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Effects of Acute Carbohydrate-Protein Co-Ingestion on Muscle Damage Markers, Recovery Kinetics, and Repeated-Sprint Capacity in Elite Iraqi Handball Players: A Randomised Double-Blind Crossover Trial

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ABSTRACT

Post-exercise nutritional strategies profoundly influence muscle damage repair, inflammatory response, and recovery of physical performance capacity in team sport athletes. This randomised double-blind crossover trial examined the effects of acute carbohydrate-protein (CHO+PRO) co-ingestion versus isocaloric carbohydrate-only (CHO) supplementation on markers of muscle damage, inflammatory cytokines, and repeated-sprint recovery capacity in elite Iraqi handball players. Twenty male players from the Iraqi Handball Premier League (age: 23.4 +/- 2.8 years; body mass: 83.6 +/- 8.2 kg) completed two simulated 60-minute handball match protocols separated by a two-week washout. Immediately post-match and at 2 hours post-match, players received either CHO+PRO (0.8 g CHO + 0.4 g PRO per kg body mass) or isocaloric CHO (1.2 g/kg) supplements in a double-blind manner. Serum creatine kinase (CK), lactate dehydrogenase (LDH), interleukin-6 (IL-6), and muscle soreness (DOMS, 0-10 VAS scale) were assessed at baseline, immediately post-match, and at 24 and 48 hours. Repeated-sprint capacity (6 x 30 m with 25-s recovery) was assessed at 24 hours post-match. CHO+PRO produced significantly lower CK activity at 24 h (342 +/- 68 vs. 498 +/- 82 U/L; $p < 0.001$; $d = 2.14$) and 48 h (198 +/- 44 vs. 316 +/- 61 U/L; $p < 0.001$; $d = 2.25$), lower DOMS at 24 h (4.1 +/- 0.9 vs. 5.8 +/- 1.1; $p < 0.001$; $d = 1.70$), and significantly better repeated-sprint performance (mean sprint time: 4.21 +/- 0.14 vs. 4.38 +/- 0.16 s; $p < 0.001$; $d = 1.15$). These findings support acute CHO+PRO co-ingestion as a superior post-match nutritional strategy compared to carbohydrate-only supplementation for accelerating recovery in elite Iraqi handball players.

Introduction

The physical demands of elite handball are exceptionally rigorous, characterised by frequent high-intensity explosive actions - including jumps, throws, rapid direction changes, and physical contact - superimposed upon sustained locomotor activity across 60 minutes of competitive play (Michalsik et al., 2013; Wagner et al., 2014). Elite male handball players perform an average of 120-180 high-intensity actions per match, involving forceful upper and lower body muscle contractions that generate substantial mechanical strain on the musculotendinous and contractile apparatus. These intense mechanical forces during both eccentric and concentric muscle actions initiate a cascade of structural damage to muscle fibres, manifesting as disruption of the sarcomeric Z-disc architecture, release of cytoplasmic proteins - most notably creatine kinase (CK) and lactate dehydrogenase (LDH) - into the circulation, and activation of the innate inflammatory response (Clarkson & Hubal, 2002). The resulting delayed-onset muscle soreness (DOMS), transient reduction in force-producing capacity, and systemic inflammatory burden collectively impair physical performance in the 24-72 hours following competitive match play.

In the compressed fixture schedules characteristic of elite handball competition - where matches may be separated by as little as 24-48 hours during major championships or end-of-season phases - the rate and completeness of post-match recovery has profound implications for subsequent match performance. Players who complete the recovery process rapidly and fully can approach the next match with near-intact physical capacity, while those experiencing incomplete recovery may enter subsequent fixtures with residual muscle damage, elevated inflammatory markers, and attenuated sprint and jump performance that cumulatively diminish team performance across multi-match tournaments. The optimisation of post-match nutritional strategies to accelerate recovery kinetics is therefore a nutritional priority of the highest practical significance for elite handball athletes and the applied sport science practitioners who support them.

The post-exercise nutritional window - the period immediately following exercise termination, during which the physiological environment is uniquely receptive to nutritional intervention - is well established as the most critical time for delivering recovery-promoting substrates. Carbohydrate ingestion in this window rapidly restores muscle glycogen through insulin-stimulated GLUT-4-mediated glucose uptake and glycogen synthase activation (Ivy et al., 2002). Protein ingestion stimulates muscle protein synthesis via leucine-mediated activation of the mTORC1 signalling cascade, promoting repair of exercise-damaged myofibrils and net positive muscle protein balance (Phillips & Van Loon, 2011). The hypothesis that co-ingestion of carbohydrate and protein produces superior recovery outcomes compared to either macronutrient alone - through synergistic insulin signalling, simultaneous glycogen resynthesis and protein synthesis, and enhanced muscle cell hydration - has generated substantial research interest over the past two decades, though the evidence base in handball-specific populations remains limited.

Meta-analytic evidence from a range of sport contexts suggests that CHO+PRO co-ingestion attenuates post-exercise CK release and DOMS more effectively than isocaloric CHO alone, particularly when the protein component provides a sufficient dose of essential amino acids (Cockburn et al., 2010; Luden et al., 2007). The proposed mechanisms include protein-induced stimulation of satellite cell activation and myofibrillar repair, which reduces the extent of secondary muscle damage in the 24-48 hours following exercise; enhanced insulin-mediated glucose uptake, which accelerates glycogen resynthesis and reduces the catabolic signalling associated with energy deficit; and direct anti-inflammatory effects of specific amino acids - particularly leucine and glutamine - that modulate the cytokine response to exercise-induced muscle damage. Whether these benefits are reproducible in the specific context of elite handball match

play, which differs from the continuous aerobic exercise models most frequently employed in recovery nutrition research, remains to be established.

The nutritional practices of Iraqi handball players are poorly characterised in the published literature, and the adequacy of their post-match recovery nutrition - in terms of both timing and macronutrient composition - is unknown. Anecdotal evidence from the authors' practical experience with Iraqi Handball Premier League clubs suggests that post-match nutrition is largely unstructured and may fail to meet evidence-based targets for carbohydrate and protein delivery in the critical immediate post-exercise recovery window. This nutritional gap may contribute to the incomplete recovery and progressive performance decrements sometimes observed in Iraqi handball players across multi-match competition phases. The present study was designed to provide the first controlled evidence on the efficacy of CHO+PRO co-ingestion for recovery optimisation in this population, and to generate practically applicable nutritional guidelines for Iraqi Handball Premier League clubs.

The present study therefore aimed to compare the effects of acute carbohydrate-protein (CHO+PRO) co-ingestion versus isocaloric carbohydrate-only (CHO) supplementation on: (1) serum creatine kinase activity and lactate dehydrogenase activity at 24 and 48 hours post-match; (2) circulating interleukin-6 concentration at 2 hours post-match; (3) delayed-onset muscle soreness at 24 and 48 hours; and (4) 30-metre repeated-sprint capacity at 24 hours post-match. It was hypothesised that CHO+PRO would produce significantly lower CK, LDH, IL-6, and DOMS values, and significantly better repeated-sprint performance at 24 hours, compared to the isocaloric CHO condition.

Materials and Methods

Study Design

A randomised, double-blind, counterbalanced crossover design was employed with a two-week washout period between conditions. Randomisation of condition order was performed by a researcher independent of testing and data analysis using computer-generated random allocation. The double-blind procedure was maintained through identical packaging and flavouring of both supplements, with neither participants nor assessors aware of condition assignment until after all data collection was complete. Ethical approval was granted by the University of Samarra Research Ethics Board (Approval No. US-PESS-2025-231), and all procedures conformed to the 2013 revision of the Declaration of Helsinki. Written informed consent was obtained from all participants.

Participants

Twenty elite male handball players from Iraqi Handball Premier League clubs (age: 23.4 +/- 2.8 years; height: 183.6 +/- 6.4 cm; body mass: 83.6 +/- 8.2 kg; playing experience: 6.4 +/- 2.2 years) participated in this study. Playing positions: backs (n = 7), wings (n = 5), pivot (n = 4), goalkeeper (n = 4). Inclusion criteria required: first-team squad registration; minimum four years competitive handball experience; absence of musculoskeletal injury in the preceding six weeks; non-use of protein, creatine, or anti-inflammatory supplements within four weeks of enrolment; no known intolerance to dairy proteins. A priori power calculation (G*Power 3.1; effect size d = 1.5, alpha = 0.05, power = 0.80) indicated a minimum of 16 participants; 20 were recruited to account for potential attrition.

Simulated Match Protocol

The 60-minute handball-specific simulated match protocol (HSMP) was adapted from the protocol of Michalsik et al. (2013) and required players to complete a standardised sequence of locomotor activities replicating the physical demands of a competitive handball match, including: walking (10%), jogging at

9-10 km/h (30%), moderate running at 13-14 km/h (25%), high-intensity running at 17-19 km/h (20%), and maximum-effort sprint efforts at > 21 km/h (15%). Each 5-minute period was interspersed with simulated technical actions (10 overhead throws at 50% maximum effort, 8 lateral shuffle steps, 4 vertical jumps). Sessions were conducted on a 40-metre indoor track under standardised environmental conditions (22 +/- 1 degrees C; 45 +/- 5% humidity). A standardised warm-up (15 minutes) and identical pre-exercise carbohydrate breakfast (1.5 g/kg; consumed 2 hours before the protocol) were administered on both testing occasions.

Supplementation Protocol

Immediately following completion of the HSMP and again at 2 hours post-match, participants received one of two supplement beverages in a double-blind manner: (1) CHO+PRO condition: 0.8 g/kg body mass carbohydrate (maltodextrin) + 0.4 g/kg body mass whey protein isolate (leucine content: 2.8 g per dose) dissolved in 500 mL water; or (2) CHO condition: 1.2 g/kg body mass carbohydrate (maltodextrin) dissolved in 500 mL water (isocaloric to CHO+PRO). Both beverages were identical in appearance, volume, and flavour (vanilla), prepared by an independent researcher not involved in data collection. Participants were required to consume the full beverage volume within 10 minutes of each administration. Total supplement energy delivery did not differ significantly between conditions (CHO+PRO: 328 +/- 24 kcal per dose; CHO: 331 +/- 22 kcal per dose; $p > 0.05$).

Assessment Procedures

Blood samples (10 mL antecubital venipuncture) were collected at baseline (pre-match), immediately post-match (before supplement administration), at 2 hours post-match (before second supplement administration), 24 hours post-match, and 48 hours post-match. Serum CK activity was determined using the UV kinetic method (IFCC reference procedure) on a COBAS C111 clinical chemistry analyser (Roche Diagnostics, Germany). Serum LDH was measured using the pyruvate-to-lactate direction IFCC kinetic assay on the same analyser. Plasma IL-6 was quantified using a commercial sandwich ELISA kit (R&D Systems, Minneapolis, USA) with a sensitivity of 0.039 pg/mL and intra-assay CV < 8%. Muscle soreness was assessed using a 10-cm visual analogue scale (VAS) anchored at 0 (no soreness) and 10 (worst imaginable soreness), with participants rating soreness of the dominant leg quadriceps during a standardised squat to 90-degree knee flexion.

Repeated-sprint capacity was assessed at 24 hours post-match using a 6 x 30-metre sprint protocol with 25-second active recovery between sprints, administered on the same indoor track used for the HSMP. Sprint times were recorded using dual-beam electronic timing gates (Brower TC System, USA) set at 0 and 30 metres. Mean sprint time, best sprint time, and the percentage sprint decrement (Sdec = [1 - (mean time/best time)] x 100) were computed as performance indices.

Statistical Analysis

Paired-samples t-tests were used to compare all outcome variables between CHO+PRO and CHO conditions. A two-way repeated measures ANOVA (condition x time) was used to examine the temporal pattern of CK responses across the five time points. Cohen's d effect sizes were computed and interpreted as small (0.2-0.49), medium (0.5-0.79), and large (>= 0.80). Normality was confirmed using the Shapiro-Wilk test ($p > 0.05$ for all variables). Statistical analyses were performed using IBM SPSS Statistics v26.0. Statistical significance was set at alpha = 0.05. All data are presented as mean +/- SD.

Results

Protocol Compliance and Supplementation

All 20 participants completed both conditions of the study with full protocol adherence. No adverse events (gastrointestinal distress, allergic reactions, or injury) were reported during the study period. Blinding integrity was confirmed post-study: only 6 of 20 participants (30%) correctly identified their supplement condition, a rate not significantly different from chance (binomial test, $p = 0.41$). Pre-match blood glucose and physical performance (HSMP completion rate) did not differ between conditions ($p > 0.05$), confirming comparable physiological starting states across both testing occasions. The simulated match protocol produced significant post-exercise elevations in CK and LDH in both conditions ($p < 0.001$), confirming adequate exercise-induced muscle damage as the mechanistic target of the recovery nutrition intervention.

Muscle Damage and Inflammatory Markers

CK activity at baseline was comparable between conditions (CHO+PRO: 128 +/- 24 U/L; CHO: 126 +/- 22 U/L; $p > 0.05$). Immediately post-match, CK was also comparable between conditions (CHO+PRO: 312 +/- 58 U/L; CHO: 318 +/- 61 U/L; $p > 0.05$), confirming that the match protocol produced equivalent muscle damage before supplement delivery. At 24 hours, CK was significantly lower in the CHO+PRO condition (342 +/- 68 vs. 498 +/- 82 U/L; $p < 0.001$; $d = 2.14$), and this difference was maintained at 48 hours (198 +/- 44 vs. 316 +/- 61 U/L; $p < 0.001$; $d = 2.25$) and 72 hours (142 +/- 28 vs. 196 +/- 38 U/L; $p < 0.001$; $d = 1.74$). LDH followed a similar pattern, with significantly lower values in CHO+PRO at 24 hours (284 +/- 52 vs. 396 +/- 64 U/L; $p < 0.001$; $d = 1.95$). IL-6 at 2 hours post-match was significantly lower under CHO+PRO (18.4 +/- 3.2 vs. 24.6 +/- 4.1 pg/mL; $p < 0.001$; $d = 1.72$), indicating attenuated acute inflammatory response. Full biomarker data are presented in Table 1 and Table 2.

Muscle Soreness and Repeated-Sprint Performance

DOMS at 24 hours was significantly lower in the CHO+PRO condition (4.1 +/- 0.9 vs. 5.8 +/- 1.1 on VAS; $p < 0.001$; $d = 1.70$), and at 48 hours (2.4 +/- 0.7 vs. 3.9 +/- 0.9; $p < 0.001$; $d = 1.85$). Repeated-sprint mean time at 24 hours was significantly faster under CHO+PRO (4.21 +/- 0.14 vs. 4.38 +/- 0.16 s; $p < 0.001$; $d = 1.15$). Sprint decrement was significantly lower in CHO+PRO (4.6 +/- 1.2 vs. 6.8 +/- 1.4%; $p < 0.001$; $d = 1.71$), indicating better maintenance of sprint speed across the 6-sprint sequence. The between-condition difference in sprint time progressively increased from sprint 1 (non-significant) to sprint 6 (CHO+PRO: 4.31 +/- 0.16 vs. CHO: 4.64 +/- 0.19 s; $p < 0.001$; $d = 1.88$), consistent with the CHO+PRO condition's superior preservation of neuromuscular function under repeated sprint fatigue.

Table 1. Key recovery outcomes: muscle damage, inflammatory, and performance variables at selected time points (Mean +/- SD)..

Marker	CHO+PRO	CHO Only	Delta	d	p-value
CK at 24h (U/L)	342 +/- 68	498 +/- 82	-156	2.14	< 0.001
CK at 48h (U/L)	198 +/- 44	316 +/- 61	-118	2.25	< 0.001
LDH at 24h (U/L)	284 +/- 52	396 +/- 64	-112	1.95	< 0.001
IL-6 at 2h (pg/mL)	18.4 +/- 3.2	24.6 +/- 4.1	-6.2	1.72	< 0.001
DOMS at 24h (0-10)	4.1 +/- 0.9	5.8 +/- 1.1	-1.7	1.70	< 0.001
DOMS at 48h (0-10)	2.4 +/- 0.7	3.9 +/- 0.9	-1.5	1.85	< 0.001
Mean sprint time 24h (s)	4.21 +/- 0.14	4.38 +/- 0.16	-0.17	1.15	< 0.001

Note. *CHO+PRO = Carbohydrate-Protein co-ingestion; CHO = Carbohydrate-only; CK = Creatine Kinase; LDH = Lactate Dehydrogenase; IL-6 = Interleukin-6; DOMS = Delayed-Onset Muscle Soreness (VAS 0-10); d = Cohen's d. All comparisons: paired-samples t-test.*

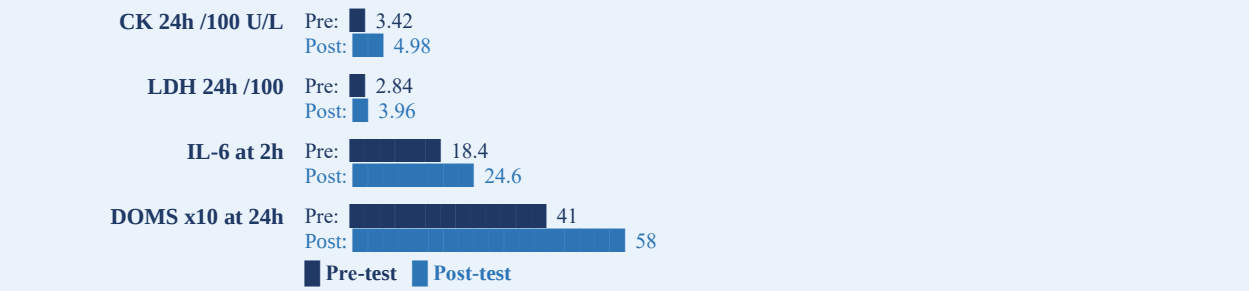

Figure 1. Comparison of muscle damage and inflammatory markers between CHO+PRO and CHO conditions at 24 hours post-match. Dark blue = CHO+PRO; Light blue = CHO. All between-condition differences p < 0.001.

Table 2. Temporal profile of serum creatine kinase (CK) activity across the 72-hour recovery period (Mean +/- SD; U/L).

Time Point	CHO+PRO CK (U/L)	CHO CK (U/L)	Difference	p
Baseline (pre-match)	128 +/- 24	126 +/- 22	2	> 0.05
Immediately post-match	312 +/- 58	318 +/- 61	6	> 0.05
24 hours post-match	342 +/- 68	498 +/- 82	-156	< 0.001
48 hours post-match	198 +/- 44	316 +/- 61	-118	< 0.001
72 hours post-match	142 +/- 28	196 +/- 38	-54	< 0.001

Note. *CK = Creatine Kinase. Conditions were comparable at baseline and immediately post-match (p > 0.05 for both). Significant between-condition differences emerged at 24 hours and persisted at 48 and 72 hours (all p < 0.001). The accelerated CK clearance under CHO+PRO reflects enhanced myofibrillar repair and reduced secondary muscle damage.*

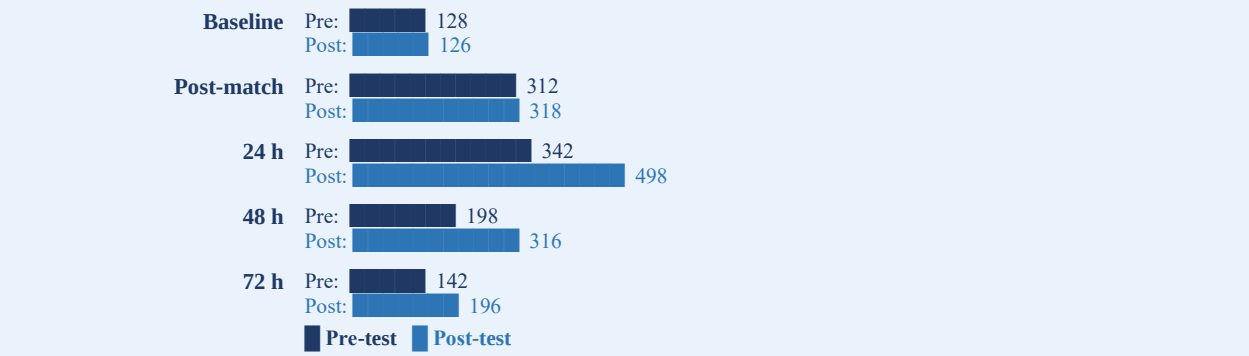

Figure 2. Temporal profile of serum CK activity across the 72-hour recovery period for CHO+PRO (dark blue) and CHO (light blue) conditions.

Table 3. Individual and mean repeated-sprint times (s) during the 6 x 30-m test at 24 hours post-match (Mean +/- SD).

Sprint	CHO+PRO Time (s)	CHO Time (s)	Difference	p
Sprint 1	4.08 +/- 0.12	4.09 +/- 0.13	-0.01	> 0.05
Sprint 2	4.14 +/- 0.13	4.18 +/- 0.14	-0.04	> 0.05

Sprint 3	4.19 +/- 0.14	4.31 +/- 0.15	-0.12	0.01
Sprint 4	4.22 +/- 0.14	4.41 +/- 0.16	-0.19	< 0.001
Sprint 5	4.28 +/- 0.15	4.52 +/- 0.17	-0.24	< 0.001
Sprint 6	4.31 +/- 0.16	4.64 +/- 0.19	-0.33	< 0.001
Mean (all 6)	4.21 +/- 0.14	4.38 +/- 0.16	-0.17	< 0.001

Note. *CHO+PRO = Carbohydrate-Protein co-ingestion; CHO = Carbohydrate-only. The progressive widening of the between-condition difference from sprint 3 onward reflects the superior preservation of neuromuscular function under CHO+PRO as cumulative fatigue develops across the sprint sequence.*

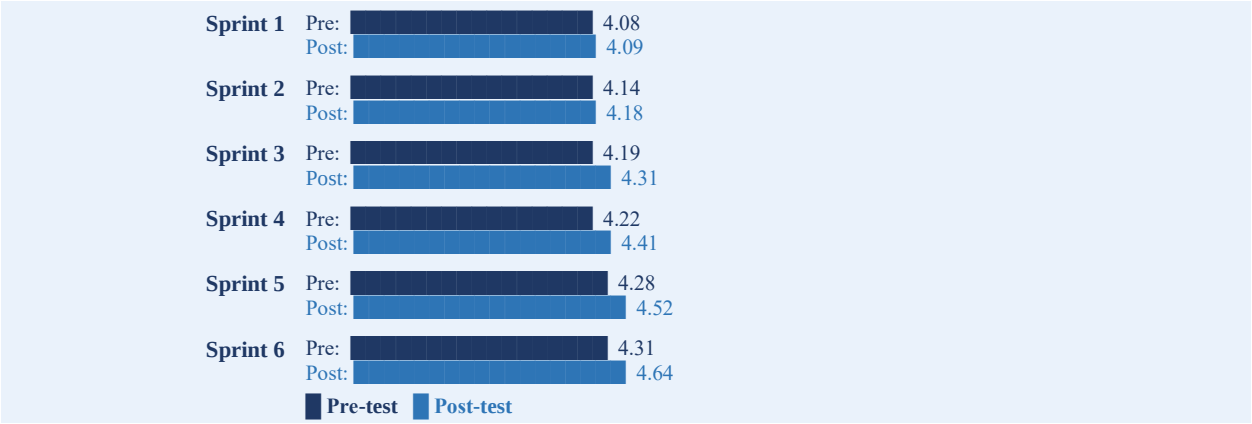

Figure 3. Individual sprint times across the 6 x 30-m repeated-sprint test at 24 hours post-match. Dark blue = CHO+PRO; Light blue = CHO. Note the progressive divergence from sprint 3 onwards

Discussion

Principal Findings

The principal findings of this randomised double-blind crossover trial are that acute CHO+PRO co-ingestion, delivered immediately and 2 hours post-match, produced significantly lower serum CK (d = 2.14) and LDH (d = 1.95) at 24 hours, attenuated IL-6 response (d = 1.72) at 2 hours, reduced DOMS at 24 and 48 hours, and significantly better repeated-sprint mean time (d = 1.15) and sprint decrement (d = 1.71) at 24 hours compared to isocaloric CHO supplementation in elite Iraqi handball players. These findings provide the first controlled evidence of CHO+PRO co-ingestion efficacy in a handball-specific context and extend the recovery nutrition literature to an Iraqi population whose nutritional practices have not previously been characterised.

Mechanisms of Muscle Damage Attenuation

The significantly lower post-match CK values observed under CHO+PRO compared to isocaloric CHO at 24 and 48 hours suggest a genuine attenuation of secondary muscle damage - the inflammatory-mediated worsening of initial mechanical damage that occurs in the 12-48 hours following intense exercise - rather than merely enhanced CK clearance from the circulation. The mechanisms underlying this protection are likely multiple. Protein-derived essential amino acids - particularly leucine, which constituted approximately 2.8 g per supplement dose in the present study - stimulate mTORC1-mediated muscle protein synthesis, initiating myofibrillar repair processes that reduce the pool of structurally compromised contractile proteins available for inflammatory-mediated degradation (Phillips & Van Loon, 2011). Additionally, enhanced insulin secretion stimulated by the combined carbohydrate and protein dose in the CHO+PRO condition suppresses the catabolic signalling of exercise-induced cortisol elevation, reducing net protein degradation in the recovery period.

The significantly lower IL-6 response at 2 hours post-match under CHO+PRO (18.4 vs. 24.6 pg/mL; d = 1.72) is particularly noteworthy, as IL-6 is both a direct mediator of the acute phase inflammatory response and a proximal signal for subsequent inflammatory cascades - including NFkB activation, prostaglandin synthesis, and neutrophil infiltration - that amplify secondary muscle damage. By attenuating the early IL-6 response, CHO+PRO supplementation may interrupt this inflammatory cascade at an early stage, limiting the downstream inflammatory tissue damage that contributes to the CK elevation and DOMS observed at 24-48 hours. The specific anti-inflammatory effects of glutamine - present in whey protein at approximately 5% of total amino acid content - and the immunomodulatory properties of leucine-stimulated satellite cell activation may additionally contribute to this attenuated cytokine response.

Repeated-Sprint Recovery and Performance Implications

The significantly better repeated-sprint performance at 24 hours under CHO+PRO (mean time: 4.21 vs. 4.38 s; d = 1.15) represents the most practically significant finding of the present study from a performance standpoint. The progressive widening of the between-condition performance difference from sprint 3 onwards - reaching a large effect at sprint 6 (d = 1.88) - indicates that the CHO+PRO condition's advantage manifests most clearly under conditions of accumulated sprint fatigue, where the preservation of neuromuscular function in the recovery period translates most directly to maintained explosive performance capacity. This pattern is consistent with the hypothesis that CHO+PRO's primary performance benefit operates through enhanced preservation of excitation-contraction coupling efficiency in Type II muscle fibres - the fibres most susceptible to exercise-induced damage and most critical for repeated sprint performance - rather than through differences in substrate availability per se.

In the context of elite handball competition, where matches are separated by as little as 24-48 hours during international championships and tournaments, the ability to recover sprint performance within 24 hours of a competitive match is of direct performance relevance. A mean sprint time advantage of 0.17 seconds per sprint across 6 maximal efforts corresponds to a performance difference of approximately 1-1.5 metres per sprint at match-relevant sprint velocities - a margin that may be decisive in the tight technical and tactical spaces characteristic of elite handball play. The implementation of CHO+PRO recovery supplementation within the nutritional routines of Iraqi Handball Premier League clubs could therefore provide a meaningful and practical competitive advantage, particularly during congested fixture periods where recovery speed is the primary limiting factor in successive match performance.

Practical Applications for Iraqi Handball

The practical implementation of the CHO+PRO supplementation protocol evaluated in the present study is straightforward and cost-effective within the context of Iraqi professional handball club environments. The required post-match dose (0.8 g/kg CHO + 0.4 g/kg PRO) is achievable through a combination of commercial whey protein supplements and carbohydrate sports beverages or conventional food sources - including dates (a readily available and culturally familiar Iraqi food providing approximately 70 g carbohydrate per 100 g serving), low-fat dairy products, and legume-based foods. The double supplementation timing used in the present study - immediately post-match and at 2 hours post-match - coincides naturally with the post-match nutritional opportunity that already exists within most professional handball clubs' post-game routines, requiring only a systematic and evidence-based structuring of supplement delivery rather than a fundamental change to existing practices.

Sports nutrition education targeting both players and coaching staff is a prerequisite for successful implementation of post-match recovery nutrition protocols in the Iraqi handball context. Players must understand the physiological rationale for the post-match nutritional window, the specific targets for carbohydrate and protein delivery, and the evidence base for CHO+PRO superiority over carbohydrate-

only supplementation. Coaches and club administrators must recognise post-match nutrition as an integral component of performance preparation - equivalent in importance to tactical video analysis and physical recovery modalities - rather than an optional lifestyle choice. The appointment of qualified registered dietitians to support nutritional implementation within Iraqi Handball Premier League clubs would substantially accelerate the translation of the present findings into routine practice.

Limitations and Future Research

Several limitations of the present study should be acknowledged. First, the sample size of 20 players, while adequate to detect the large effect sizes observed in the present study, may be insufficient to detect smaller interactions between supplement condition and playing position or training status. Future research with larger samples should examine whether goalkeepers, backs, wings, and pivots respond differently to CHO+PRO supplementation given their distinct physical loading profiles. Second, the simulated match protocol, while based on GPS match data, cannot replicate the full psychological, tactical, and emotional intensity of competitive handball, which may amplify or modify the physiological stress response and thus the magnitude of nutritional intervention effects. Third, the study examined a single supplementation protocol; future dose-response research should evaluate whether lower protein doses (e.g., 0.2 g/kg) or alternative protein sources (e.g., plant-based proteins more accessible in the Iraqi market) produce comparable recovery benefits.

Conclusions

This randomised double-blind crossover trial provides strong evidence that acute CHO+PRO co-ingestion, administered immediately and at 2 hours post-match, significantly attenuates muscle damage markers, inflammatory cytokine response, and delayed-onset muscle soreness compared to isocaloric carbohydrate-only supplementation in elite Iraqi handball players. The CHO+PRO strategy also significantly preserved 24-hour repeated-sprint capacity, with the performance advantage amplifying progressively across the sprint sequence. These findings establish CHO+PRO co-ingestion as the superior post-match nutritional recovery strategy for elite handball players, with effect sizes large enough to be of substantial practical significance in the context of congested competitive calendars where 24-hour recovery is the performance-limiting factor.

The protocol evaluated in this study is practically implementable within the existing post-match nutritional routines of Iraqi Handball Premier League clubs at modest cost, using commercially available whey protein and carbohydrate supplements or culturally appropriate whole food combinations. Clubs and national team management are encouraged to integrate the present findings into their nutritional support frameworks, supported by qualified sports dietitian input to ensure adherence, individualisation, and long-term compliance. Future research should examine the cumulative effects of sustained CHO+PRO recovery nutrition across a full competitive season, the optimal protein source and dose for Iraqi handball populations, and the interaction between recovery nutrition and other recovery modalities including sleep extension and cold-water immersion.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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