practice. A typical daily schedule for both players included: breakfast (09:00 a.m.), soft tissue therapy (09:30 a.m.), movement preparation (10:00 a.m.), bike session (10:30 a.m.), upper body strength or cardiovascular (11:00 a.m.), movement skills in water (12:00 p.m.) and lunch (1:00 p.m.).

## Results

### Player 1

Mean TDEE over the data collection period was 3538 kcal·day<sup>-1</sup> (37.8 kcal·kg BM<sup>-1</sup>·day<sup>-1</sup>). In Week 1, mean TDEE was 3143 kcal·day<sup>-1</sup> (33.5 kcal·kg BM<sup>-1</sup>·day<sup>-1</sup>), increasing to 4156 kcal·day<sup>-1</sup> (44.4 kcal·kg BM<sup>-1</sup>·day<sup>-1</sup>) in Week 2. Energy and macronutrient intakes for both weeks are presented in Table 2. Self-reported EI was lower than TDEE by 526 kcal·day<sup>-1</sup> in Week 1 and 1035 kcal·day<sup>-1</sup> in Week 2. Based on this energy deficit, predicted BM losses were ~1.1 kg in Week 1 and ~3.3 kg in Week 2. However, actual BM decreased by only 0.5 kg in Week 1 (from 93.7 kg on Day 1 to 93.2 kg on Day 8) and increased by 0.6 kg during Week 2 (from 93.2 kg on Day 8 to 93.8 kg on Day 14).

**Table 3** Dietary intake and exercise program performed by player 2 during the data collection period

		Partial Weight Bearing (PWB)	Full Weight Bearing (FWB)
Dietary Intake	Energy	2498 kcal (28.2 kcal·kg BM <sup>-1</sup> )	2857 kcal (32.3 kcal·kg BM <sup>-1</sup> )
	Carbohydrate	206 g (2.3 g·kg BM <sup>-1</sup> )	244 g (2.8 g·kg BM <sup>-1</sup> )
	Protein	160 g (1.8 g·kg BM <sup>-1</sup> )	210 g (2.4 g·kg BM <sup>-1</sup> )
	Fat	115 g (1.3 g·kg BM <sup>-1</sup> )	116 g (1.3 g·kg BM <sup>-1</sup> )
Exercise Program	Lower Body Exercise		
	Aim	Muscle endurance	Muscle endurance
	Frequency/Week	5x	5x
	Repetition Range	12–15	12–15
	Sets/Session	24–26	36
	Exercise Selection	2x OKC quadriceps exercises	3x OKC quadriceps exercises
		2x OKC exercises for adductors, hamstrings, hip extensors	4x CKC quadricep exercises
		3x OKC exercises for ankles	3x OKC exercises for Adductors, hamstrings, hip extensors
		1x CKC exercise for calves	3x OKC exercises for ankles
		2x OKC strength exercises for contralateral side	2x CKC exercises for calves
			2x OKC strength exercises for contralateral side
	Upper Body Strength		
	Aim	Hypertrophy	Hypertrophy
	Frequency/Week	3x	3x
	Repetition Range	6–10	6–10
	Sets/Session	15–24	15–24
	Exercise Selection	DB incline bench press	DB incline bench press
		SA seated Keiser row	SA bench row
		Seated lateral raise	Seated land mine press
		Seated Keiser fly's	Seated Keiser fly's
DB biceps curl		DB biceps curl	
Seated FT triceps extension		Seated FT triceps extension	
Upper Body Cardiovascular			
Aim	Not performed for wound protection	Cardiovascular fitness	
Frequency/Week		3x	
Duration		30 min per session	
Exercise Selection		Battle ropes	
		Assault bike	
		Seated skiing ergometer	

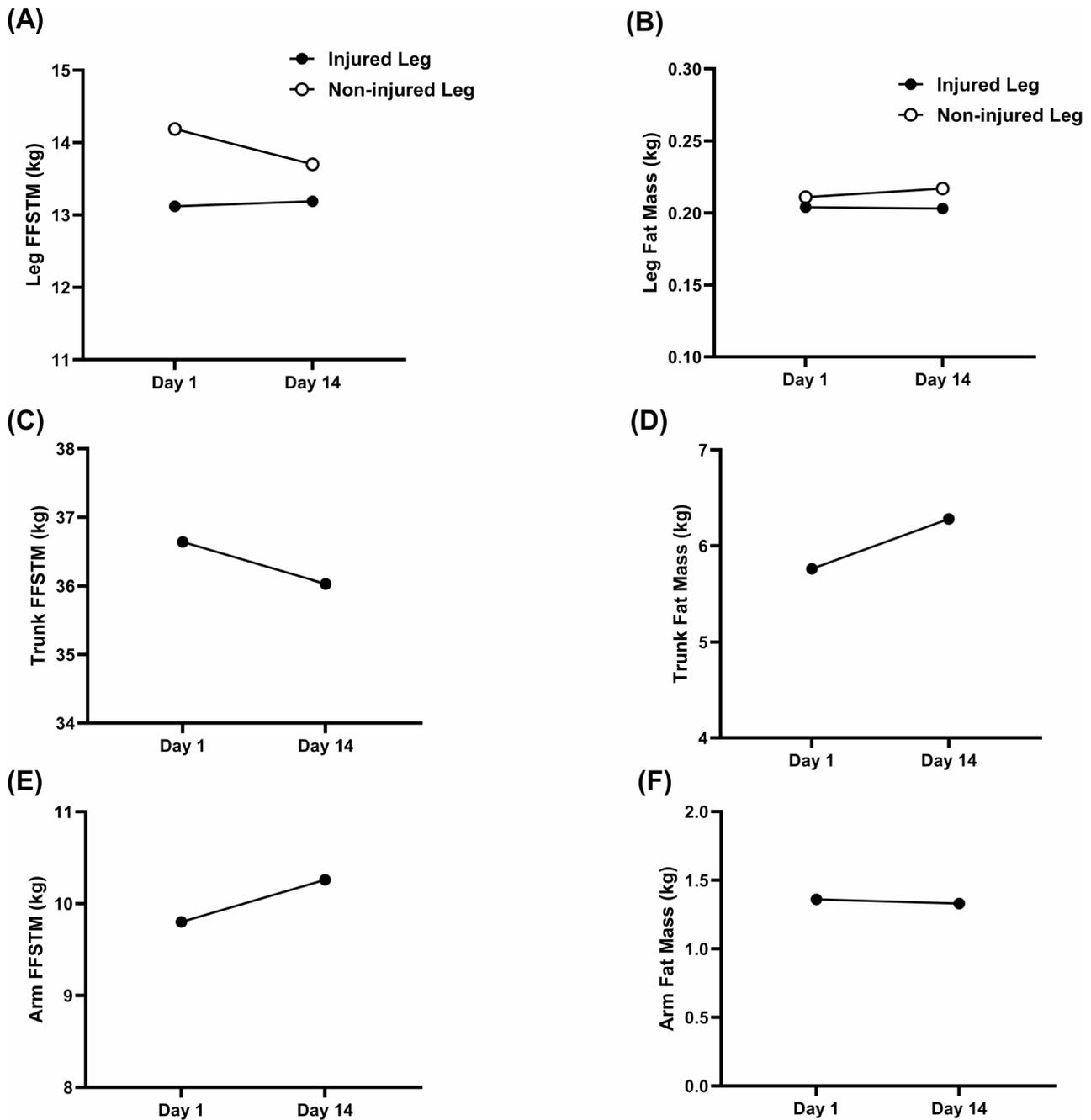
OKC open kinetic chain, CKC close kinetic chain, DB dumbbell, SA single arm, FT functional trainer

Estimated EI via the DLW method was 2911 kcal·day<sup>-1</sup> in Week 1 and 4343 kcal·day<sup>-1</sup> in Week 2, values that were 294 kcal·day<sup>-1</sup> and 1222 kcal·day<sup>-1</sup> higher, respectively, than EI reported via the RFPM. Over the 14-day period, total FFSTM decreased by 0.50 kg, slightly above RMS-SD (0.32 kg). Meaningful reductions were evident in non-injured left leg (-0.49 kg, Fig. 2A) and trunk (-0.60 kg, Fig. 2C), both exceeding their respective RMS-SD (0.15 kg and 0.42 kg). In contrast, FFSTM increased in the arms (+0.46 kg, Fig. 2E), surpassing the RMS-SD (0.14 kg), while the small increase in injured right leg (+0.07 kg, Fig. 2A) fell below the RMS-SD (0.37 kg), likely reflecting measurement variability. Total fat mass increased by 0.65 kg, above the RMS-SD (0.28 kg), driven primarily by a 0.52 kg gain in the trunk (Fig. 2D), which exceeded the RMS-SD (0.30 kg). Fat mass also increased in non-injured left leg (+0.07 kg); however, this change was smaller than reported RMS-SD (0.37 kg), suggesting

it may fall within the expected measurement error rather than reflecting a true physiological change (Fig. 2B). Similarly, the reduction of fat mass in both injured right leg (-0.01 kg) and arms (-0.03 kg) was within the RMS-SD (0.15 kg and 0.06 kg, respectively).

**Player 2**

Mean TDEE during the PWB phase was 3175 kcal·day<sup>-1</sup> (35.8 kcal·kg BM<sup>-1</sup>·day<sup>-1</sup>). Upon transitioning to FWB, mean TDEE increased by 538 kcal·day<sup>-1</sup>, reaching 3713 kcal·day<sup>-1</sup> (42.0 kcal·kg BM<sup>-1</sup>·day<sup>-1</sup>). Nevertheless, TDEE during rehabilitation remained substantially lower than when the player was at full fitness, where TDEE was 4546 kcal·day<sup>-1</sup> (51.5 kcal·kg BM<sup>-1</sup>·day<sup>-1</sup>) over a 15-day period in which the player competed in three matches (Fig. 3A). The energy and macronutrient intakes during the PWB and FWB phases are detailed in Table 3. Self-reported EI was 677 kcal·day<sup>-1</sup> and 856 kcal·day<sup>-1</sup> lower



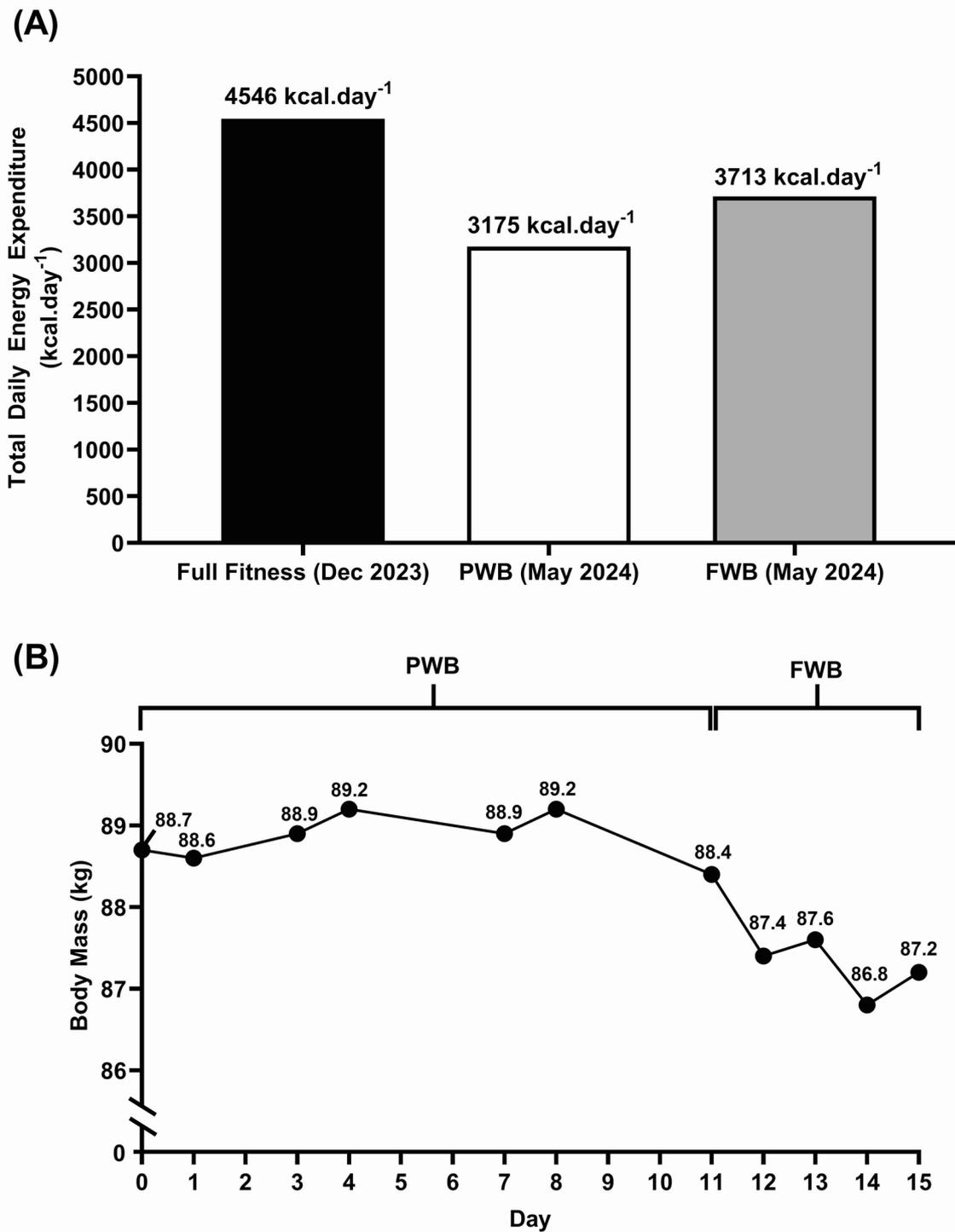
**Fig. 2** Changes in total (a) leg FFSTM, (b) leg fat mass, (c) trunk FFSTM, (d) trunk fat mass, (e) arm FFSTM and (f) arm fat mass throughout the rehabilitation

than TDEE during the PWB and FWB phases, respectively. Based on the observed energy deficit, the player was expected to lose 1.5 kg during PWB and 1.9 kg during FWB. However, BM decreased by only 0.3 kg from Days 1–10 (PWB) and 1.2 kg from Days 11–15 (FWB) (Fig. 3B), suggesting potential inaccuracies in self-reported EI. Specifically, EI derived from the DLW method was 3036 kcal·day<sup>-1</sup>, exceeding self-reported EI by 538 kcal·day<sup>-1</sup> during the PWB phase. Similarly, a difference of 299 kcal·day<sup>-1</sup> was observed between DLW

derived EI (3156 kcal·day<sup>-1</sup>) and self-reported EI during the FWB phase.

**Discussion**

Using the DLW method and a case series approach, we evaluated TDEE of two professional soccer players undergoing rehabilitation from lower limb injuries. Case Study 1 focused on the early phase of rehabilitation following a hamstring injury, while Case Study 2 examined the transition from PWB to FWB during the third- and



**Fig. 3** Total daily energy expenditure of the player during full fitness, partial weight bearing and full weight bearing phases (A) and body mass changes observed throughout the rehabilitation process (B)

fourth-weeks post rectus femoris surgery. A marked increase in TDEE was observed in both cases, with Player 1 demonstrating a rise of  $1013 \text{ kcal}\cdot\text{day}^{-1}$  from Week 1 to Week 2, and Player 2 showing a  $538 \text{ kcal}\cdot\text{day}^{-1}$  increase during the PWB to FWB transition. These increases likely reflect the progressive elevation in exercise volume and intensity as rehabilitation advanced (Tables 2 and 3). Collectively, these data suggest that TDEE can escalate rapidly during the early rehabilitation phase and during key transition periods, highlighting the need for dynamic adjustment of energy and macronutrient intake to support recovery and mitigate losses in FFSTM.

In case study 1, relative TDEE increased markedly from Week 1 ( $33.5 \text{ kcal}\cdot\text{kg BM}^{-1}\cdot\text{day}^{-1}$ ) to Week 2 ( $44.4 \text{ kcal}\cdot\text{kg BM}^{-1}\cdot\text{day}^{-1}$ ), reaching values comparable to fit outfield players ( $\sim 44.6 \text{ kcal}\cdot\text{kg BM}^{-1}\cdot\text{day}^{-1}$ ) [38]. This substantial rise in TDEE likely reflects the progressive increase in training volume and intensity of lower-body, upper-body and cardiovascular exercises (Table 2), which collectively increase energy demands. Similarly, in case study 2, a notable rise in TDEE was observed as Player 2 transitioned from the PWB phase ( $3175 \text{ kcal}\cdot\text{day}^{-1}$ ) to the FWB phase ( $3713 \text{ kcal}\cdot\text{day}^{-1}$ ). This increase is likely due to the greater exercise volume and intensity (Table 3) as well as increased non-exercise activity thermogenesis from weight bearing mobility [39]. However, even during the FWB phase, TDEE remained  $\sim 800 \text{ kcal}\cdot\text{day}^{-1}$  below pre-injury levels, exceeding reductions observed in prior research ( $\sim 300 \text{ kcal}\cdot\text{day}^{-1}$ ) [18]. The findings from both case studies highlighted the significant variations of TDEE across different phases of rehabilitation process, driven by changes in exercise volume, intensity and mobility status. Future research should seek to quantify both exercise energy expenditure and resting metabolic rate to provide a more comprehensive understanding of how energy demands fluctuate across different stages of rehabilitation and to identify the key factors influencing these changes. These fluctuations in TDEE emphasize the importance of continuous monitoring of energy balance throughout rehabilitation. Indeed, inadequate energy availability has been linked to impaired wound healing, which can delay tissue repair and prolong return-to-play timelines [40, 41]. Collectively, these observations highlight the need for personalised nutritional strategies that adapt to the players' changing energy demands throughout rehabilitation.

In Case Study 1, BM remained stable ( $+0.10 \text{ kg}$ ), despite a decrease in total FFSTM ( $-0.50 \text{ kg}$ ) and an increase in fat mass ( $+0.65 \text{ kg}$ ), both of which exceeded the corresponding RMS-SD ( $0.32 \text{ kg}$  and  $0.28 \text{ kg}$ , respectively). Notably, FFSTM in the injured leg increased slightly ( $+0.07 \text{ kg}$ ); however, this change is within the measurement error, as it falls below the RMS-SD ( $0.37 \text{ kg}$ ) and is therefore unlikely to represent a true physiological

change. In contrast, Anderson et al. [18] and Milsom et al. [42] reported FFSTM losses of  $0.90 \text{ kg}$  and  $1.35 \text{ kg}$ , respectively, following six to eight weeks of rehabilitation. The relatively greater preservation of FFSTM in the present case may be attributed to differences in injury type and rehabilitation strategy, as previous studies involved ACL reconstructions requiring extended periods of immobilisation [14, 15]. Immobilisation, coupled with reduced EI, likely contributed to accelerated FFSTM loss in those studies, given the established link between low energy availability and impaired myofibrillar protein synthesis [43]. In Case Study 1, a modest energy deficit during Week 1 ( $-232 \text{ kcal}\cdot\text{day}^{-1}$ ), followed by a surplus in Week 2 ( $+187 \text{ kcal}\cdot\text{day}^{-1}$ ), in combination with a high protein diet ( $> 2.5 \text{ g}\cdot\text{kg BM}^{-1}\cdot\text{day}^{-1}$ ), may have helped attenuate anabolic resistance and support maintenance of FFSTM [9]. However, a greater reduction in FFSTM was observed in the uninjured limb ( $-0.49 \text{ kg}$ ), contrasting with previous reports that typically found greater FFSTM losses in the injured limb [18, 42]. This may be explained by the fact that the left limb was the player's dominant side, which could have undergone a greater degree of detraining during the injury period [44] as it was previously shown that predominant use of one of the lower limbs is associated with increased muscle thickness of dominant leg in young soccer players [45]. Further research is warranted to explore the difference in FFSTM between dominant and non-dominant limbs during rehabilitation.

In contrast, Player 2 experienced a  $1.2 \text{ kg}$  reduction in BM during the FWB phase, which coincided with an energy deficit of  $557 \text{ kcal}\cdot\text{day}^{-1}$ , as determined via the DLW method. This level of energy deficit may compromise recovery by reducing myofibrillar protein synthesis [43], slowing wound healing [21, 40, 41] and accelerating FFSTM loss [42]. Despite protein intake aligning with current recommendation ( $2.4 \text{ g}\cdot\text{kg BM}^{-1}\cdot\text{day}^{-1}$ ) [9], EI appears inadequate. Increasing carbohydrate intake by  $\sim 140 \text{ g}$  ( $\sim 1.6 \text{ g}\cdot\text{kg BM}^{-1}\cdot\text{day}^{-1}$ ) may have been necessary to meet the elevated energy demands associated with the transition from the PWB to FWB phase. The present findings reinforce the need to ensure sufficient energy and protein intakes throughout the rehabilitation process to minimise FFSTM loss. Notably, the transition from PWB to FWB appears to be a critical period of changing energy demands, warranting careful nutritional management. Further research is needed to understand energy requirements across specific rehabilitation phases and injury types, which would aid in the development of tailored nutritional strategies to support recovery and optimise return-to-play outcomes.

A key limitation of this study is its sample size, capturing the energy demands of two players undergoing two specific rehabilitation protocols aligned with the

medical department's approach at a single professional soccer club. Future studies should investigate the energy requirements of a wider cohort of players, across diverse rehabilitation strategies and injury types, and from multiple teams. Although self-reported dietary intake data are inherently susceptible to bias, the incorporation of DLW-derived energy intake estimates strengthens the reliability of the findings. Furthermore, dietary intake was assessed over only two training days in both case studies. Extending the assessment period to include additional days, particularly rest days, would provide a more comprehensive representation of players' dietary intake throughout the rehabilitation period. Moreover, a further limitation of this case series is the absence of hydration status assessment, which may have affected BM measurements and the accuracy of the DXA-derived outcomes [46].

## Conclusion

We provide novel data on TDEE and EI in elite EPL soccer players during two distinct phases of rehabilitation: the initial two weeks post hamstring injury and the transition from PWB to FWB during rectus femoris injury rehabilitation. TDEE increased substantially by  $\sim 1000$  kcal·day<sup>-1</sup> from Week 1 to Week 2 of hamstring injury rehabilitation, reaching levels comparable to those observed in match-fit players. Additionally, the transition from PWB to FWB was associated with  $\sim 500$  kcal·day<sup>-1</sup> increase in TDEE. Despite these increases, TDEE during the FWB phase remained  $\sim 800$  kcal·day<sup>-1</sup> lower than values reported during full fitness.

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## Authors' contributions

The study was designed by W.L.F, E.T and J.P.M. Data were collected and analysed by W.L.F, P.T.F, R.A.C and C.H. Data interpretation and manuscript preparation were undertaken by W.L.F, P.T.F, R.A.C, J.L.A, G.L.C, C.H, J.R.S, E.T and J.P.M. All authors approved the final version of this paper.

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## Data availability

All data generated or analysed during this study are included in this published article.

## Declarations

### Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and received approval from the Liverpool John Moores University ethics committee (23/SPS/052). All participants provided informed consent.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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