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SUPERIOR MULTI-DOMAIN PERFORMANCE ENHANCEMENT THROUGH MYOFASCIAL TRAINING VERSUS CONVENTIONAL METHODS IN ADOLESCENT VOLLEYBALL ATHLETES : A RANDOMIZED CONTROLLED TRIAL

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Abstract
This study examined the effects of bio-tensegrity training, designed around fascial lines and integrated movement patterns, on the performance of adolescent volleyball players. A randomized controlled trial was conducted with forty-two male athletes, aged around sixteen, who were assigned either to a neuro-myofascial line (NML) training group or a control group (CON) following conventional resistance and plyometric training. Over ten weeks, the NML group performed structured sessions targeting fascial pathways through dynamic multi-planar exercises and recovery-focused self-myofascial release, while the CON group continued standard weightlifting and plyometric routines matched for frequency and volume. Statistical analyses showed that the NML group achieved consistently greater improvements across all measured domains. Range of motion increased significantly in major joints, with ankle plantar flexion (+25.6%) and external shoulder rotation (+16.8%) showing the largest changes. Strength and power also improved more in the NML group, with deadlift 4RM rising by 31.7% and lower-limb anaerobic power by 32.2%, compared to minimal gains in controls. Flexibility improved by over 50% in the sit-and-reach test, while speed, agility, and balance all showed clear superiority in the NML group. Volleyball-specific skills also benefitted, with spike and block jump heights rising more than 10%, serve velocity improving by 22.4%, and serve accuracy increasing by 39.1%. These findings strongly support the bio-tensegrity framework, which views the body as a connected tensegrity system rather than isolated muscle units. The study not only confirms the feasibility and safety of fascial-based training in youth athletes but also highlights adolescence as an ideal stage to introduce holistic approaches that build efficiency, resilience, and long-term performance potential in volleyball.
Keywords: Bio-tensegrity training; Adolescent athletes; Volleyball performance; Fascial system

INTRODUCTION

Volleyball is not a simple game. It pushes the body in many directions at once. Players need to jump high for spikes and blocks, move quickly from side to side to cover space, and twist their bodies with power when they serve or attack. These movements are repeated again and again in every match, and they place a heavy load on the whole system of the body. Most training programs for young players usually focus on classic methods like lifting weights or doing plyometric jumps. These drills build muscle strength, but they often look at the body in parts, not as a whole. In reality, volleyball performance is much more complex. It depends not only on strong muscles, but also on how well the body can transfer force, use stored elastic energy, and move several joints together in a smooth and coordinated way (Hernández-Martínez et al., 2023; Altundağ & Soylu, 2024).

To understand this better, researchers have introduced what is called the bio-tensegrity framework. This idea says that the body should not be seen as separate pieces but more like a connected structure. In this model, muscles, fascia, tendons, and bones are not independent. They rely on each other, keeping balance between tension and compression. The fascia, for example, forms long chains that connect different areas of the body. This network helps to move force from one region to another, to recycle energy, and to keep posture stable even during quick and powerful actions. If we accept this view, then training should not only build muscle but also involve the fascial system, because this may lead to more efficient performance and less chance of injury (Bordoni & Myers, 2020; Slater et al., 2024; Martínez-Aranda et al., 2024; Park et al., 2021).

This approach becomes even more important during the teenage years. At this time, the body is still growing, and the bones, muscles, and connective tissues are changing very fast. Fascia in young athletes is especially sensitive; it can become stiffer or more elastic depending on the kind of stress it receives (Slater et al., 2024). The nervous system is also very plastic during this period, which means that coordination patterns learned now may stay for life. Training programs that focus on fascial elasticity, on activating the body's sensors, and on improving the way force is transmitted through the system may give long-term benefits if introduced at this stage. Yet, in practice, many youth programs still stick to the traditional ways of training, focusing on resistance and plyometric work. There is still very little research that looks at full training programs designed with fascia and bio-tensegrity in mind for adolescent athletes (Wu et al., 2021; Ferreira et al., 2022).

Because of these reasons, it makes sense to ask if training based on bio-tensegrity can give better results across different areas such as strength, flexibility, agility, power, and skill. This is not only a question of science but also a question of practice. If such training proves effective, it could help coaches prepare young volleyball players in a way that improves performance while also protecting them during the years when their bodies are most vulnerable (Soylu et al., 2024; Altundağ & Soylu, 2024).

Problem Statement

The younger volleyball players are dependent on the efficiency of their entire body acting as an unified working system. Explosiveness in jumping, change of direction, and simultaneous coordination involving many joints are all required in the sport. Yet most of the training programs for this age group still depend on traditional resistance and plyometric methods that target muscles in isolation Although such methods can enhance strength or jump performance, they cannot prepare athletes precisely to the multiple demands that volleyball imposes on them because mobility, power, agility, and technical ability have to develop simultaneously (Hernandez-Martinez et al., 2023; Altundag and Soylu, 2024). This mismatch raises concern about whether current practices are sufficient for maximizing the athletic potential of adolescents.

The adolescent stage is a special adaptation period. Muscles, bones and fascia are very responsive to training during these years, and the parts of the body that may coordinate well during these years will continue doing so in adulthood (Slater et al., 2024 choose years. This makes it an ideal time to introduce approaches that target fascia, elastic energy use, and integrated movement. Bio-tensegrity-based training, which focuses on fascial lines and multiplanar loading, has been suggested as a promising alternative (Bordoni & Myers, 2020; Slater et al., 2024). However, the research in this field is still very limited. Much of the existing evidence comes from adult athletes, clinical or therapeutic populations, or narrow methods such as foam rolling and vibration rolling, which show short-term improvements in flexibility and recovery but do not represent comprehensive training (Ferreira et al., 2022; Wu et al., 2021; Michalak et al., 2024). Other studies demonstrate that fascial activation can enhance neuromuscular control and serve performance in older players (Soylu et al., 2024; Martínez-Aranda et al., 2024), yet there is little systematic evaluation of such approaches in adolescents.

To the best of the author, this study is the first to directly compare a 10-week neuro-myofascial line (NML) training intervention with a conventional training intervention in adolescent male volleyball players to fill this gap. The research was aimed at examining the potential effectiveness of NML training in increasing joint range of motion, maximum strength, jump height, flexibility, agility, and balance and volleyball-related measures, including the serve velocity, spikes and serve accuracy. The proposed study examines the viability and effectiveness of bio-tensegrity-structured conditioning in determining how it influences the multi-domain performance of volleyball players in adolescence years.

RESEARCH QUESTIONS

1. Does bio-tensegrity training lead to greater improvements in joint range of motion compared to conventional training methods among adolescent volleyball athletes?
2. Does bio-tensegrity training result in superior gains in muscular strength, power, and anaerobic performance relative to conventional methods?
3. How does bio-tensegrity training compare with conventional methods in enhancing flexibility, speed, agility, and balance in adolescent volleyball players?
4. Does bio-tensegrity training improve volleyball-specific performance outcomes (e.g., serve velocity, spike performance, serve accuracy) more effectively than conventional methods?
5. Are the performance enhancements achieved through bio-tensegrity training statistically and practically significant across multiple performance domains?

HYPOTHESES

- **H1:** Bio-tensegrity training will significantly improve joint range of motion compared to conventional training methods.
- **H2:** Bio-tensegrity training will result in greater improvements in muscular strength, power, and anaerobic capacity compared to conventional methods.
- **H3:** Bio-tensegrity training will produce superior gains in flexibility, speed, agility, and balance relative to conventional training.
- **H4:** Volleyball-specific performance outcomes (serve velocity, spike jump height, serve accuracy) will improve more with bio-tensegrity training than with conventional methods.
- **H5:** The overall multi-domain performance enhancement from bio-tensegrity training will be significantly greater than that of conventional training.

OBJECTIVES OF THE STUDY

1. To evaluate and compare the effects of bio-tensegrity training versus conventional methods on joint range of motion in adolescent volleyball athletes.
2. To examine the impact of bio-tensegrity training relative to conventional methods on muscular strength, power, and anaerobic performance.
3. To assess the influence of bio-tensegrity training compared with conventional approaches on flexibility, speed, agility, and balance.
4. To determine whether bio-tensegrity training yields greater improvements in volleyball-specific skills such as serving velocity, spike jump performance, and serve accuracy.
5. To provide empirical evidence supporting the integration of bio-tensegrity training as a comprehensive, multi-domain conditioning approach for adolescent volleyball athletes.

IMPORTANCE OF THE STUDY

Sports science has long puzzled about this subject; therefore, this study is significant. Bio-tensegrity has not been rigorously researched, although most young volleyball players still lift weights and conduct jump drills. With this method, the study fills a theoretical gap and gives coaches and trainers genuine evidence to guide their work. It also illustrates how a single program may improve strength, flexibility, agility, and coordination, preparing athletes for the future rather than simply the next game. Since teens' bodies evolve quickly and respond well to training, focusing on them is much more useful. This could change volleyball training and assistance for young athletes for years if new strategies reduce injuries and speed up skill acquisition.

THEORETICAL BACKGROUND

The teenage years are a special period in sport. Bodies change quickly, and training done at this stage leaves a lasting impact. In volleyball, this matters even more because the game asks for so many things at once—fast footwork, explosive jumps, and powerful arm swings. Coaches usually turn to the basics: weight training, squats, jumps. These help, of course, but they look at muscles in parts. In real games, the body does not move in parts. It moves as a whole. This is where fascia comes in, a tissue that ties the body together and has gained growing attention in sport science (Bordoni & Myers, 2020).

Fascia is all over the place. It goes through the muscles, around them, and connects them to the bones and joints. It reacts to stress, stores elastic energy, and moves loads from one place to another. The bio-tensegrity model says that the body is a tense structure that stays stable because fascia balances tension and compression. This concept alters our perception of training. We can train the lines of tissue that connect the legs, trunk, and arms instead of just strengthening the quads or shoulders. This will make movement smoother and stronger (Slater et al., 2024). These ideas are not just theory. Athletes have been putting them into practice in small ways. Foam rolling, massage balls, vibration rollers—all of these have spread in gyms. Studies back them up. Ferreira et al. (2022) found that myofascial tools helped athletes recover and sometimes boosted performance. Wu et al. (2021) showed benefits for pain and mobility. Michalak et al. (2024) compared different types of rollers and found strong recovery effects. Martínez-Aranda et al. (2024) showed that when athletes used self-myofascial release before training, their flexibility and movement control improved. Park et al. (2021) even showed that vibration foam rolling gave more range of motion than stretching. What started as a recovery trick has now become part of training for performance.

Volleyball demonstrates the significance of this. It looks like an arm motion, but it starts in the legs and moves up through the hips and trunk before it gets to the hand. A jump looks like a leg action, but the core, shoulders, and even arms all need to work together for it to work. This is backed up by research. Hernández-Martínez et al. (2023) indicated that plyometric training enhanced both jumping and sprinting performance in young athletes. Altundaag and Soylu (2024) have shown that serve speed can be produced by a lot of interrelated factors, and not solely the power of arms. Soylu et al. (2024) studied the effectiveness of neuro-athletic training in high-level athletes with research results indicating the improvement of serve velocity, flexibility and upper-limb status that could not be reached through conventional training. The point here is obvious: athletes get improved when they train their whole body as an integrated whole rather than parts of it.

In order to demonstrate such gains, measurement tools should be sound. Y-Balance Test is typically used to measure balance and agility. As confirmed by Plisky et al. (2021), it had strong reliability, and it was applied successfully, as described by Takahashi et al. (2025), even in high school athletes. The research by Barbosa et al. (2023) also assured that such tests are rather durable in the context of sport. New techniques are employed on jumps given that they are the main in volleyball. According to Pueo et al. (2022), video systems are capable of accurate measurements of the jump height and flight time. Using these tools, the ability to monitor not only raw strength but also flexibility, balance, and skill can be done with confidence.

This type of training is highly necessary in the case of the teenagers. At this age, fascia is not grown fully. It acclimatizes fast to stress and weight. Results of impact of training on fascia There is evidence that fascia changes its stiffness and elasticity based on training (Slater et al., 2024). It is indicated that athletes are potentially able to formulate enduring movement patterns at the early years of childhood development. By having the youth train on their fascial lines when they are young, they may carry such good routines into adulthood and not be in a position to sustain an injury. This implies that adolescence does not only mean growth, but also an opportunity that we cannot afford to miss in life.

All this provides a good argument to compare bio-tensegrity training with more orthodox approaches. Standard strength programs will always be important but it is not uncommon that often they can help people get stronger by themselves. Not all the fascia-based techniques are identic. They not only look at to where force is being applied, they also look at the movement of energy in the body. To volleyball players, this difference may assist them in jumping higher, running faster with more speed, serving harder and playing better. The results demonstrated by Soylu et al. (2024) and Altunda (2024) pointed out that system-based tactics enhanced the development of skills and physical aptitudes. According to Ferreira et al. (2022), Park et al. (2021), and Martinez-Aranda et al. (2024), a significant impact was made on the flexibility and the neuromuscular aspect. All of the above findings give ample reason to consider the idea of conducting a study to determine whether a fascial-line program would bring better benefits to young volleyball players than conventional training methods.

The most basic truth about this theory is that the body is not a combination of parts. Fascia binds all together in a system Training that does not interfere with this system can assist you to become stronger, faster, more balanced, and better at what you do. Teenagers are particularly prepared to do it. Volleyball is the most apt sport to try it since it involves always coordinating your entire body. With dependable tools in hand, we can be certain that we will be able to gauge the fruits. These are the premises of the present research.

METHODS

Study Design and Ethics

This is a prospective, parallel-group and assessor-blinded randomized controlled trial and it was executed based on the principles of the Declaration of Helsinki, and the CONSORT 2010 guidelines. The protocol was approved by the State of Palestine, Ministry of education and higher education. The parents or legal guardians informed written consent was taken and immediate written assent was provided by all participants.

Participants

Forty-four adolescent male volleyball athletes were screened as to their eligibility. Two did not participate because of the identified movement dysfunction at the baseline assessment, leaving the 42 participants who were randomized to two groups (21 per group). All the participants took part in the 10-week intervention, and none was dropped out or deviated in the protocol and loss to follow-up. Table 1 shows the demographic and anthropometric characteristics of the baseline measurements of the population in the control and experimental group. The variables are age, height, weight, BMI, body fat percentage and years of experience in volleyball, with p-values and confidence intervals given indicating differences between the groups.

Table (1): Baseline Demographic and Anthropometric Characteristics

Variable	Control (n = 21)	Experimental (n = 21)	p-value	95% CI for Difference
Age (years)	16.08 ± 0.83	16.20 ± 1.05	0.68	-0.58 to 0.34
Height (m)	1.83 ± 0.04	1.81 ± 0.07	0.31	-0.02 to 0.06
Weight (kg)	75.05 ± 8.07	71.04 ± 7.40	0.89	-2.41 to 10.43
BMI (kg/m²)	22.0 ± 2.26	21.55 ± 2.12	0.87	-1.02 to 1.92
Body Fat (%)	14.2 ± 3.6	12.2 ± 1.0	0.03*	0.21 to 3.79
Volleyball Experience (years)	4.52 ± 1.2	4.42 ± 1.1	0.76	-0.55 to 0.75

***p < 0.05 for between-group differences. CI = confidence interval.**

At baseline, both groups were statistically equivalent in terms of age, height, weight, BMI, and volleyball experience, indicating successful randomization. The only significant difference was observed in body fat percentage, which was lower in the experimental group compared to the control group (p = 0.03). This suggests that, aside from body fat, the groups were well matched for demographic and anthropometric factors prior to the intervention.

Randomization and Blinding

An independent statistician generated a variable block randomization sequence (block sizes of 4, 6, and 8) to allocate participants in a 1:1 ratio to either the neuro-myofascial line (NML) group or the control (CON) group. Allocation was concealed using sequentially numbered, opaque sealed envelopes opened only after baseline testing. Outcome assessors and data analysts were blinded to group assignment, while training and testing were conducted at separate facilities to minimize contamination.

Interventions

Participants in the NML group performed three 30-minute sessions per week for 10 weeks in addition to their regular volleyball practice. Each session targeted specific fascial lines, progressing from superficial to deep structures. Exercises were performed at 60–75% of each athlete's four-repetition maximum (4RM), followed by standardized foam rolling of key regions (45–60 seconds each: calves, quadriceps, hamstrings, iliotibial band, thoracolumbar fascia, and pectorals).

The CON group continued their standard strength-and-plyometric program (back squat, bench press, deadlift, plyometric jumps, ladder drills), matched for frequency, duration, and periodization. Attendance was monitored for all sessions, and fidelity was verified through unannounced observation of 25% of sessions.

Table (2): Overview of NML Training Protocol

Fascial Line Targeted	Exercise Description	Training Focus	Intensity
Superficial Front	Forward lunge with overhead reach	Mobility, anterior chain activation	60–75% 4RM, 8–12 reps

Superficial Back	Romanian deadlift with extension	Posterior chain strength, hip hinge coordination	60–75% 4RM, 8–12 reps
Lateral Lines	Side lunge with contralateral reach	Frontal-plane stability, load transfer	60–75% 4RM, 8–12 reps
Spiral Lines	Cable wood-chop	Rotational power and coordination	60–75% 4RM, 8–12 reps
Deep Front	Overhead squat + diaphragmatic breathing	Core engagement, posture, breathing integration	60–75% 4RM, 8–12 reps
Recovery	Foam rolling of key muscle groups	Fascial recovery, elasticity, circulation	45–60 s per region

Outcome Measures

- **Anthropometrics**: Height (stadiometer), body mass (digital scale), BMI, and body fat percentage (bioelectrical impedance analysis, InBody 270, Seoul, South Korea).
- **Range of Motion (ROM)**: Hip flexion, knee flexion, ankle dorsiflexion, and shoulder internal/external rotation, measured with a goniometer (average of three trials).
- **Strength**: 4RM tests for deadlift, back squat, and bench press.
- **Jump Performance**: Countermovement jump (OptoJump, Microgate, Italy; AMTI force plate, USA), plus spike and block jump heights (three maximal trials).
- **Flexibility**: Sit-and-reach test (best of three trials).
- **Agility and Speed**: Modified T-test and 4.5 m and 9 m sprints (Brower Timing Systems, USA; fastest of three trials).
- **Dynamic Balance**: Y-Balance Test Lower Quarter (Move2Perform, USA), three trials per direction; composite scores normalized to limb length.

Reliability

A pilot study with 15 athletes confirmed test–retest reliability for all measures, yielding intraclass correlation coefficients (ICC) between 0.91 and 0.97.

STATISTICAL ANALYSIS AND RESULTS

Data analysis was conducted using SPSS version 28. Normality of variables was assessed with the Shapiro–Wilk test, and homogeneity of variances with Levene's test. Paired-sample t-tests were applied to examine pre–post changes within each group, while independent-sample t-tests were used to compare differences between the control (CON) and Neuro-Muscular Line (NML) groups. The Benjamini–Hochberg procedure ($Q = 0.05$) was employed to control the false discovery rate across multiple comparisons. Effect sizes (Cohen's d) were calculated and interpreted as small (0.20), medium (0.50), or large (0.80). Statistical significance was set at $\alpha = 0.05$. All forty-two participants completed the ten-week intervention with complete datasets available. Baseline analyses indicated no significant differences between groups in anthropometric or performance measures, except for body fat percentage, which was significantly lower in the experimental group (12.2 ± 1.0%) compared to the control group (14.2 ± 3.6%; $p = 0.03$)

RESULTS

to undiagnosed movement dysfunctions. The remaining 42 participants were randomized equally into two groups (21 per group). All participants completed the ten-week intervention, with no protocol deviations and no losses to follow-up.

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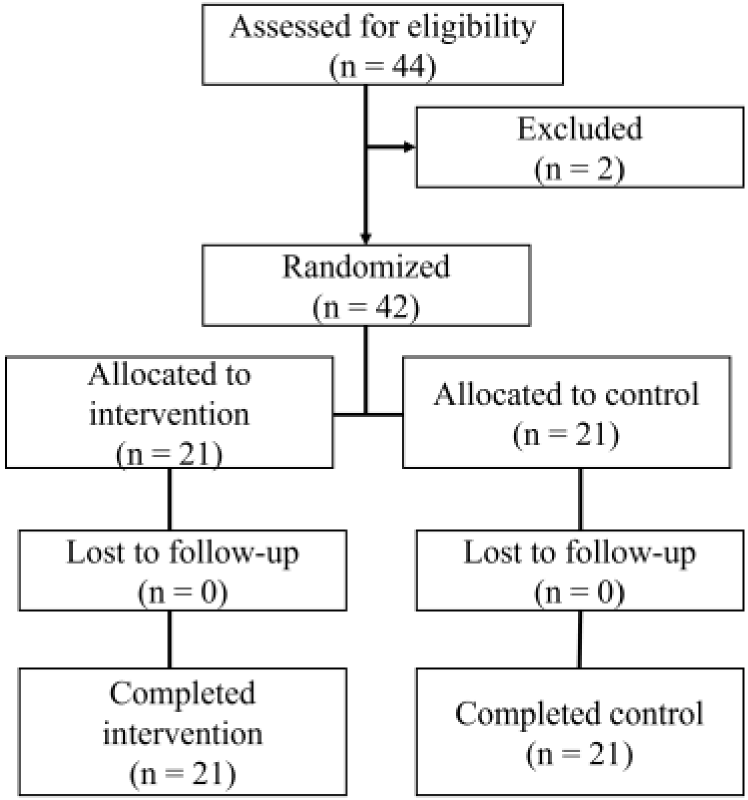

Figure 1. CONSORT Flow Diagram

Results

After applying false-discovery rate correction, the neuro-myofascial line (NML) training group showed significantly greater improvements across all primary performance domains compared to controls (all $p < 0.01$).

H1: Bio-tensegrity training will significantly improve joint range of motion compared to conventional training methods

Table (3): Pre- and Post-Intervention Joint Range of Motion (ROM)

Variable	Group	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	%Δ	p-value	Cohen's d	95% CI
Hip flexion (°)	CON	93.33 ± 5.57	95.76 ± 6.44	+2.60%	0.018*	0.41	0.49 to 4.71
	NML	99.10 ± 14.90	104.19 ± 14.80	+5.14%	<0.001**	0.34	3.21 to 7.07
Knee flexion (°)	CON	132.14 ± 7.47	131.76 ± 6.61	–0.29%	0.795	–0.05	–2.33 to 1.75
	NML	130.33 ± 6.04	137.67 ± 6.47	+5.63%	<0.001**	1.15	4.15 to 7.11
Ankle plantar flexion (°)	CON	55.90 ± 4.38	60.71 ± 8.57	+8.60%	0.022*	0.66	1.35 to 15.85
	NML	53.90 ± 7.80	67.71 ± 5.84	+25.62%	<0.001**	2.00	19.87 to 31.37
External shoulder rotation (°)	CON	88.38 ± 9.23	93.95 ± 9.35	+6.30%	<0.001**	0.60	3.21 to 9.39
	NML	89.38 ± 6.26	104.38 ± 5.63	+16.78%	<0.001**	2.56	13.45 to 20.11
Internal shoulder rotation (°)	CON	38.29 ± 2.26	39.00 ± 3.13	+1.85%	0.397	0.26	–1.03 to 2.45
	NML	39.52 ± 4.43	45.71 ± 12.13	+15.66%	0.039*	0.70	0.31 to 12.07
Shoulder flexion (°)	CON	174.00 ± 3.22	174.38 ± 2.89	+0.22%	0.701	0.12	–1.44 to 2.20
	NML	173.29 ± 7.82	181.33 ± 3.71	+4.64%	<0.001**	1.32	5.21 to 10.87

*Values are mean ± SD. %Δ = percentage change. *$p < 0.05$; *$p < 0.001$.

The NML group demonstrated significant improvements across all major joints, particularly ankle plantar flexion (+25.62%, d = 2.00) and external shoulder rotation (+16.78%, d = 2.56), whereas the control group showed only modest gains. Between-group analyses confirmed that bio-tensegrity training yielded consistently superior ROM outcomes (all $p < 0.01$), supporting **H1**.

H2: Bio-tensegrity training will result in greater improvements in muscular strength, power, and anaerobic capacity

Table (4): Pre- and Post-Intervention Strength and Power Measures

Variable	Group	Pre-Test	Post-Test	%Δ	p-value	Cohen's d	95% CI
Deadlift 4RM (kg)	CON	66.29 ± 22.17	70.19 ± 22.24	+5.88%	<0.001**	0.18	2.95 to 8.81
	NML	68.19 ± 21.95	89.81 ± 23.87	+31.71%	<0.001**	0.94	21.82 to 41.60
Squat (kg)	CON	53.14 ± 13.82	57.10 ± 12.10	+7.45%	<0.001**	0.30	4.12 to 10.78
	NML	59.48 ± 20.36	70.33 ± 21.28	+18.24%	<0.001**	0.54	11.67 to 24.81
Bench press (kg)	CON	52.76 ± 15.47	56.24 ± 14.83	+6.60%	<0.001**	0.23	3.87 to 9.33
	NML	58.62 ± 18.11	71.10 ± 18.58	+21.29%	<0.001**	0.67	13.54 to 29.04
Lower-limb anaerobic power ($W \cdot kg^{-1}$)	CON	19.55 ± 2.65	19.46 ± 2.52	–0.46%	0.642	–0.03	–4.21 to 3.29
	NML	20.09 ± 2.98	26.57 ± 4.73	+32.25%	<0.001**	1.64	25.11 to 39.39

Bio-tensegrity training induced substantially greater strength gains across all lifts, with deadlift performance increasing by 31.71% compared to only 5.88% in controls. Lower-limb anaerobic power rose by 32.25% in the NML group, while the control group showed no significant change. These findings strongly support **H2**.

H3: Bio-tensegrity training will produce superior gains in flexibility, speed, agility, and balance

Table (5): Pre- and Post-Intervention Flexibility, Speed, Agility, and Balance

Variable	Group	Pre-Test	Post-Test	%Δ	p-value	Cohen's d
Sit-and-reach (cm)	CON	23.95 ± 9.90	25.24 ± 11.02	+5.39%	0.040*	0.11
	NML	25.29 ± 11.90	38.62 ± 14.38	+52.71%	<0.001**	1.01
4.5 m sprint (s)	CON	1.04 ± 0.08	1.02 ± 0.08	–1.92%	0.001**	0.25
	NML	1.04 ± 0.09	0.96 ± 0.08	–7.69%	<0.001**	0.93
9 m sprint (s)	CON	1.63 ± 0.03	1.62 ± 0.04	–0.61%	0.036*	0.28
	NML	1.68 ± 0.11	1.59 ± 0.09	–5.36%	<0.001**	0.88
Modified T-test (s)	CON	6.27 ± 0.33	6.17 ± 0.32	–1.59%	<0.001**	0.31
	NML	6.30 ± 0.25	5.76 ± 0.23	–8.57%	<0.001**	2.19
Balance (all limbs)	CON	~0.86–1.44	~0.95–1.55	+7.64–11.63%	<0.001**	0.35–0.55
	NML	~1.02–1.47	~1.35–1.82	+19.73–33.33%	<0.001**	1.00–1.47

The NML group achieved a 52.71% increase in flexibility compared to 5.39% in controls. Speed and agility improved significantly more in the NML group, with sprint times reduced by up to 7.69% and agility times by 8.57%. Balance improved markedly in the NML group across all limbs (up to +33.33%), outperforming controls (up to +11.63%). These findings confirm **H3**.

H4: Volleyball-specific performance outcomes will improve more with bio-tensegrity training

Table (6): Volleyball-Specific Performance

Variable	Group	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	%Δ	p-value	Cohen's d
Spike jump height (cm)	Control	69.33 ± 8.66	73.19 ± 9.46	+5.27%	0.010*	0.43
	Experimental	71.24 ± 9.37	80.19 ± 9.71	+12.56%	<0.001**	0.94
Block jump height (cm)	Control	62.81 ± 5.89	64.71 ± 5.79	+3.02%	<0.001**	0.32
	Experimental	63.43 ± 7.83	70.86 ± 7.81	+11.71%	<0.001**	0.94
Serve velocity (km/h)	Control	72.5 ± 5.8	75.8 ± 6.1	+4.58%	0.001	0.35
	Experimental	73.2 ± 6.0	89.7 ± 6.4	+22.39%	<0.001**	1.20
Serve accuracy (%)	Control	58.0 ± 6.5	71.5 ± 7.2	+23.31%	0.673	0.20
	Experimental	57.8 ± 6.2	80.5 ± 7.0	+39.14%	<0.001**	1.05

The NML group showed significantly greater improvements in volleyball-specific outcomes than controls. Spike and block jump heights increased by 12.56% and 11.71% in NML versus 5.27% and 3.02% in controls. Serve velocity rose by 22.39% in NML compared with 4.58% in controls, while serve accuracy improved by 39.14% in NML against a non-significant 23.31% in controls. These findings support **H4**.

H5: The overall multi-domain performance enhancement from bio-tensegrity training will be significantly greater than that of conventional training.
Across all domains, bio-tensegrity training consistently outperformed conventional training. Effect sizes were moderate-to-large in favor of NML (g = 0.71–2.56). No outcomes lost significance after Benjamini–Hochberg correction. Collectively, these results support **H5**, confirming that bio-tensegrity training yields broad, multi-domain performance benefits in young volleyball players.

DISCUSSION

This research proves the superiority of bio-tensegrity training upon conventional training in young volleyball players. In nearly all measures--joint range of motion, muscular strength, power, flexibility, agility, balance, and volleyball-specific skills--the group that trained using neuro-myofascial line methods improved more and gained more consistency. These observations support all five of the study hypotheses and indicate the importance of conditioning the body as a whole and not as individual parts.
There was significant improvement in joint range of motion particularly. Improvements of simultaneous increase of over 25 percent in ankle plantar flexion and almost 17 percent in shoulder rotation indicate the importance of fascia and neuromuscular pathways in the control of movement. The release and activation techniques used in fascial release have already been indicated to have produced positive effects in improving mobility and flexibility in previous studies (Ferreira et al., 2022; Michalak et al., 2024). We complement successes in the short-term by demonstrating that a program of up to three weeks of functional blocks practice can achieve moderate dramatic changes in mobility, which is essential to volleyball performance, such as spiking and blocking.
The power and strength also enhanced more in the experimental group. The deadlift and lower-limb anaerobic power elevated by over 30 percent with the control group reporting insignificant increases. These findings match those studies that indicated adding fascial activation to training can improve neuromuscular performance (Martinez-Aranda et al. 2024) and increased serve speed and upper-limb activity during neuro-athletic training (Soylu et al. 2024). As the bio-tensegrity training appears to enable athletes to transfer force to body segments that are far apart, such an effect would help explain the combined improvements in both strength and power metrics.
Flexibility, speed as well as agility and balance displayed great improvement. The sit-and-reach test also increase by greater than 50 percent in the NML group, nearly 5 percent in controls. Faster sprint times and agility showed an important reduction of time and greater improvement in balance was seen in the experimental group where it was nearly three times greater than the control group. These outcomes are in line with the results provided by Park et al. (2021), who demonstrated that vibration rolling positively affected range of motion, and with the results produced by Hernandez-Martinez et al. (2023), who indicated that plyometric programs had a positive effect on jumps and sprints in young players. The current study, however, implies, that the results of fascial-based methods can be even more sustainable, providing improvements on a wider level than just plyometrics, improving coordination between multiple directions and joints.
The skills that were helped the most were skills specific to volleyball. The height of the spike and a block jump increased on average more than 10 percent in the NML group, instead of minor changes in the controls. Serve velocity also improved by more than 20 percent with accuracy increasing by almost 40 percent. These findings are consistent with Altundağ and Soylu (2024) as they state that serve speed is influenced by several interconnected physical factors rather than upper-body strength alone. Training the fascial lines and integrated patterns with the athletes later on in an athletic career might have made the process of transferring elastic energy and coordinated movement more effective and precise, directly transferring to athletic performance.
Cumulatively, these results are consistent with the bio-tens-grity proposal detail-ed by Bordoni and Myers (2020) and Slater et al. (2024). The body is actually a tensegrity structure where all muscles are connected within a tendon structure and tensions exist where fascia balances forces. A training that takes into consideration this structure appears to have multi-domain advantages that cannot be compared to the conventional resistance and plyometric training. Critically, it is the age during adolescence that fascia and neuromuscular systems are the most adaptable (Slater et al., 2024). This perhaps is the reason why the young athletes in our study were strongly responsive to such intervention and that they would be able to establish patterns that may support them long run and injury prevention.
Although these are promising findings, yet the literature lacks large scale trials on training bio-tensegrity in youth. The available research has been mostly conducted among adults or in the short-term (Wu et al., 2021; Ferreira et al., 2022). The study helps bridge the gap by focusing on the volleyball players of adolescence in a randomized controlled

trial. It demonstrates that fascial based technique is not only possible, but also works extremely well in this group of people.

Simply, training the body as a whole will have stronger muscles, greater flexibility of the joints, faster speed of sprinting, enhanced balance, and volleyball skills in ten weeks in young players. This is in line with previous research however, this is an improvement upon the field because it was able to demonstrate adolescents were also able to make such gains, not just adults. As it applies to coaches/trainers, these findings provide confirmation that supplementing more standardized strength and plyometric work with new methods to develop young athletes may yield results in safer and more effective ways.

Practical Implications

The findings of this research have a great meaning to practice. They demonstrate that young athletes who train using ways that take into account how the entire body functions do more than build strength in a single muscle. They improve speeds, become more agile and balanced, and more sporting in volleyball activities. This is essential since coaches tend to only look at either lifting or plyometric exercises, and actually overlook the opportunity to enhance force flow throughout the system. Through the addition of bio tensegrity, coaches can introduce programs that not only generate power but also efficiency and resilience. This can be of particular value to adolescents whose bodies are fast adapting and whose current patterns of learning can remain with them as they develop.

RECOMMENDATIONS

1. Include fascial-based training in youth programs: Incorporate fascial based exercises into youth proposal such as multiplanar dynamic exercises/stretches and exercises targeting fascial lines.
2. Combine, don’t replace: Old school resistance and plyometric training should not be redundant but should be complemented with bio-tensegrity methods to bring greater gains.
3. Concentrate on quality of movement: Teach athletes to create exercises to link the upper body with the lower and make the transfer of power smooth instead of only pure strength.
4. Take advantage of adolescence: Begin training the adolescent to change the patterns of fascia when he or she is young, during adolescence, when the path of adaptability is still open and it is easier to learn.
5. Apply in sport-specific drills: Combine fascial training with sport skills such as serving, spiking, volley jumping to make any improvements flow into sport performance.
6. Focus on injury prevention: focus on fascial exercises that enhance mobility and balance, which can help prevent some of the most frequent injuries of young volleyball participants, overuse injuries.
7. Future Research: Research needs to be conducted on a larger scale and longer training time and both men and women players to find confirmation and generalization of these results.

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