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High prevalence of subclinical energy availability and poor diet quality among paralympic basketball athletes

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Abstract

Background The aim of this study was to evaluate the pre-season nutritional status, diet quality, and energy availability levels of Paralympic athletes competing in wheelchair basketball.

Methods Thirty-two male paralympic athletes, aged 18–63 years, from the Turkish Wheelchair Basketball League participated in the study. Body composition was assessed using dual-energy X-ray absorptiometry (DEXA), while resting metabolic rate (RMR) was measured through indirect calorimetry. Seven-day dietary intake and physical activity records were also collected. Diet quality was analyzed using the Healthy Eating Index- 2020 (HEI- 2020), and energy availability levels were calculated based on the collected data.

Results The findings revealed that 81.8% of the athletes exhibited poor diet quality. On average, the athletes dietary carbohydrate intake was 2.75 ± 1.22 g/kg/day, while their protein intake was 1.04 ± 0.49 g/kg/day. The proportion of energy derived from dietary fat was 38.81 ± 6.7%, with 13.39 ± 2.99% coming from saturated fat. Intake levels of thiamine, folate, vitamin A, calcium, potassium, magnesium, and zinc were found to be inadequate. The average energy level among paralympic athletes was 37.41 ± 11.01 kcal/kg FFM/day, with 21.2% classified as having low energy availability levels and 57.5% as having subclinical energy availability levels. The athletes demonstrated a negative energy balance (- 560.02 ± 593.43 kcal/day), which was more pronounced on training days (- 889.04 ± 683.84 kcal/day).

Conclusions These results suggest that paralympic athletes had insufficient dietary intake of energy, macronutrients, and micronutrients, alongside a high prevalence of low and subclinical energy availability levels. Developing nutrition recommendations tailored specifically for paralympic athletes, combined with implementing nutrition education programs led by qualified dietitians, could play a crucial role in safeguarding and improving their health, enhancing training adaptations, and optimizing athletic performance.

Keywords Paralympic athletes, Wheelchair basketball, Body composition, Nutritional status, Energy availability

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Introduction

Paralympic sports have advanced significantly in recent years, with a steady rise in the number of athletes competing in the Paralympic Games. Today, the Paralympic Games rank among the largest sporting events worldwide. The performance levels and training intensities of Paralympic athletes have increased remarkably, reaching levels comparable to those of able-bodied athletes [1, 2]. Therefore, nutrition has become one of the critical factors in Paralympic athletes. As is well-known, an appropriate nutritional strategy not only enhances athletic performance but also offers additional benefits, including the maintenance of ideal body composition, reduced recovery time, increased substrate oxidation capacity, decreased fatigue, and accelerated healing of injuries [3]. Nevertheless, current sports nutrition guidelines have been developed primarily for able-bodied athletes [4, 5]. Evidence-based recommendations for energy, macro- and micronutrient intake specifically tailored to Paralympic athletes are currently lacking [6–8].

Adequate carbohydrate intake is essential for Paralympic athletes to supply energy for muscle contraction, delay fatigue, and support immune function. Proteins are essential for adapting to strength training, supporting muscle remodeling and repair, and maintaining lean body mass. Sufficient carbohydrate and protein intake are particularly crucial for optimizing muscle protein synthesis and facilitating recovery after exercise [9, 10]. Research has shown that Paralympic athletes often consume inadequate levels of energy, macro- and micronutrients, and generally exhibit poor diet quality [1, 6, 11–14]. For example, a study on wheelchair basketball athletes found insufficient intake of carbohydrates, fiber, thiamine, magnesium, iron, folic acid, and fluids, while fat consumption exceeded recommended levels [1, 11]. Weijer et al. reported that carbohydrate intake was low, while protein intake was adequate among Paralympic athletes [14].

Metabolic and physiological changes observed in Paralympic athletes with conditions such as amputations, spinal cord injuries (SCI), and cerebral palsy result in different nutritional and energy requirements compared to able-bodied athletes [2, 7]. For instance, sensory and motor dysfunctions occurring below the lesion level in athletes with SCI often lead to muscle atrophy. This muscle atrophy results in challenges such as reduced basal metabolic rate, lower daily energy expenditure, decreased exercise-related energy expenditure, and reduced muscle glycogen storage. Consequently, these athletes require less energy overall [9, 15]. Additionally, attention should be directed towards monitoring energy availability (EA) levels in Paralympic athletes. Egger et al. (2020) reported that the energy availability (EA) level of male wheelchair athletes was 36.1 $\pm$6.7 kcal/kg FFM/day, with 30% of the analyzed days reflecting low energy availability (LEA) levels. Similarly, a seven-day observation of female wheelchair athletes indicated that they experienced LEA on 73% of the observed days [16]. Low energy availability is a critical issue that leads to both short- and long-term complications in athletes, including hormonal dysfunction, reduced metabolic rate, compromised bone health, weakened immunity, and increased risk of cardiovascular diseases, all of which significantly diminish athletic performance [17].

Despite the unique nutritional challenges paralympic athletes encounter due to the individual characteristics of their disabilities, there is a limited number of studies assessing the nutritional status of this population. This study aims to evaluate the dietary habits, nutrient intake, diet quality, and energy availability levels of male Paralympic athletes competing in wheelchair basketball teams.

Methods

Participants

This study was conducted with 32 male para-athletes aged between 18 and 63 years, representing three different teams from İzmir competing in the Turkish Wheelchair Basketball League. The study population initially consisted of all athletes from these teams (n =36): 13 from Team A, 13 from Team B, and 10 from Team C. Four athletes were excluded: two female athletes and one athlete with celiac disease from Team A, and one athlete from Team B due to the inability to complete DEXA and indirect calorimetry measurements. All individuals who met the inclusion criteria and voluntarily agreed to participate were included in the study. Consequently, the final analysis was conducted with 32 athletes: 10 from Team A, 12 from Team B, and 10 from Team C. Athletes with lower extremity amputation or spinal cord injury (SCI) were included in the study. Exclusion criteria included individuals with physician-diagnosed conditions requiring medical nutrition therapy-such as diabetes managed with multiple insulin injections, celiac disease, Crohn's disease and other gastrointestinal disorders, inborn errors of metabolism, and renal diseases- due to their potential direct impact on dietary habits, energy intake, and expenditure. Athletes who had difficulty communicating in Turkish were also excluded. The present study was conducted in accordance with the Helsinki Declaration. It was approved by an independent review board of the Ege University (Medical Ethics Committee decision no: 22–4.1 T/27 and 21.04.2022). All participants were informed of the study's purpose, procedures, potential risks, and benefits, and they voluntarily agreed to participate. Written informed consent was obtained before data collection.

Procedure

Data were collected from October 2023 to December 2023 using a structured questionnaire administered by researchers through face-to-face interviews. The data collection form consisted of four sections: the first section gathered general information on participants (sociodemographic characteristics, disability status); the second section recorded anthropometric measurements and body composition; the third section documented food consumption records; and the fourth section included physical activity records.

Assessment of food consumption and diet quality

Food consumption was recorded over seven consecutive days to evaluate the nutritional status of participants. Initially, athletes have been given training on how to record their food intake. These trainings included practical measurement methods (such as bowl, spoon, cup, etc.) and measurement quantities. A photographic food catalog was used as a reference to support accurate recording [18]. Each athlete was paired with a researcher (dietitian) and recorded their daily food intake using 24-h dietary recall forms provided to them. Additionally, they were instructed to photograph each food item before and after consumption and to share these images, along with photos of their completed dietary records, with their assigned researcher via social media platforms. Researchers thoroughly reviewed the collected records and images and conducted phone interviews with the athletes at the end of each day to verify the data and address any discrepancies. This process was repeated for seven consecutive days. Daily energy intake as well as macro and micronutrient consumption of the athletes were analysed by the dietitians in the research team using the Nutrition Information System (BeBiS 9).

Diet quality was assessed using the Healthy Eating Index- 2020 (HEI- 2020), with calculations based on data from the food consumption records. The HEI- 2020, developed in alignment with the Healthy Eating Guidelines for Americans, evaluates individuals' adherence to healthy eating practices. It comprises 13 components: nine that should be consumed adequately and four that should be consumed in limited amounts. Each component is scored from 0–5 or 0–10 points, with higher scores indicating better diet quality. A score below 51 indicates a poor diet, 51–79 reflects a moderate diet, and 80 or above represents a good diet [19].

Determination of energy expenditure and energy availability levels

To determine total daily energy expenditure and energy expenditure from physical activity, athletes were asked to maintain physical activity records for seven consecutive days. They were asked to record their total sleep duration, daily living activities (such as tooth brushing, desk work, etc.), and the duration of all physical activities in the physical activity log form. Total energy expenditure was calculated by summing the resting metabolic rate (RMR), measured via indirect calorimetry, activity-induced energy expenditure, and the thermic effect of foods (TEF) [20, 21]. The following formula was used to determine the TEF [21].

$$TEF = \alpha_F FI + \alpha_P PI + \alpha_C CI$$

$$\begin{aligned}[&\alpha_F = 0.025, \alpha_P = 0.025, \alpha_C = 0.075,\\ &\mathrm{FI} = \text{Fat intake rate in kcal/d},\\ &\mathrm{PI} = \text{Protein intake rate in kcal/d},\\ &\mathrm{CI} = \text{Carbohydrate intake rate in kcal/d}]\end{aligned}$$

One metabolic equivalent (MET) is defined as the amount of oxygen consumed while sitting at rest and is equal to 3.5 ml O_2 per kg body weight x min [22]. Metabolic equivalent values specifically established for wheelchair users were applied to calculate individual energy expenditure [23]. If a MET value specific to wheelchair users was unavailable for a given activity, the corresponding MET value for able-bodied individuals was used instead [24]. To assess the participants' *energy balance (EB)*, the formula *EB = Total Energy Intake (TEI) (kcal) – Total Energy Expenditure (TEE) (kcal)* was applied. The following formula was then used to determine the energy availability level.

$$\begin{aligned}EA =& [TEI(kcal) - Net\ Exercise\ Energy\ Expenditure(kcal)]\\ &/Fat\ Free\ Mass\ (kg)\ (FFM)\end{aligned}$$

A usable energy value of 30 kcal/kg FFM/day or below was classified as a low energy availability level, values between 30–45 kcal/kg FFM/day were considered decreased EA, and values above 45 kcal/kg FFM/day were deemed adequate [16, 17].

Resting metabolic rate (RMR) measurement

Paralympic athletes arrived at the laboratory between 08.00–09.00 by their own vehicles or public transportation. The measurements were performed following an overnight fast (at least 8 h fasting) and the athletes were instructed not to smoke 2 h before the measurement, not to take caffeine 4 h before the measurement and not to perform exercise for 48 h before the measurement. An indirect calorimeter (COSMED, Fitmate Pro; COSMED, Canopy Module) was used for measurement. Before each test, the indirect calorimeter was calibrated according to the manufacturer's instructions. RMR measurements were performed in a quiet room at a temperature between 20–25 °C. Before the measurement, the participants rested in a sitting position for 20 min and then the test was performed in a lying position for 15 min. The first and last five minutes of measurements were excluded from the recordings and the RMR values between the 5 th and 10 th minutes were averaged and calculated.

Body composition measurement and anthropometric measurements

Body composition, including fat mass, body fat percentage, and fat free mass, was measured using whole-body dual-energy x-ray absorptiometry (DEXA; GE-Lunar DPX Pro, GE Healthcare, WI, USA). A trained and experienced radiographer positioned all participants as best as possible to obtain a valid measurement. The athlete was positioned on the DEXA device with arms slightly separated from the torso, ensuring they were centered between the detector and the X-ray tube. A whole-body scan was conducted, beginning at the head and ending at the feet. The measurement duration ranged from 10 to 15 min, depending on the athlete's body size. DEXA measurements were performed between 08:00 and 10:00 am after an overnight fast. During the measurements, the athletes wore only their underwear and removed all metal objects (e.g., jewellery), prostheses, and shoes.

Body Weight (BW): Body weight was measured using a digital disability scale, equipped with a ramp system for wheelchair access, with 100 g accuracy, a maximum capacity of 300 kg, and double-sided grab bars. For athletes using a wheelchair, the measurement was first taken with the athlete in the wheelchair, followed by a separate measurement of the wheelchair alone. The net body weight of the individual was then calculated by subtracting the weight of the wheelchair.

Height: The heights of individuals able to stand upright were measured using a stadiometer, with participants positioned on the Frankfurt plane, looking straight ahead. For individuals unable to stand, height was estimated using the arm span method.

$$Height\ (cm) = 68.7363 + 0.63008\ x\ Arm\ Span\ (cm) - 0.1010\ x\ Age\ (year)$$

Arm Span (cm): Measurements were taken with the individual's back against the wall, arms extended to the sides and parallel to the floor, with the dorsal side of the hands in contact with the wall. The distance between the middle fingertips of both hands was measured using a non-stretch tape measure (Seca, Germany).

Statistical analysis

Statistical analyses were performed using SPSS 25.0 (IBM SPSS Statistics, version 25; IBM, New York, NY, USA). Continuous variables were presented with mean ± standard deviation, and classified data were presented with numbers and percentages. Data were analyzed for normality of distribution with the Shapiro–Wilk test. Paired-samples t-test was used to compare nutrient intake levels, total energy expenditure and energy availability levels between training days and rest days. $p < 0.05$ was considered evidence of statistical significance.

Results

Thirty-two male paralympic athletes competing in the Turkish Wheelchair Basketball League participated in the study, with a mean age of 40.06 ± 11.5 years. Participant information is summarized in Table 1. Among the athletes, 84.4% had spine and brain injuries, and 9.4% had congenital developmental anomalies. Polio was the cause of disability for 53.1% of the participants, while 28.2% were disabled due to congenital sequelae and anomalies. Additionally, 46.9% of the athletes were wheelchair dependent. Among the athletes who participated in the study, 34.4% were Paralympic athletes working in the national team. The majority (84.4%) consumed two main meals per day, while 56.3% reported having only one snack daily. While 15.6% of the athletes used supplements, all of the athletes who used supplements used protein powder. The mean diet quality score was 42.02 ± 12.79, with 81.3% of athletes classified as having poor diet quality and 15.6% as having a diet quality needing improvement.

Table 2 presents the anthropometric measurements and body composition of the Paralympic athletes. The mean body weight was 74.5 ± 14.6 kg, and the mean waist circumference was 89.83 ± 11.2 cm. Using DEXA, the mean fat free mass was determined to be 60.3 ± 11.2%, while the mean fat mass was 37.2 ± 11.9%.

Diet quality assessment is presented in Fig. 1. The mean diet quality score was 42.02 ± 12.79, with 81.3% of athletes classified as having poor diet quality and 15.6% as having a diet quality needing improvement.

Table 3 shows the daily dietary energy and macronutrient intake levels of the paralympic athletes. The mean daily dietary energy intake was 1825.6 ± 531.2 kcal/day. It was observed that energy intake on training days was lower than on rest days. Similarly, carbohydrate consumption on training days (2.63 ± 1.28 g/kg BW) was significantly lower than on rest days (2.83 ± 1.43 g/kg BW, $p < 0.05$). Moreover, only 31.25% of the athletes met the recommended carbohydrate intake levels. The protein intake of the athletes (1.04 ± 0.49 g/kg BW) was below the recommended levels, with only 31.25% of the athletes meeting the protein intake requirements. In contrast, fat and saturated fatty acid (SFA) intakes exceeded recommended levels. Dietary fat consumption was above the reference values for 78.3% of the athletes, while 90.62% exceeded the recommended SFA intake.

The micronutrient intakes of the athletes are presented in Table 4. The results indicate that all micronutrient intakes, except for vitamin B_{12}, biotin, copper, and manganese, were inadequate. Among water-soluble vitamins,

Table 1 Socio-demographic characteristics of paralympic athletes

Variables	n	%
Education		
Primary education	5	15.6
High school	15	46.9
Undergraduate	12	37.5
Marital status		
Single	16	50.0
Married	16	50.0
Disability condition		
Spinal cord injury	27	84.4
Congenital developmental anomaly	3	9.4
Amputation	2	6.2
Cause of disability		
Poliomyelitis	17	53.1
Congenital sequelae & anomaly	9	28.2
Accident & trauma	4	12.5
Cancer	1	3.1
Scoliosis	1	3.1
Duration of life without disability (years)		
0	13	40.6
1–2	11	34.4
3–5	3	9.4
> 5	5	15.6
Use of wheelchair		
Fully dependent on wheelchair	15	46.9
Partially dependent on wheelchair	4	12.5
Does not use a wheelchair/uses other mobility aid	13	40.6
National team athlete	11	34.4
Nutritional habits		
Number of main meals		
1	1	3.1
2	27	84.4
3	4	12.5
Reason for skipping meals		
Lack of time	7	25.0
No appetite	12	42.8
Wants to lose weight	6	14.3
Other	3	10.7
Number of snacks		
None	9	28.1
1	18	56.3
2–3	5	15.6
Receiving nutrition education from a dietitian		
Yes	1	3.1
No	31	96.9
Supplement use		
Yes	5	15.6
No	27	84.4
Supplement		
Protein Powder (Whey protein)	5	100.0
Creatine	2	40.0

Table 2 Anthropometric measurements and body composition of Paralympic athletes

Variables	Mean ± SD	Median	Min–Max
Age (years)	40.06 ± 11.5	43	18–63
Body weight (kg)	74.5 ± 14.6	75.2	46.3–100
Estimated weight (cm)*	178.6 ± 9.8	178.0	170.4–190.0
Height (cm)	176.7 ± 9.8	173.5	161.0–193.0
BMI (kg/m^2)	23.27 ± 4.29	23.45	15.73–30.90
Arm span (cm)	180.9 ± 8.4	181.0	166.0–199.0
MUAC (cm)	33.8 ± 34.2	34.2	26–40.0
Waist circumference (cm)	89.83 ± 11.2	89.5	70.0–115.0
FFM (%)	60.3 ± 11.2	58.3	42.5–88.5
FFM (kg)	42.2 ± 8.5	39.9	27.8–60.8
FM (%)	37.2 ± 11.9	38.7	6.8–55.9

BMI Body mass index, *MUAC* Mid-upper arm circumference, *FFM* Fat free mass, *FM* Fat mass, *Min–Max* Minimum–Maximum

* The estimated height of 22 paralympic athletes was determined using arm length

none of the athletes met the folate requirement, while only 9.38% consumed adequate levels of thiamine and 21.88% met the requirement for vitamin C. The proportion of individuals meeting the adequate intake for fat-soluble vitamins was similarly low. Calcium intake averaged 586.87 mg, with only 3.22% of the athletes meeting their daily requirement. Iodine and selenium intakes were also found to be insufficient, and no athlete completely met their daily requirements.

Table 5 and Table 6 give information about energy expenditure and energy availability levels of the athletes. It was determined that Paralympic athletes had a negative energy balance (− 560.02 ± 593.43 kcal/day) and 57% of the individuals had subclinical energy availability level and 21.2% had LEA level. While the energy availability levels of Paralympic athletes were found to be 37.1 ± 11.01 kcal/kg FFM/d, their EA on training days was 29.87 ± 12.60 kcal/kg FFM/d. It was determined that the individuals were at LEA level in 34.82% of the seven days when the records were kept.

Discussion

This study revealed that Paralympic athletes had inadequate intake of energy, macronutrients, and micronutrients, as well as poor diet quality and suboptimal eating habits. Using the HEI- 2020, 81.8% of the athletes were classified as having poor diet quality. Furthermore, only 31.25% met the recommended intake levels for carbohydrates and protein, while a significant proportion demonstrated excessive fat and saturated fatty acid intake. Micronutrient deficiencies were notable, particularly for folate, vitamin C, vitamin D, calcium, and potassium. In addition, it was determined that 57.6% of the athletes had subclinical EA, while 21.2% had LEA during

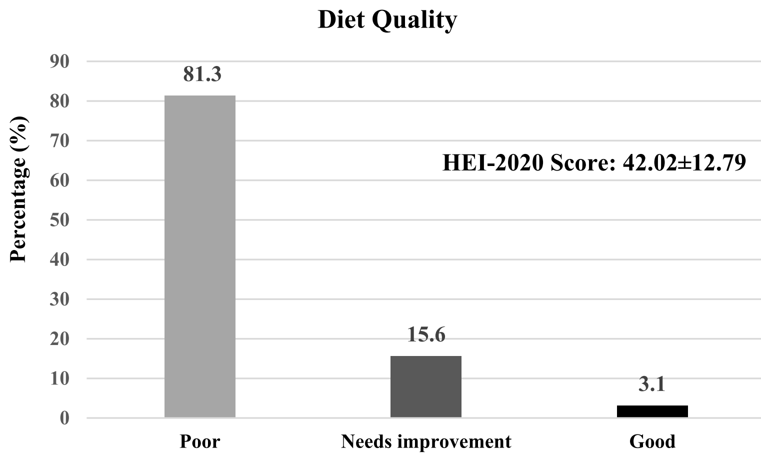

Fig. 1 Assessment of athletes according to the HEI- 2020 classification

Table 3 Dietary macronutrient intake of Paralympic athletes

Variables	RI	Total ($n = 32$)		Resting day ($n = 32$)		Training day ($n = 32$)		p
		Mean ± SD	Meeting recs n (%)	Mean ± SD	Meeting recs n (%)	Mean ± SD	Meeting recs n (%)	
Energy (kkal)	NA	1825.6 ± 531.2	NA	1857.39 ± 581.85	NA	1786.30 ± 601.21	NA	0.354
Carbohydrate (g)	NA	193.95 ± 64.75	NA	201.47 ± 83.16	NA	184.32 ± 69.52	NA	**0.019**
Carbohydrate (%)	45–65[a]	43.87 ± 6.96	12 (37.5)	45.00 ± 7.51	13 (41.94)	42.47 ± 7.79	13 (41.29)	**0.020**
Carbohydrate (g/kg BW)	3–5 g/kg BW[b] (RD) 6–10 g/kg BW[b](TD)	2.75 ± 1.22	10 (31.25)	2.83 ± 1.43	9 (29.03)	2.63 ± 1.28	10 (32.26)	0.052
Fiber (g)	25–30 g	17.48 ± 7.03	4 (12.5)	18.84 ± 8.57	6 (19.35)	17.08 ± 7.28	4 (12.9)	**0.016**
Protein (g)	NA	73.38 ± 26.85	NA	67.45 ± 34.77	NA	74.82 ± 31.05	NA	0.269
Protein (%)	10–35[b]	16.53 ± 2.97	32 (100.0)	15.78 ± 1.69	31 (100.0)	17.36 ± 4.03	31 (100.0)	**0.021**
Protein (g/kg BW)	1.2–2.0 g/kg BW[a]	1.04 ± 0.49	10 (31.25)	0.98 ± 0.54	8 (25.8)	1.07 ± 0.46	9 (29.03)	0.313
Fat (g)	NA	80.41 ± 26.22	NA	78.76 ± 27.86	NA	79.90 ± 30.64	NA	0.900
Fat (%)	20–35[a]	38.81 ± 6.7	25 (78.13)	37.14 ± 8.02	24 (77.4)	39.36 ± 7.48	25 (80.65)	0.169
Satured fat (%)	< %10	13.39 ± 2.99	3 (9.38)	13.11 ± 3.79	5 (16.)12)	13.84 ± 3.32	3 (9.70)	0.305
MUFA (%)	% 12–15	14.13 ± 3.63	12 (37.5)	14.03 ± 4.06	6 (19.3)	14.23 ± 3.93	10 (32.26)	0.636
PUFA (g)	NA	17.15 ± 6.90	NA	16.62 ± 7.39	NA	15.83 ± 6.83	NA	0.265
Omega- 3 (%)	0.6–1.2	0.64 ± 0.27	15 (48.39)	0.61 ± 0.18	16 (51.61)	0.66 ± 0.34	11 (35.48)	0.627
Omega- 6 (%)	5–10	6.96 ± 2.23	24 (77.42)	6.94 ± 2.22	19 (61.30)	6.97 ± 1.77	18 (58.07)	0.935
Omega- 6/Omega- 3	NA	10.77 ± 3.11	NA	10.99 ± 4.05	NA	11.07 ± 6.40	NA	0.788

NA Not applicable, *MUFA* Monounsaturated fatty acid, *PUFA* Polyunsaturated fatty acid, *BW* Bodyweight, *Recs* Recommendations, *RI* Recommended intake, *RD* Resting day, *TD* Training Day, *sc* score

[*] $p < 0.05$. Paired-samples t-test

[a] Acceptable macronutrient distribution range [25]

[b] Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine [5]

the seven-day observational period. This situation can be attributed to the limited knowledge on sports nutrition among Paralympic athletes, as well as challenges related to physical limitations, such as grocery shopping and meal preparation, in addition to the influence of social, cultural, and religious beliefs [11]. These findings underscore the importance of tailored nutritional strategies to address the specific dietary challenges faced by Paralympic athletes.

A high-quality diet enhances athletic performance by promoting overall health and reducing the risk of nutritional deficiencies, while poor diet quality negatively

Table 4 Dietary micronutrient intake of paralympic athletes

Variables	RI	Total ($n = 32$)			Rest day ($n = 32$)			Training day ($n = 32$)			p
		Mean ± SD	RDA (%)	Meeting recs n (%)	Mean ± SD	RDA (%)	Meeting recs n (%)	Mean ± SD	RDA (%)	Meeting recs n (%)	
Water-soluble vitamins											
Thiamine (mg)	1.2	0.79 ± 0.28	66.08	3 (9.38)	0.81 ± 0.38	67.63	4 (12.90)	0.80 ± 0.34	66.46	4 (12.90)	0.559
Riboflavin (mg)	1.3	1.33 ± 0.53	102.69	16 (50.00)	1.35 ± 0.83	104.03	5 (16.13)	1.37 ± 0.59	105.24	14 (45.16)	0.963
Niacin (mg)	16	14.59 ± 5.62	91.19	11 (34.38)	14.62 ± 7.17	91.39	10 (32.25)	15.42 ± 7.23	96.37	15 (49.39)	0.683
Vitamin B_6 (mg)	1.3	1.18 ± 0.40	90.62	10 (31.25)	1.14 ± 0.41	87.68	10 (32.25)	1.20 ± 0.54	92.02	12 (38.71)	0.689
Vitamin B_{12} (µg)	30	43.94 ± 20.03	146.47	26 (81.25)	41.09 ± 20.03	136.97	22 (70.97)	44.63 ± 23.64	148.76	24 (77.42)	0.523
Folate (µg)	400	260.62 ± 68.51	65.16	0 (0.00)	264.78 ± 85.60	66.19	3 (9.68)	256.07 ± 89.00	64.02	3 (9.68)	0.508
Biotin (µg)	2.4	6.01 ± 7.27	250.27	30 (93.75)	7.94 ± 17.33	330.97	22 (70.97)	5.79 ± 7.93	241.45	26 (84.87)	0.490
Vitamin C (mg)	90	88.85 ± 65.31	98.72	7 (21.88)	90.98 ± 60.56	101.08	12 (38.71)	84.15 ± 79.49	93.50	9 (29.04)	0.563
Fat-soluble vitamins											
Vitamin A (mg)	900	1092.67 ± 904.02	121.41	9 (28.13)	1023.10 ± 939.02	113.68	11 (35.48)	1163.37 ± 1373.84	129.26	11 (35.48)	0.633
Vitamin D (µg)	10	3.00 ± 1.92	30.04	0 (0.00)	2.81 ± 2.61	28.05	0 (0.00)	3.53 ± 4.12	35.34	2 (6.45)	0.414
Vitamin E (mg)	15	15.72 ± 6.68	104.79	24 (43.75)	16.53 ± 7.78	110.18	16 (51.61)	15.39 ± 8.55	102.58	12 (38.71)	0.421
Vitamin K (µg)	120	85.48 ± 53.43	71.24	7 (21.88)	86.99 ± 75.28	72.49	7 (21.88)	83.15 ± 78.09	69.29	5 (16.13)	0.926
Macrominerals											
Calcium (mg)	1000	586.87 ± 163.41	58.69	1 (3.13)	597.85 ± 214.86	43.32	1 (3.23)	574.79 ± 184.15	57.48	2 (6.45)	0.607
Phosphorus (mg)	700	1057.05 ± 348.38	151.01	27 (84.38)	1045.29 ± 363.63	100.18	26 (83.87)	1053.51 ± 400.94	150.50	26 (83.87)	0.892
Sodium (mg)	1500	1757.80 ± 655.96	117.19	19 (59.38)	1912.31 ± 1023.5	71.45	17 (54.84)	1766.50 ± 719.85	117.77	20 (64.52)	0.447
Potassium (mg)	4700	2126.54 ± 642.91	45.25	0 (0.00)	2196.59 ± 798.08	30.76	0 (0.00)	2051.46 ± 765.77	43.65	0 (0.00)	0.325
Magnesium (mg)	420	249.58 ± 78.91	59.42	1 (3.13)	259.56 ± 98.02	37.40	3 (9.68)	239.33 ± 89.95	56.98	2 (6.45)	0.205
Trace minerals											
Iron (mg)	8	9.65 ± 3.42	120.6	18 (56.25)	10.28 ± 4.99	128.5	20 (64.52)	9.49 ± 3.95	118.6	18 (58.06)	0.325
Zinc (mg)	11	9.45 ± 2.82	85.9	5 (15.63)	10.09 ± 3.89	91.7	12 (38.71)	9.31 ± 3.69	84.6	6 (19.35)	0.302
Copper (mg)	0.9	1.44 ± 0.49	159.7	29 (90.63)	1.48 ± 0.61	163.91	29 (93.55)	1.39 ± 0.55	154.64	27 (87.10)	0.384
Manganese (µg)	2.3	6.88 ± 3.45	299.1	31 (96.88)	8.24 ± 7.23	358.4	30 (96.77)	6.45 ± 4.68	280.5	27 (87.10)	0.223
Iyodine (µg)	150	51.98 ± 20.09	34.7	0 (0.00)	50.04 ± 23.91	33.4	0 (0.00)	54.32 ± 28.72	36.2	1 (3.23)	0.555
Selenium (µg)	55	17.09 ± 13.24	31.1	0 (0.00)	15.04 ± 13.87	27.3	1 (3.23)	18.18 ± 15.82	33.1	1 (3.23)	0.396

$p < 0.05$, Paired-samples t-test

Recs Recommendations, *RI* Recommended intake

affects training adaptation and recovery [26]. Despite its importance, studies evaluating diet quality in Paralympic athletes remain limited. Schneider et al. reported that Paralympic athletes'diet quality was in need of modification and associated with the risk of noncommunicable diseases [27]. Similarly, a study on Paralympic track & field athletes found that all participants had diet quality levels needing improvement, emphasizing the necessity of long-term nutrition education programs tailored for Paralympic athletes. In this study, 81.8% of athletes were classified as having poor diet quality, with the only athlete demonstrating good diet quality having received prior nutrition education. This finding underscores the critical role of sports nutrition education and dietitian support in optimizing dietary habits. Additionally, Yokoyama et al. highlighted that national wheelchair athletes lacked access to dietitian counseling, further emphasizing the need for professional dietary guidance to ensure optimal nutrition [3].

Carbohydrates are crucial for energy production in athletes, making their storage and oxidation vital before, during, and after training [7]. Recommendations suggest a carbohydrate intake of 5–12 g/kg BW/day based on activity intensity to maintain glycogen stores [4, 5, 28]. Due to differences in the number of training days, training durations, and training intensities among athletes from the three different teams included in the study, carbohydrate requirements varied accordingly. Therefore, a broad range was applied to reflect this variability. In this study, athletes' carbohydrate intake was insufficient, averaging 2.75 ± 1.22 g/kg BW/day. Similarly, Eskici et al. reported that while the energy intake of Paralympic wheelchair basketball players was adequate, carbohydrate-derived energy was low (42.7 ± 8.8%) [11]. A study

Table 5 Energy availability levels of Paralympic athletes

Participant	FFM (kg)	EA Day 1	EA Day 2	EA Day 3	EA Day 4	EA Day 5	EA Day 6	EA Day 7	Weekly mean of EA	Number of days of LEA
M01	44.1	*33.6*	*28.7*	*28.5*	*34.1*	*24.5*	*32.5*	*35.2*	31.01 ± 3.87	3
M02	39.9	*19.0*	*36.1*	*26.9*	*41.5*	*66.7*	38.3	*30.7*	37.03 ± 15.11	2
M03	30.7	*14.1*	*39.6*	43.8	*42.6*	*41.7*	45.9	43.3	38.71 ± 11.02	1
M04	53.1	*27.7*	*25.7*	*17.9*	*22.8*	31.9	51.4	*13.7*	27.30 ± 12.24	5
M05	35.6	*29.9*	*41.8*	*39.2*	*34.3*	*44.5*	58.6	*32.3*	40.09 ± 9.69	1
M06	60.5	*17.5*	*64.4*	*46.7*	*52.9*	*23.6*	55.2	*10.1*	38.63 ± 21.19	3
M07	37.6	*37.5*	*25.8*	*17.4*	*67.7*	*30.1*	66.4	*51.8*	42.39 ± 19.92	2
M08	41.2	*48.4*	*35.2*	*30.5*	*32.7*	*63.4*	30.5	*26.1*	38.11 ± 13.19	1
M09	31.8	*36.0*	*66.7*	*18.6*	74.9	*65.5*	**26.9**	*33.6*	46.03 ± 22.41	2
M10	55.6	*81.8*	*39.5*	*37.3*	*46.6*	*62.1*	65.7	*77.4*	58.63 ± 17.87	0
M11	37.7	*33.1*	*− 1.7*	*19.0*	*17.0*	55.2	49.0	40.5	30.30 ± 20.04	3
M12	57.5	*28.3*	*3.2*	*35.7*	*24.8*	40.1	43.8	*24.4*	28.61 ± 13.49	4
M13	36.6	74.5	*25.2*	78.0	*39.3*	40.6	67.8	46.8	53.17 ± 20.24	1
M14	49.9	61.5	*30.3*	44.3	*36.7*	**18.3**	44.7	42.7	39.79 ± 13.45	1
M15	36.5	37.9	43.8	**28.1**	52.9	31.2	**22.4**	35.8	36.01 ± 10.17	2
M16	44.2	34.9	*− 4.2*	43.0	*2.3*	30.8	30.1	*6.0*	20.41 ± 18.55	3
M17	42.3	*15.7*	38.4	47.5	**22.5**	*25.6*	**24.8**	**27.4**	28.84 ± 10.66	5
M18	41.3	30.0	*24.7*	32.1	*21.9*	51.5	**28.8**	*17.5*	29.50 ± 10.93	4
M19	39.4	30.7	*24.0*	38.1	*31.6*	**27.1**	48.3	**28.9**	32.67 ± 8.16	3
M20	50.3	35.5	*7.1*	**26.4**	*14.8*	**12.0**	**21.3**	*14.1*	18.74 ± 9.70	6
M21	45.2	**24.4**	*12.8*	38.8	41.9	54.9	31.6	*47.2*	35.94 ± 14.45	2
M22	38.1	51.9	*24.8*	32.8	29.9	40.9	39.1	*24.4*	34.83 ± 9.83	3
M23	50.3	**24.7**	*25.3*	**26.0**	**14.0**	**20.4**	**13.8**	*11.9*	19.44 ± 6.11	7
M24	36.4	35.0	*37.5*	48.3	*33.1*	40.9	43.7	**28.2**	38.10 ± 6.79	1
M25	42.5	55.7	*30.7*	54.5	*19.9*	36.3	47.2	**24.6**	38.41 ± 14.33	2
M26	27.8	75.8	*73.8*	60.3	*54.8*	83.0	80.6	53.6	68.84 ± 12.34	0
M27	34.3	70.0	*34.6*	40.7	*45.7*	62.4	67.1	77.9	56.91 ± 16.49	0
M28	32.5	37.5	*24.1*	41.3	*35.5*	64.8	**28.5**	41.8	39.07 ± 13.07	2
M29	38.4	42.7	*27.3*	58.4	*24.0*	57.5	83.5	46.0	48.49 ± 20.39	2
M30	45.6	**27.4**	*57.9*	39.7	*10.2*	**24.8**	30.3	34.9	32.17 ± 14.66	3
M31	37.1	58.0	*22.6*	**22.8**	*20.9*	31.9	48.3	30.9	33.63 ± 14.27	3
M32	60.8	33.2	*39.8*	31.6	*22.5*	53.7	36.9	30.3	35.43 ± 9.73	1
						Mean EA:			37.41 ± 11.01	% 34.82

[*] Italic numbers indicate the EA value on the days the athlete trained

[**] Bold numbers indicate the days the athletes had LEA levels

on male athletes from the Spanish Wheelchair Basketball National Team also found inadequate carbohydrate intake [1], aligning with other research on Paralympic athletes [9, 13].

Inadequate carbohydrate intake may impair performance, particularly in athletes with spinal cord injury, cerebral palsy, or amputation, who often have reduced glycogen stores due to lower active muscle mass. Additionally, increased atrophied muscle mass alters fiber composition, reducing type IIx fibers, which have twice as many glycolytic enzymes as type I fibers [10]. Consequently, Paralympic athletes may require higher carbohydrate intake than able-bodied athletes [8].

Adequate dietary fiber intake supports intestinal microbiota and protects against gastrointestinal diseases, obesity, cardiovascular diseases, diabetes, and infections [29]. However, studies indicate insufficient fiber intake among Paralympic athletes [30, 31]. For instance, 75% of elite male and 42% of female para-cyclists had inadequate fiber intake [2], while 63.6% of wheelchair basketball players also consumed insufficient amounts [11]. In this study, only 12.5% of Paralympic athletes met fiber

Table 6 Energy expenditure and energy availability levels of Paralympic athletes

Variables	Total ($n = 32$)	Resting day ($n = 32$)	Training day ($n = 32$)	*p*
TDEE (kcal/d)	2382.49 ± 465.91	2137.81 ± 430.02	2600.36 ± 492.76	< 0.001
TDEE (kcal/FFM (kg)/d)	56.96 ± 8.64	50.51 ± 8.59	61.29 ± 9.28	< 0.001
EI-TEE difference (kcal/d)	− 560.02 ± 593.43	− 322.85 ± 690.71	− 889.04 ± 683.84	< 0.001
EA (kcal/kg FFM/d)	37.41 ± 11.01	44.08 ± 12.75	29.87 ± 12.60	< 0.001
PAEE (kcal/d)	543.60 ± 165.28			
RMR (kcal/d)	1476.79 ± 214.43			
VO_2 (mL/kg/min)	2.90 ± 0.39			
EA classification				
Low EA (< 30 kcal/kg FFM/d)	7 (21.2)	2 (6.25)	16 (50.0)	
Subclinical EA (30–45 kcal/kg FFM/d)	19 (57.6)	20 (62.5)	14 (43.75)	
Adequate EA (> 45 kcal/kg FFM/d)	6 (18.2)	10 (31.25)	2 (6.25)	

[*] $p < 0.05$, Paired-samples t-test

TDEE Total daily energy expenditure, *FFM* fat-free mass, *EI* Energy intake, *EA* Energy availability, *PAEE* Physical activity energy expenditure, *RMR* Resting metabolic rate

recommendations. Individuals with spinal cord injury (SCI) often experience dysbiosis, prolonged intestinal transit, and constipation [1, 2]. Adequate fiber intake can alleviate these issues, enhance gut health, and improve overall diet quality in Paralympic athletes [10]. Given its role in digestive and metabolic health, optimizing fiber intake should be a nutritional priority.

Protein intake in athletes supports muscle protein synthesis, maintains a positive protein balance, and enhances training adaptation. A recommended intake of 1.2–2.0 g/kg BW/day is suggested for able-bodied athletes [5], with a minimum of 1.2 g/kg BW/day recommended for Paralympic athletes [30]. Previous studies indicate that male Paralympic athletes generally meet protein intake requirements, ranging from 1.4 to 2.7 g/kg BW [2, 13, 14]. For example, wheelchair athletes had a mean intake of 1.5 ± 0.3 g/kg BW/day, with 74% meeting recommendations [32]. However, while protein intake (1.7 ± 0.6 g/kg BW/day) in wheelchair basketball players was adequate, carbohydrate intake was insufficient. A higher intake of 2.0 g/kg BW/day is recommended to support wound healing in wheelchair athletes [1, 14, 31]. In this study, only 31.25% of athletes met the recommended protein levels. Tailored strategies are needed to ensure adequate protein intake at appropriate times.

Fats are a crucial energy source, especially for endurance athletes, but studies show excessive intake of dietary fat, saturated fat, and trans fats [13, 30]. This study's findings align with previous research. For example, male hand-cyclists derived 39.7% of their energy from fat, with high consumption of processed foods [9]. Similarly, Eskici et al. reported that wheelchair basketball players had 44% of their energy from fat, attributed to limited knowledge of sports nutrition [11]. Excessive fat intake may worsen gastrointestinal issues and negatively affect blood lipid profiles, increasing the risk of chronic diseases in Paralympic athletes [9].

Energy balance is essential for maintaining body composition and mass. In this study, it was found that the athletes experienced a negative energy balance, particularly on training days, primarily due to insufficient energy intake. While previous studies have reported energy intakes for Paralympic athletes ranging 1893–4139 kcal/day, the athletes in this study had an average dietary energy intake of 1825.6 kcal/day [2, 8, 32]. The low energy intake observed may be attributed to intentional energy restriction for weight loss before the season. Additionally, the potential for underreporting food consumption should not be overlooked. It is known that the rate of underreporting is high in studies where food consumption records are taken [33].

Low energy intake resulted in the athletes remaining at a LEA level for 34.82% of the one-week follow-up period. Consistent with previous studies, this research also found that Paralympic male athletes exhibited subclinical LEA [16, 32]. Egger et al. reported that paralympic male athletes were in a state of LEA for 30% of the follow-up period, with an EA of 36.1 ± 6.7 kcal/kg FFM/day. Studies conducted on able-bodied athletes have demonstrated that LEA contributes to Relative Energy Deficiency in Sport (REDs), which negatively impacts both overall health and athletic performance [16].

Athletes with SCI have been reported to exhibit decreased sympathetic nervous system activity due to spinal lesions and the use of β-adrenergic blockers. This results in a 14–27% lower basal metabolic rate and reduced energy requirements compared to able-bodied athletes [1, 15, 34]. However, Weijer et al. noted that previous studies relying on energy intake measurements from double-labeled water administration may have significantly underestimated the actual energy requirements of Paralympic athletes [14]. The energy requirements of Paralympic athletes are influenced by individual factors such as the type of disability (e.g., SCI, amputation), the specific sport they perform, and the varying demands across different stages of the athletic season and periods of high training load. Consequently, developing tailored approaches for this unique group of athletes is essential to accurately meet their energy needs and reduce the risk of REDs.

Vitamins and minerals are essential for regulating metabolic pathways, and inadequate intake, along with factors like gastrointestinal dysfunction and increased catabolism, can negatively impact athletic performance [34, 35]. Sasaki et al. found that over 60% of Paralympic athletes had insufficient vitamin D and calcium intake, more than 50% lacked adequate vitamin A, and over 33% were deficient in vitamin C [6]. A study on hand-cyclists also reported inadequate intake of calcium, vitamin D, folic acid, and potassium, while wheelchair basketball players had insufficient intake of thiamine, calcium, vitamin C, and vitamin D [9, 30]. In this study, athletes were found to have inadequate intake of most micronutrients, except for energy, vitamin B_{12}, copper, biotin, and manganese. Grams et al. observed a positive correlation between insufficient energy intake and micronutrient deficiencies [36], highlighting energy intake as the primary issue for athletes in this study.

This study has several limitations. First, the evaluation of macronutrient, micronutrient intake levels, and usable energy levels for Paralympic athletes relied on reference values established for able-bodied individuals. This may have led to potential misinterpretation of the results. Second, athletes were asked to maintain a physical activity diary to assess their activity levels, which could have resulted in under- or over-reporting and, consequently, an under- or overestimation of daily energy expenditure and usable energy levels. It would be a more useful approach to use an accelerometer to assess the level of physical activity. Third, although athletes were closely monitored by the researchers and were asked to provide photographs of their meals in addition to keeping dietary records, under- or over-reporting is a common limitation in dietary intake studies. Fourth, since the study included only male Paralympic athletes, the findings cannot be generalized to female Paralympic athletes. Differences in physiological and metabolic responses between sexes could influence energy availability and nutritional status, which were not accounted for in this research. Fifth, the assessment of LEA was based only on the energy values of the athletes. Blood markers such as testosterone, triiodothyronine (T3), insulin-like growth factor (IGF- 1) or bone mineral density z-score were not used in the assessment. Lastly, the study focused solely on the preseason preparation period. Conducting longer studies that include the competition season could yield more comprehensive and accurate insights.

Conclusions

This study found that Paralympic athletes had inadequate intake of energy and nutrients. Previous studies have demonstrated that nutrition education provided to able-bodied athletes significantly improves their dietary habits, whereas paralympic athletes often exhibit insufficient nutrition knowledge. Consequently, it would be highly beneficial to implement nutrition education programs specifically designed by dietitians for paralympic athletes. An equally important need is the establishment of reference values for dietary energy, macro-, and micronutrient requirements tailored to specific disabilities such as SCI, amputations, and cerebral palsy. Furthermore, EA cut-off points should be developed specifically for this population. Addressing these needs could significantly enhance both the general health and athletic performance of paralympic athletes. Conducting well-designed systematic research is crucial for developing evidence-based guidelines tailored to athletes participating in the increasingly popular Paralympic sports.

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Authors' contributions

Conceptualization: Ö.K. and R.M. Data curation: E.K., R.N.A and C.A. Formcurations: R.M. and M.U. Funding acquisition: All authors. Investigation: All authors. Methodology: Ö.K., R.M. and M.U. Project administration: Ö.K. and R.M. Visualization: E.K., R.N.A and C.A. Writing—original draft: M.U., R.M. and Ö.K. Writing—review and editing: All authors. All authors have read and agreed to the published version of the manuscript.

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Data availability

The questionnaire used in the study has been provided as a supplementary file.

Declarations

Ethics approval and consent to participate

The present study was conducted in accordance with the Helsinki Declaration. It was approved by an independent review board of the Ege University (Medical Ethics Committee decision no: 22–4.1 T/27 and 21.04.2022). All participants were informed of the study's purpose, procedures, potential risks, and benefits, and they voluntarily agreed to participate. Written informed consent was obtained before data collection.

Consent for publication

Not applicable.

Competing interests
The authors declare no competing interests.

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