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Effect of Nutrient Timing and an Integrated Rehabilitation Intervention on Muscle Recovery, Physical Performance, and Body Composition Among Bodybuilders: An Experimental Study of a Sample of Athletes in Janzour

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Abstract

Background: Nutrient timing and rehabilitation have each been studied in resistance-trained athletes, but few studies have examined them together in bodybuilders, particularly in Arab settings. **Objective:** To test whether a program combining precisely timed nutrition with preventive rehabilitation improves muscle recovery, physical performance and body composition in bodybuilders in Janzour, Libya. **Methods:** Thirty male bodybuilders aged 20–35 years were randomly assigned to an experimental or a control group (15 each) in a two-group pre-test/post-test design lasting 10 weeks. The outcomes were body composition (InBody 770), one-repetition maximum (1RM) in the bench press, squat and deadlift, muscular endurance, delayed-onset muscle soreness (DOMS, visual analog scale), shoulder and knee range of motion (ROM, goniometer) and blood lactate (Biosen C-Line). **Results:** The experimental group did better than the control group on nine of the ten variables ($p < 0.05$; Cohen's $d = 0.87–2.70$). Knee ROM did not differ significantly in the direct comparison ($p = 0.053$); it was significant in ANCOVA ($p = 0.034$) but not after Bonferroni correction ($\alpha = 0.005$). MANCOVA showed a significant multivariate effect (Wilks' $\Lambda = 0.126$, $p < 0.001$). **Conclusion:** The integrated program improved body composition, physical performance and recovery indicators. Because it was a multicomponent package, the effects cannot be credited to nutrient timing alone. Timed nutrition combined with preventive rehabilitation, and sports-nutrition specialists in gyms, are recommended.

Keywords: nutrient timing; rehabilitation; muscle recovery; physical performance; bodybuilding; lactate; DOMS

1. Introduction

Bodybuilding depends on three things working together: resistance training, a well-planned diet, and movement rehabilitation that lets the athlete keep training without injury. Nutrient timing, meaning the planned intake of protein and carbohydrate around training, is one way to support recovery and adaptation (Kerksick et al., 2017). The International Society of Sports Nutrition suggests spreading 20–40 g of good-quality protein over the day at intervals of about three to four hours (Kerksick et al., 2017; Jäger et al., 2017). The evidence is not one-sided, though. Meta-analyses suggest that much of the apparent benefit of timing disappears once total daily protein is accounted for (Schoenfeld et al., 2013; Aragon & Schoenfeld, 2013), which is why timing is best studied inside a complete nutritional plan rather than on its own. More recent reviews report that protein supplementation lowers markers of muscle damage and speeds the return of strength (Pearson et al., 2023), and that protein before exercise, after exercise and before sleep is among the most effective patterns for gaining muscle and strength (Zhou et al., 2023; Lak et al., 2024).

Nutrition also matters during rehabilitation, where it appears to speed functional recovery, although standard field protocols are still missing (Giraldo-Vallejo et al., 2023). Nutritional periodization is likewise rarely applied outside elite sport, and even less in strength sports (Morton et al., 2025). In local gyms, training and diet usually follow the coach's experience, preventive rehabilitation is largely absent, and injury or fatigue is dealt with only after it appears. The Arabic literature on bodybuilders consists mostly of descriptive studies of nutritional and health awareness (Waddak et al., 2023; Al-Kasasbeh et al., 2023; Haddal & La'our, 2026) and a few small experimental studies that looked only at maximal strength (Izzeddine et al., 2024; Zidan & Barqiya, 2025). Foreign trials have tested recovery methods,

supplements or the mode of supervision (Trybulski et al., 2025; Wei et al., 2025; Crupnik et al., 2025; Tao et al., 2025; Gavanda et al., 2025). To our knowledge, none of them combined precisely timed nutrition with preventive rehabilitation in a single program, and none was carried out in a Libyan setting. This study was designed to fill that gap.

Objective. The aim was to measure how an integrated program of timed nutrition and preventive rehabilitation affects (1) body composition (body fat percentage and muscle mass), (2) physical performance (1RM and muscular endurance) and (3) muscle recovery (DOMS, ROM and blood lactate) in bodybuilders at gyms in Janzour.

Hypotheses. The experimental group was expected to show better post-intervention results than the control group in (H1) body composition, (H2) physical performance and (H3) recovery indicators, and overall across the three domains.

2. Methods

2.1 Design and participants

A randomized two-group pre-test/post-test design with a control group was used (Schulz et al., 2010). The population was all 45 male bodybuilders aged 20–35 years registered at two gyms in Janzour municipality, including Sultan Hall. Ten of them formed a pilot sample (26–29 June) and were left out of the main study, and two more did not meet the inclusion criteria, which left 33 eligible athletes (Figure 1). Thirty were randomly assigned to the experimental group (n = 15) or the control group (n = 15), and the remaining three were kept in reserve in case of dropout. Nobody dropped out, adherence was at least 85% of sessions in both groups, and all 30 athletes were analyzed.

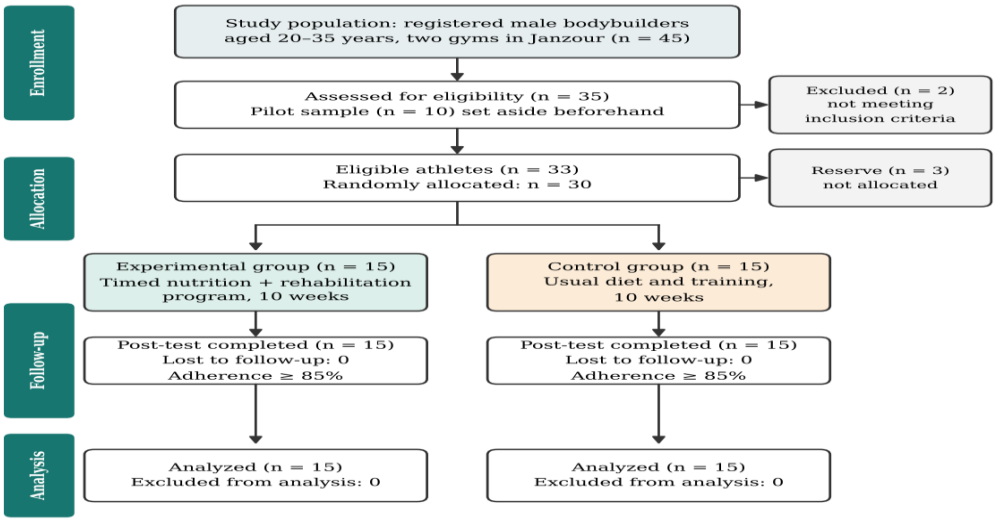


Figure 1. CONSORT flow diagram of participants (Schulz et al., 2010).

The sample size was calculated in G*Power 3.1 (two-tailed independent t-test, $\alpha = 0.05$, power = 0.80; Faul et al., 2007). Assuming a very large effect ($d = 1.1$), 15 athletes per group were enough (actual power ≈ 0.83). A conventional large effect ($d = 0.8$) would have needed 26 per group, more than the available population could supply, and this is acknowledged as a limitation.

Inclusion criteria: men aged 20–35 with at least six months of regular bodybuilding training at the study gyms, free of current muscle or joint injury and of disabling chronic disease, who gave signed informed consent and took no doping agents or anabolic hormones during the study. *Exclusion criteria:* acute injury or surgery in the previous six months, disabling chronic disease, attendance below 85%, undeclared doping or hormonal supplements, or withdrawal from the study.

2.2 Measurements

Body fat percentage and muscle mass were measured with an InBody 770 (multi-frequency bioelectrical impedance, eight electrodes; reported correlation with DXA r = 0.95). Maximal strength was the one-repetition maximum (1RM) in the bench press, squat and deadlift, and muscular endurance was the maximum number of repetitions. Soreness (DOMS) was rated on a visual analog scale (VAS), shoulder and knee range of motion were measured with a goniometer, and blood lactate was taken at 3 minutes

with a Biosen C-Line analyzer (range 0.5–40 mmol/L, CV ≤ 1.5%). Testing conditions were the same for every session: 08:00–10:00, fasting for at least 8 h, 22–24 °C, 40–50% humidity, 24 h of rest beforehand, the same calibrated devices and the same examiner. The measurements were taken by an independent examiner (single-blind), and the statistical analyst did not know which group was which.

2.3 Intervention

The experimental group followed an integrated 10-week program that paired a nutritional periodization model (Morton et al., 2025) with progressive-loading rehabilitation. Table 1 gives the full specification; in brief:

- **Nutrition:** energy from the Mifflin-St Jeor equation × activity factor plus a ~10% surplus; protein 1.6–2.2 g/kg/day across 4–5 meals at 3–4-hour intervals; 20–40 g protein within 30–60 minutes before and after training; carbohydrate 5–7 g/kg (emphasis on peri-exercise meals); fat 0.8–1.0 g/kg; slowly digested (casein) protein before sleep; fluids 35–40 mL/kg/day.
- **Training:** 4–5 split-routine sessions per week in three mesocycles: foundation/volume (weeks 1–3), intensification (weeks 4–7), and an advanced phase using FST-7 (weeks 8–10).
- **Rehabilitation and prevention:** dynamic warm-up and 10–15 minutes of joint mobility before training; post-session stretching and foam-roller self-massage; corrective exercises three times weekly (2–3 sets × 12–15 repetitions) for the shoulder and lower back, with load increased 5–10% per week at RPE ≤ 7/10.

Table 1. Summary of the experimental program

Component	Specification
Energy	Mifflin-St Jeor × activity factor, ~10% surplus
Protein	1.6–2.2 g/kg/day; 4–5 meals every 3–4 h; 20–40 g within 30–60 min before and after training; casein before sleep
Carbohydrate / fat	5–7 g/kg (peri-exercise emphasis) / 0.8–1.0 g/kg
Hydration	35–40 mL/kg/day plus replacement of training losses
Training	4–5 split sessions/week; weeks 1–3 foundation, 4–7 intensification, 8–10 advanced (FST-7)
Rehabilitation	Dynamic warm-up and 10–15 min mobility; post-session stretching and foam rolling; corrective exercises 3×/week (2–3 × 12–15) for shoulder and lower back; +5–10% load/week at RPE ≤ 7/10
Control group	Usual diet and training; weekly attendance log; program offered after the study

The control group continued its usual diet and training without specific nutritional or rehabilitative intervention; attendance and activity were logged weekly. The program was offered to controls afterward (wait-list design). The timeline was: pre-test 3–5 July (followed by random assignment), intervention 6 July–14 September, and post-test 15–18 September.

2.4 Statistical analysis

Descriptive statistics (M ± SD); independent t-tests for baseline equivalence and post-test comparison (with 95% CIs); paired t-tests for within-group change; MANCOVA (group effect on all ten outcomes, adjusted for pre-test values); and ANCOVA per outcome with pre-test as covariate. Because ten outcomes were tested, ANCOVA results were also compared against a Bonferroni-corrected level ($0.05 \div 10 = 0.005$) as a sensitivity analysis. Effect sizes were Cohen's d and partial η^2; $\alpha = 0.05$.

2.5 Ethics

The study followed the Declaration of Helsinki (World Medical Association, 2024): signed informed consent, independent ethical review, stopping of training for abnormal symptoms, data confidentiality,

disclosure of funding and conflicts of interest, and fair distribution of benefits through the wait-list offer to controls.

3. Results

3.1 Sample description and baseline equivalence

Sample description. The final sample comprised 30 male bodybuilders (15 per group) aged 20–35 years (overall mean age 26.8 ± 3.8 years; height 176.1 ± 5.0 cm; body mass 82.2 ± 7.0 kg; muscle mass 42.0 ± 3.2%; body fat 18.9 ± 4.0%; training age 4.3 ± 1.7 years), all with at least six months of regular training at the two study gyms and free of injury, disabling chronic disease and doping agents. The experimental and control groups were comparable in mean age (26.4 ± 3.8 vs 27.1 ± 4.0 years), height (175.8 ± 5.2 vs 176.4 ± 4.9 cm), body mass (82.6 ± 7.4 vs 81.9 ± 6.9 kg), body fat (18.7 ± 4.2% vs 19.2 ± 3.9%), and training age (4.2 ± 1.6 vs 4.5 ± 1.8 years), and in strength, endurance and recovery indicators (Table 2).

The groups did not differ at baseline on any variable ($p = 0.627–0.857$; all $|d| \leq 0.18$; Table 2), confirming group equivalence. Coefficients of variation were below 30% except for training age (38.1%), reflecting natural variability in training experience.

Table 2. Baseline characteristics (independent-samples t-test, df = 28)

Variable	Experimental (n = 15)	Control (n = 15)	t	p	CV %
Age (years)	26.4 ± 3.8	27.1 ± 4.0	0.49	0.627	14.4
Height (cm)	175.8 ± 5.2	176.4 ± 4.9	0.33	0.747	3.0
Body mass (kg)	82.6 ± 7.4	81.9 ± 6.9	0.27	0.791	9.0
Muscle mass (%)	42.3 ± 3.1	41.8 ± 3.4	0.42	0.677	7.3
Body fat (%)	18.7 ± 4.2	19.2 ± 3.9	0.34	0.738	22.5
Training age (years)	4.2 ± 1.6	4.5 ± 1.8	0.48	0.633	38.1
1RM bench press (kg)	102.4 ± 12.1	100.8 ± 11.7	0.37	0.716	11.8
1RM squat (kg)	145.6 ± 18.3	143.9 ± 17.8	0.26	0.798	12.6
1RM deadlift (kg)	168.3 ± 20.5	166.7 ± 19.9	0.22	0.830	12.2
Muscular endurance (reps)	18.4 ± 3.2	18.1 ± 3.4	0.25	0.805	17.4
DOMS (VAS score)	6.8 ± 1.4	6.9 ± 1.3	0.20	0.841	20.6
Shoulder ROM (°)	172.3 ± 5.8	171.9 ± 6.2	0.18	0.857	3.4
Knee ROM (°)	138.4 ± 6.7	139.1 ± 6.4	0.29	0.772	4.8
Blood lactate, 3 min (mmol/L)	11.2 ± 1.8	11.4 ± 1.7	0.31	0.757	16.1

Values are M ± SD. CV % = coefficient of variation of the experimental group; the high CV for training age reflects natural variability in years of experience.

3.2 Within-group changes

In the experimental group, all ten variables improved significantly from pre- to post-test ($p < 0.001$; $d = 0.81–3.25$). In the control group, only the bench press ($p = 0.047$), the squat ($p = 0.037$) and DOMS ($p = 0.009$) changed significantly, and by small amounts (3.3%, 3.0% and 17.4%). These small changes

most likely reflect continued training, familiarity with the tests and the repeated-bout effect on soreness (Table 3).

Table 3. Pre- to post-test changes in each group (paired t-test, df = 14)

Variable	Exp. pre → post	Δ %	d	p	Ctrl. pre → post	Δ %	p
Body composition							
Muscle mass (%)	42.3 → 44.8	+5.9	0.85	<0.001	41.8 → 42.0	+0.5	0.325
Body fat (%)	18.7 → 15.6	−16.6	0.81	<0.001	19.2 → 18.8	−2.1	0.235
Physical performance							
1RM bench press (kg)	102.4 → 115.2	+12.5	1.09	<0.001	100.8 → 104.1	+3.3	0.047
1RM squat (kg)	145.6 → 164.3	+12.8	1.06	<0.001	143.9 → 148.2	+3.0	0.037
1RM deadlift (kg)	168.3 → 188.5	+12.0	1.02	<0.001	166.7 → 171.8	+3.1	0.055
Muscular endurance (reps)	18.4 → 24.8	+34.8	1.88	<0.001	18.1 → 19.4	+7.2	0.092
Muscle recovery							
DOMS (VAS)	6.8 → 3.1	−54.4	3.25	<0.001	6.9 → 5.7	−17.4	0.009
Shoulder ROM (°)	172.3 → 178.8	+3.8	1.32	<0.001	171.9 → 173.2	+0.8	0.189
Knee ROM (°)	138.4 → 144.5	+4.4	1.05	<0.001	139.1 → 140.5	+1.0	0.235
Blood lactate (mmol/L)	11.2 → 8.2	−26.8	1.91	<0.001	11.4 → 10.8	−5.3	0.128

Exp. = experimental; Ctrl. = control. Δ % = percentage change from pre-test (sign shows direction of change); d = mean difference ÷ pooled SD of pre- and post-test.

3.3 Between-group comparison at post-test

At post-test the experimental group was significantly better on nine of the ten variables ($p < 0.05$), with large effects ($d = 0.87–2.70$). Knee ROM was the exception ($p = 0.053$; $d = 0.74$; 95% CI [−0.06, 8.06]). The largest effects were for DOMS ($d = 2.70$), blood lactate ($d = 1.85$) and muscular endurance ($d = 1.56$) (Table 4, Figure 2).

Table 4. Post-test between-group comparison (independent t-test, df = 28) and covariate-adjusted ANCOVA (df = 1, 27)

Variable	Exp. M ± SD	Ctrl. M ± SD	t	p	d	95% CI	F	ANCOVA p	η²p
Muscle mass (%)	44.8 ± 2.8	42.0 ± 3.3	2.51	0.018	0.91	[0.51, 5.09]	15.5	<0.001	0.36
Body fat (%)	15.6 ± 3.4	18.8 ± 3.7	2.47	0.020	0.90	[−5.86, −0.54]	18.1	<0.001	0.40
1RM bench press (kg)	115.2 ± 11.3	104.1 ± 11.5	2.67	0.013	0.97	[2.57, 19.63]	11.6	0.002	0.30
1RM squat (kg)	164.3 ± 16.8	148.2 ± 17.4	2.58	0.015	0.94	[3.31, 28.89]	13.8	<0.001	0.34
1RM deadlift (kg)	188.5 ± 18.9	171.8 ± 19.6	2.38	0.025	0.87	[2.30, 31.10]	12.2	0.002	0.31
Muscular endurance (reps)	24.8 ± 3.6	19.4 ± 3.3	4.28	<0.001	1.56	[2.82, 7.98]	49.6	<0.001	0.65
DOMS (VAS)	3.1 ± 0.8	5.7 ± 1.1	7.40	<0.001	2.70	[−3.32, −1.88]	69.8	<0.001	0.72
Shoulder ROM (°)	178.8 ± 3.9	173.2 ± 5.9	3.07	0.005	1.12	[1.86, 9.34]	16.7	<0.001	0.38
Knee ROM (°)	144.5 ± 4.8	140.5 ± 6.0	2.02	0.053	0.74	[−0.06, 8.06]	5.0	0.034*	0.16
Blood lactate (mmol/L)	8.2 ± 1.3	10.8 ± 1.5	5.07	<0.001	1.85	[−3.65, −1.55]	29.6	<0.001	0.52

*95% CI = difference in means (experimental − control); η²p = partial eta squared. *Not significant after Bonferroni correction (α = 0.005); all other ANCOVA effects survive it (largest p = 0.002). The pre-test covariate was significant for every outcome (p < 0.001).*

Figure 2. (a) Percentage change from pre-test in each group, in the favorable direction. (b) Between-group effect sizes (Cohen's d) at post-test; the gold bar marks the non-significant difference (knee ROM).

3.4 Multivariate and covariate-adjusted analyses

Table 5. MANCOVA: group effect on the ten outcomes, adjusted for pre-test values

Test	Value	F	df (hyp, error)	p	η²
Pillai's trace	0.874	12.49	10, 18	<0.001	0.874
Wilks' lambda	0.126	12.49	10, 18	<0.001	0.874
Hotelling's trace	6.937	12.49	10, 18	<0.001	0.874
Roy's largest root	6.937	12.49	10, 18	<0.001	0.874

η² = multivariate eta squared (1 − Λ).

After adjusting for the pre-test values, MANCOVA showed a significant multivariate effect of group across the ten outcomes on all four multivariate tests (Table 5): Pillai's trace = 0.874; Wilks' Λ = 0.126; Hotelling's trace = 6.937; Roy's largest root = 6.937; $F(10, 18) = 12.49$, $p < 0.001$; multivariate $\eta^2 = 0.874$. Ten outcomes in 30 athletes is a thin ratio, so the multivariate values are read together with the univariate results. In ANCOVA the group effect was significant for every variable ($\eta^2p = 0.16$–0.72, all large). Knee ROM ($p = 0.034$) reached significance only because adjusting for the pre-test reduced the error variance, and it did not survive Bonferroni correction, whereas the other nine did (Table 4).

3.5 Hypothesis testing

H1 (body composition) and H2 (physical performance) were fully supported. H3 (recovery) was supported in part: DOMS, shoulder ROM and lactate improved significantly, but knee ROM did not differ significantly in the direct comparison. The general hypothesis is therefore accepted with that reservation.

4. Discussion

4.1 Body composition

Muscle mass rose by 5.9% and body fat fell by 16.6% in the experimental group, while the controls showed no significant change. These results fit with trials in which timed high-protein feeding, and protein before exercise, after exercise and before sleep, improved body composition in trained people (Lak et al., 2024; Zhou et al., 2023). They also agree with ISSN advice on 20–40 g doses every 3–4 hours and pre-sleep protein (Kerksick et al., 2017; Jäger et al., 2017), and the intake used here (1.6–2.2 g/kg/day) covers the level of about 1.6 g/kg/day beyond which extra protein adds little (Morton et al., 2018). Several parts of the program probably contributed: evenly spread protein, a modest energy surplus, carbohydrate around training, a protein meal before sleep, and direct supervision, which has been linked to larger gains in fat-free mass and better adherence (Gavanda et al., 2025; Buechel et al., 2025). Local reports of unbalanced diets and a lack of nutrition specialists in gyms (Waddak et al., 2023) suggest that the program met a real need.

One caveat matters. Meta-analyses attribute most of the benefit of timing to total daily protein and energy (Schoenfeld et al., 2013; Aragon & Schoenfeld, 2013). Because this program bundled timing, quantity, an energy surplus and rehabilitation, and the control diet was not controlled, the results reflect the whole program and cannot be credited to timing alone.

4.2 Physical performance

Strength rose by 12.0–12.8% across the three lifts and endurance by 34.8%, against roughly 3% and 7.2% in the controls. This agrees with experimental work on structured programs in bodybuilders (Izzeddine et al., 2024; Zidan & Barqiya, 2025), supervised training (Gavanda et al., 2025) and nutritional support (Tao et al., 2025). Part of the strength gain certainly comes from the progressive training program itself, which the control group did not follow, and the small improvements in the controls probably reflect their regular training and growing familiarity with the tests. The lower lactate and better recovery may help explain the gain in endurance, but this link was not tested statistically and should be taken as a hypothesis.

4.3 Muscle recovery

DOMS fell by 54.4% (17.4% in controls), shoulder ROM improved by 3.8% and lactate fell by 26.8%. This is in line with evidence that protein supplementation lowers markers of muscle damage and speeds strength recovery (Pearson et al., 2023; Ramos Junior et al., 2025), that nutrition alongside rehabilitation speeds functional recovery (Giraldo-Vallejo et al., 2023), and that structured recovery and rehabilitation methods help (Trybulski et al., 2025; Wei et al., 2025; Crupnik et al., 2025). Foam rolling and similar techniques, which were part of this protocol, modestly improve range of motion and reduce soreness (Wiewelhove et al., 2019; Dupuy et al., 2018). The likely contributors are post-exercise stretching and self-massage, corrective exercises, protein around training, hydration and gradual load progression. DOMS is a subjective rating, and the athletes could not be blinded to their group, so the difference may be somewhat inflated. The objective measures (lactate and goniometry), taken by an independent examiner, partly offset this concern.

4.4 Knee range of motion

The knee ROM difference (4.0°; $p = 0.053$; $d = 0.74$) was not significant, and it did not survive Bonferroni correction in the ANCOVA. Several explanations are possible. The knee has less room to improve than the shoulder and lower back, where the corrective work was concentrated, and its pre-test value (138.4°) was already high. Ten weeks may also be too short, goniometer error of a few degrees is similar to the difference observed, and with 15 athletes per group the power is limited. The medium-to-large effect, with a confidence interval that only just includes zero, points to a trend that needs confirming in larger samples.

4.5 Limitations

Several limitations should be kept in mind. First, diet outside the supervised setting could not be fully controlled, and the control group's diet was not controlled at all. Second, some measures, such as DOMS and food records, are self-reported. Third, because the program was a bundle, the effects cannot be assigned to any single component. Fourth, the sample is small, and the sample-size calculation assumed a very large effect (d = 1.1). Fifth, the ratio of outcomes to participants in the MANCOVA is limited, and testing several outcomes raises the risk of type I error. Sixth, 10 weeks is a short period. Finally, the participants were purposively selected men from two gyms in one city, which limits generalization.

4.6 Strengths and practical implications

The study has several strengths: random assignment with confirmed baseline equivalence, a control group, objective instruments used under standardized conditions, an independent single-blind examiner and a blinded analyst, complete follow-up, covariate-adjusted multivariate and univariate analyses, and open reporting of the non-significant knee ROM result together with its sensitivity analysis. In practice, the program can be run in a gym by a trained nutrition specialist or coach, because its components are cheap: meal scheduling, protein distribution, warm-up and mobility routines, foam rolling and corrective exercises. It offers a field model that other gyms in Libya could adapt.

5. Conclusions and Recommendations

In this randomized experimental study, an integrated program of precisely timed nutrition and rehabilitation led to significant improvements over usual practice in body composition (muscle mass +5.9%, body fat −16.6%), strength (+12.0–12.8%), muscular endurance (+34.8%), DOMS (−54.4%), shoulder ROM and blood lactate (−26.8%). The multivariate effect remained significant after adjusting for pre-test values. Knee ROM moved in the right direction, but the result was statistically inconclusive. Given the bundled design, small sample and short duration, the findings support the program as a whole and need replication.

Recommendations: (1) Bodybuilders' preparation programs should include timed protein distribution (4–5 meals, 20–40 g around training, casein before sleep). (2) Preventive rehabilitation (dynamic warm-up, mobility work, stretching, self-massage and corrective exercises) should be built into daily sessions. (3) Gyms should have sports-nutrition specialists, and coaches should be trained in nutrient timing and rehabilitation. (4) Objective monitoring tools (body-composition analysis, lactate, goniometry) should be used. (5) Future studies should be larger and longer (at least 6 months), include other strength sports, use conservative sample-size assumptions, and compare timing patterns while holding total protein and energy constant so that the effect of timing can be isolated.

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