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Research Article

METHODICAL CONSIDERATIONS ON APPROACHING PHYSICAL TRAINING AT THE CHILDREN'S LEVEL IN TENNIS

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Abstract

Training children to achieve outstanding performance levels involves developing capacities that far exceed ordinary human capabilities, even among individuals with an aptitude for sport. Currently, a player's innate abilities, however good they may be, can no longer guarantee performances that would rank them the highest in major sporting competitions. At this level, it is essential to improve the exceptional abilities of athletes through systematic and long-term training. Progress in the theory of high-performance sports training has led to the definition of specific requirements and the consolidation of the primary aspects of training. Although the training of a player is a unified process, from a methodological perspective, it is worth noting several factors that contribute to it: physical, technical-tactical, and psychological training. In our opinion, in practical work with children, technical-tactical aspects are often developed to a very high standard, while the methodology of physical training is neglected or addressed only in general terms, thus remaining behind in the development of these factors. This has a negative impact on players' development because technical-tactical knowledge is often not acquired effectively due to physical limitations with which many players, especially younger athletes, struggle. The purpose of this article is to present the main methodological aspects of physical training in children's tennis.

Keywords: tennis game, physical practice, children, performance, methodical aspect

1. Introduction

In high-performance tennis, success depends on the effective integration of technique, tactics, physical conditioning, and mental training. Proper technique, acquired through systematic training, enables players to execute precise and efficient strokes; appropriate tactics allow them to adapt quickly to any opponent's style of play; and physical training serves to help players reach their full potential.

At the children's level, poor development of motor qualities, especially coordination and speed, often leads to the emergence of barriers in the acquisition of technical-tactical skills. For instance, children with poor hand-eye coordination will encounter major challenges in learning the basic stroke technique, while children with low agility will have difficulty executing strokes while moving under conditions similar to those encountered in match play. In this context, we propose that coaches approach the physical training of young players primarily with the aim of providing them with the foundation necessary for the correct acquisition of the technical-tactical skills specific to tennis, while remaining aware of their difficulty and complexity (Bompa, 2021).

In our country, the physical training of children who play tennis remains a subject addressed in a rather rudimentary manner, especially when compared to the scale of Romanian tennis from material, financial, and performance perspectives. Currently, it can be stated that there are still relatively few works dealing with physical training in tennis, which is one of the reasons why we chose this topic. The ultimate goal is to improve this aspect, which we consider highly relevant to sports training. Practical experience leads us to believe that physical training is often a subject "forgotten" by coaches or, in the best-case scenario, approached only superficially (Tudurache, Cojocariu, 2025).

Presently, in most sports, specialists are focusing on solving problems related to physical training, rightly considering that future qualitative advances are possible primarily by bringing physical training to the same level as other training factors. In junior tennis, we believe that a set of motor abilities, such as agility, hand-eye coordination, strength, and mobility, must be improved, until reaching a level that enables the proper acquisition of the technical-tactical skills addressed at this age. Not least, good physical training will help prevent injuries (Roșculeț, 2025).

2. Material and method

The purpose of this research is to identify the most significant methodological aspects of the physical training for children in tennis.

Achieving this purpose required the finalisation of the following *tasks*:

- Conducting a literature review related to the research topic;
- Determining the sample of participants who would take part in the study;
- Designing and administering the research instrument used in the study – the direct questionnaire;
- Collecting, processing, analysing, and interpreting the results following the administration of the questionnaire;
- Formulating the conclusions derived from the research.

Research hypotheses:

Hypothesis 1 – We assume that, if we administer a questionnaire addressed to coaches, we will observe a low level of interest on their part regarding the physical training of children who practice tennis.

Hypothesis 2 – We assume that, if we administer a questionnaire addressed to coaches, we will gather useful information for designing a training programme intended for children who practice tennis.

Subjects and conditions for the research:

The research participants consist of 20 coaches who carry out their activity in tennis clubs located in the Municipality of Iași. The questionnaire was administered in April 2026, at the training facilities of the following tennis clubs:

- iTenis Iași;
- Teo Tenis Club;
- Tenis Club Coreco;
- Tenis Club Tomești;
- Tenis Club Leo;
- Tenis Club Micul As;

Research methods:

Within the research, we have used the following methods:

1. Literature review – examining books dealing with tennis and sports training, reviewing recent studies related to this topic, and consulting specialised websites;
2. Survey method – designing and administering a questionnaire regarding the physical training of children in tennis;
3. Statistical-mathematical method – using Microsoft Excel to process the data collected through the questionnaire;
4. Graphical method – using Microsoft Excel to generate charts, making the data easier to observe and interpret.

3. Discussions

In the following section, we present the interpretation of the results for the nine key items of the research questionnaire.

According to the recorded responses, at level of the children, 70% of coaches allocate the most time to technical training, while 30% allocate the most time to physical training. Consequently, all coaches place the other components of sports training – tactical, psychological, and theoretical training – in secondary positions.

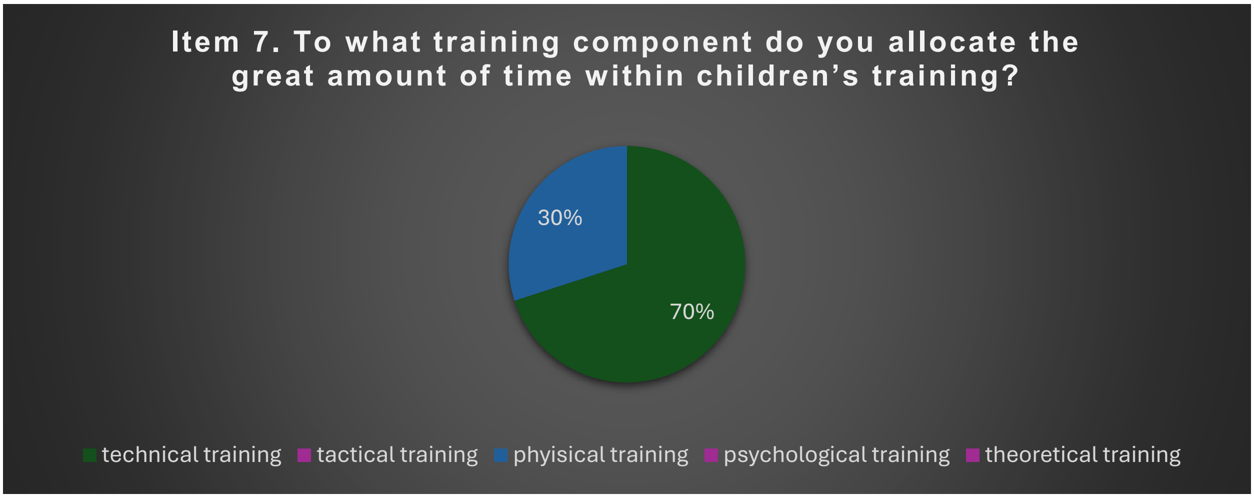

Figure 1. Attention allocated to the different components of sports training

The responses obtained reveal that 80% of tennis coaches consider physical training to be absolutely essential for achieving a good technical-tactical level. Consequently, 20% of the coaches believe that a good technical-tactical level can be attained in tennis even without an adequate level of physical training.

Figure 2. The relationship between technical-tactical and physical training

According to the responses recorded, 40% of coaches believe that physical training should be introduced as early as 6–7 years of age, 30% consider 7–8 years of age to be the appropriate time, 20% opted for 8–9 years of age, and 10% selected 9–10 years of age. In our opinion, when discussing physical training, age is not the most significant factor; rather, the manner in which it is approached and the methods used are of greatest relevance.

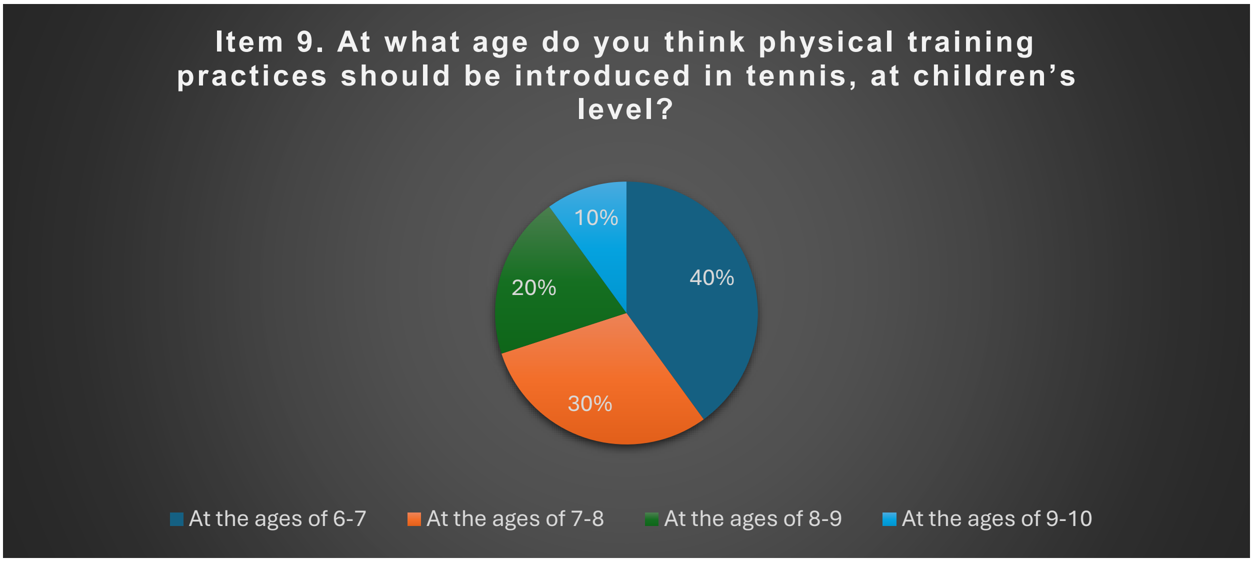

Figure 3. The age at which physical training is introduced into children's training

According to data from the coaches, 80% believe that both general and sport-specific physical training should be used at the level of the children. Only 20% stated that sport-specific physical training is not necessary for children.

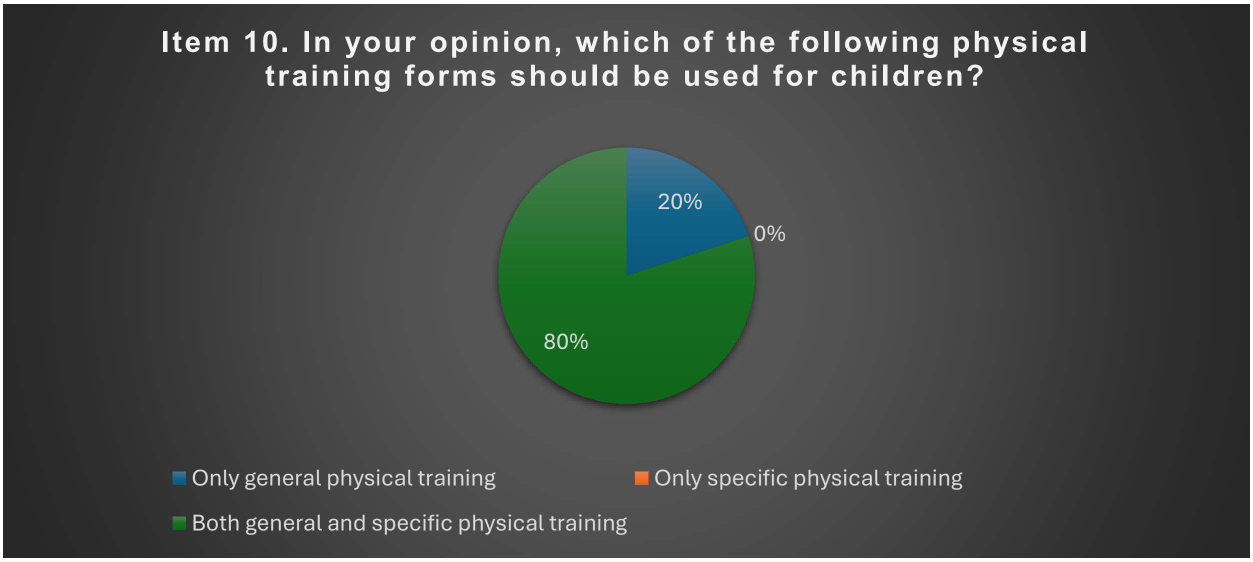

Figure 4. The forms of physical training used for children

According to the responses provided by the coaches, most children who practice tennis participate in one physical training session per week (40%). In contrast, 30% do not engage in any physical training sessions, while 30% participate in two physical training sessions per week.

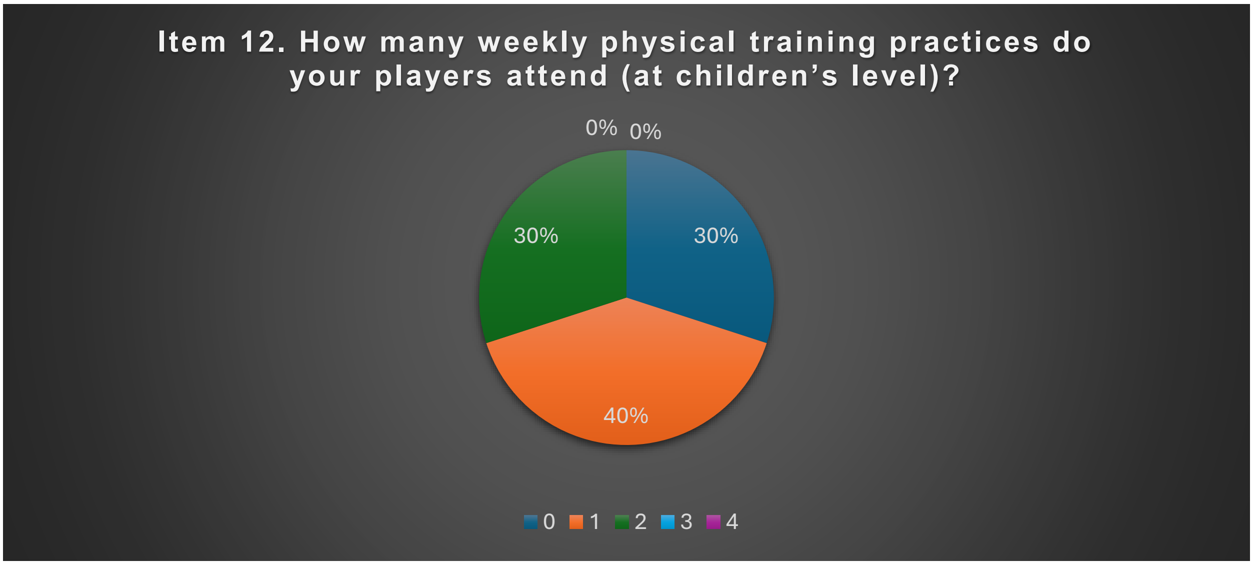

Figure 5. The frequency of weekly physical training sessions

The responses to Item 13 indicate that, according to coaches, coordination is the most important motor quality to develop in children's tennis, as reported by 60% of the coaches. Speed ranks second, selected by 30% of coaches, while strength completes the podium, with 10% of coaches identifying it as the most significant aspect. Endurance and mobility occupy the bottom positions in the ranking, receiving no votes at all.

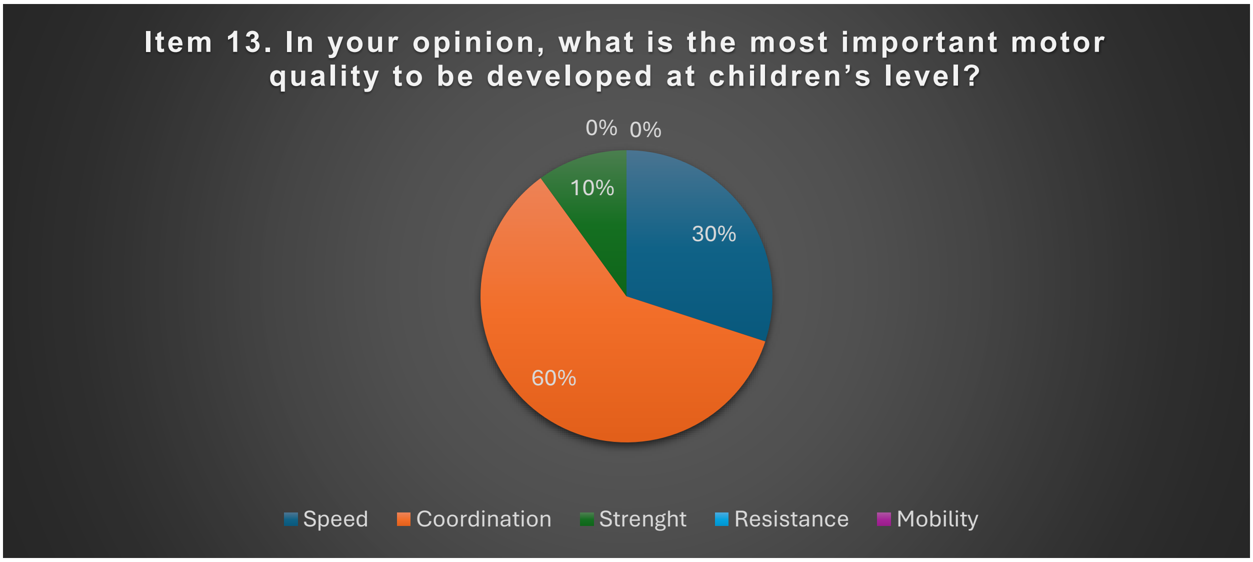

Figure 6. The importance of developing motor qualities at the youth level

According to the responses recorded for Item 15, 70% of coaches believe that physical training at children's level should not be carried out predominantly in the form of games. Consequently, 30% of coaches believe that games should be the primary means of physical training for young tennis players.

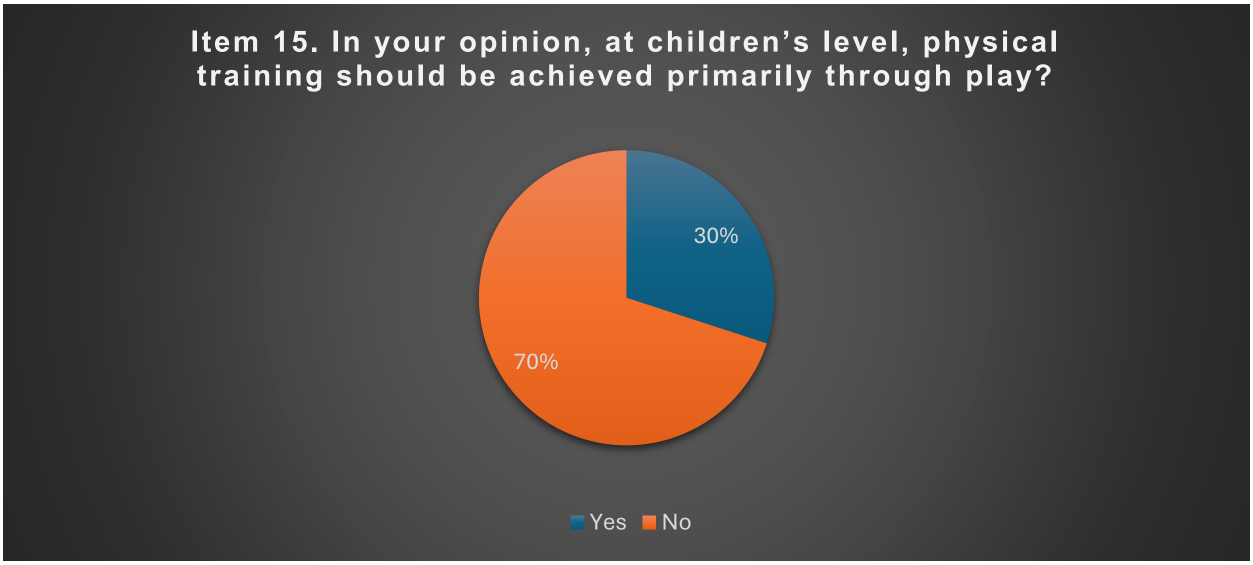

Figure 7. The importance of physical training through play at children's level

The results obtained for the following item reveal that most coaches (70%) do not collaborate with a strength and conditioning coach in the training of tennis players. Only 30% of the coaches work with a strength and conditioning coach, even at the youth level.

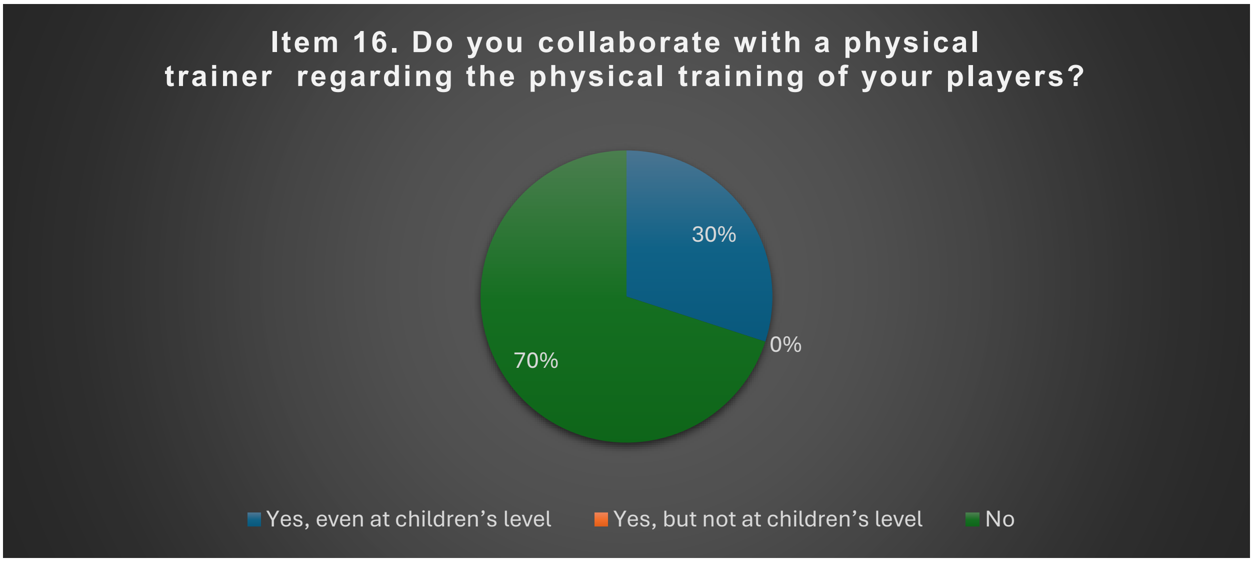

Figure 8. Preferences regarding collaboration with a strength and conditioning coach at children's level

The final item of the questionnaire has indicated that, in the opinion of most coaches (70%), physical training is absolutely essential from the youth level onward if the goal is to achieve a good technical-tactical standard. The remaining 30% do not consider physical training an indispensable requirement for attaining a high technical-tactical level in young tennis players.

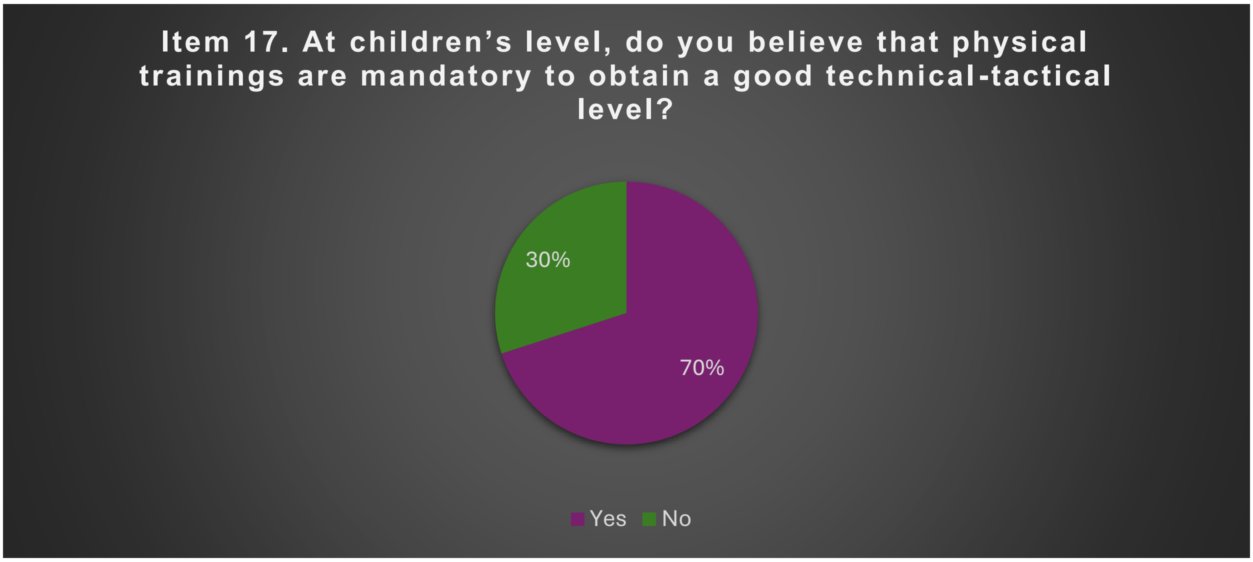

Figure 9. The importance of physical training at children's level in tennis

4. Conclusions

The relevance of physical training is universally recognised, as it constitutes the foundation of players' activity, enabling them to fully activate their technical, tactical, and psychological potential. Children represent a distinct group, given that their physical development undergoes significant fluctuations, with periods of rapid growth and tremendous changes. At this level, the manner in which physical training is introduced and subsequently implemented is particularly relevant.

Following the interpretation of the results, the following research conclusions can be drawn:

1. At the youth level, tennis coaches dedicate the greatest amount of time to technical training, while physical training occupies a secondary position. Nevertheless, the latter is considered an essential prerequisite for achieving a good technical-tactical level.

2. Opinions were divided regarding the age at which physical training should be introduced. However, we believe that the age itself is not the most relevant factor; rather, the key issue is the manner in which physical training is approached in the case of children.

3. Most coaches believe that both general physical training and sport-specific physical training should be used at children's level. However, only one-third of tennis coaches collaborate with a strength and conditioning coach.

Hypothesis 1 – *"We assume that, if we administer a questionnaire addressed to coaches, we will observe a low level of interest on their part regarding the physical training of children who practice tennis"* – was not confirmed.

4. At the youth level, most tennis players participate in one to two physical training sessions per week, the primary objective of these sessions being the development of coordination and speed.

5. Although the playful nature of activities is important when working with children, games should not constitute the predominant component of physical training sessions. Such sessions should target both general physical training and sport-specific physical training.

Hypothesis 2 – *"We assume that, if we administer a questionnaire addressed to coaches, we will gather useful information for designing a training programme intended for children who practice tennis"* – was confirmed.

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Review Article

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Abstract

Physical training is an essential element of performance in tennis, and at the children's level, improving physical skills can provide young players with a significant competitive advantage. In the early days of the training process, physical training serves as a belt surrounding the central technical-tactical core. It develops in accordance with the technical-tactical core, with the aim of speeding up the learning process and increasing the efficiency coefficient of technical-tactical actions. Tennis is a physically demanding sport that requires a combination of endurance, strength, and agility. Consequently, it is highly valuable to identify effective training methods that can improve the physical performance of young tennis players and help them reach their full potential. Research has shown that plyometric and explosive training, or so-called "plyo-specific" training, can enhance key physical attributes such as endurance, strength, and agility. The aim of this article is to outline the primary theoretical aspects of physical training in tennis at the children's level.

Keywords: tennis game, physical training, children, performance, practice

1. Introduction

In performance tennis, success depends on the efficient integration of technique, tactics, physical fitness, and mental training. In sports games in general, a solid technique acquired through systematic training allows players to execute precise and effective strokes. Adequate tactics enable them to adapt quickly to the opponent's style, and physical training helps players attain their full potential (Bompa, 2021).

The development of motor skills in tennis ensures, through this complex process, the biological and functional substrate of the effort required by the demands of competition. Training children to achieve outstanding performance levels involves acquiring capabilities that greatly exceed the ordinary possibilities of human beings, even when referring to individuals with a talent for sports activities. Currently, a player's innate abilities, however good they may be, can no longer guarantee performances securing top positions in the major sporting competitions. At this level, it is mandatory for athletes' exceptional abilities to be refined through systematic and long-term training (Bompa, 2021).

In most sports, specialists focus on solving problems related to physical training, rightly considering that achieving new qualitative leaps in the future is possible mainly by bringing physical training to the level of the other factors. The progress of sports training methodology, as a logical consequence of the new achievements registered by the "auxiliary" sciences (biochemistry, physiology, biomechanics, and so on), has direct consequences on all training factors. Mostly, though, these new forms of knowledge are found in the improvement of physical training (Kotzamanidis et al., 2005).

Recent research supports the statement that plyometric, explosive training can improve players' physical attributes, including strength, power, and agility. Tennis-specific plyometric training may be defined as physical training comprising short sprints forwards, backwards, and to the sides (over distances of 3–5 metres), performed in combination with plyometric training for speed, strength, and agility (Marin, A., Ștefănică, V., Roșculeț, I., 2023).

2. Main text

The training practices of some of the world's top athletes in recent years clearly show that physical training has contributed tremendously to these outcomes. Physical training represents a solid foundation for the technique and tactics specific to each sporting discipline. More and more evidently, elite athletes dedicate a great deal of time to physical training; this is not a mere coincidence, but closely related to the demands of the sport they practise.

Great swimmers, alongside their specific training, follow intensive workout routines using barbells and various auxiliary equipment to develop strength and endurance. Moreover, many Olympic medallists have stated that they achieved these performances only after broadening the range of their training methods, using weight training to develop the motor qualities required in Greco-Roman wrestling. Even in sports such as shooting, which by their very nature involve static effort and considerable nervous loading, physical training has a specific role. World and Olympic champions (Anastasiu, Dumitrescu, Bogdanov) have always paid attention to their physical training, practising complementary sports or performing various weight-bearing exercises to improve the muscle groups involved in shooting. We are currently witnessing a spectacular increase in performance across most sports disciplines and events. This situation results from advances in knowledge across various scientific fields, which have been applied to athletes' training. Consequently, the entire teaching and educational process is carried out at an increasingly higher level, with a greater focus on the functional aspect of the human body and its adaptation possibilities (Ciuntea, 2015).

The game of tennis, through its dynamic character, can successfully develop all motor qualities:

• Speed – the development of speed in all its forms (reaction speed because the ball travels at a very high speed; speed of motion because the court has considerable dimensions and players must reach the ball quickly; speed of repetition because the contesting of points involves repeating strokes again and again);

• Skill – the development of hand-eye coordination, the development of orientation in time and space, the development of leg coordination;

• Strength – its development because the game of tennis also involves power strokes (the serve, the smash);

• Endurance – its development because a match can last for several hours;

• Mobility – its development because tennis involves great-range movements, such as lunging at the net.

According to Teodorescu, L. (1975), the first step in approaching physical training is to determine the dominant motor qualities of the sport in question. The author considers that, in team sports, the dominant motor quality is endurance under different regimes, specific to each sport. If we agree with this idea, we believe that in tennis we can speak of speed, strength, and skill (or technical) endurance. The second step is to characterise the effort specific to each sports game. We reiterate that effort is assessed by the following factors: intensity, duration (volume), complexity, and metabolic processes involved in energy release. In tennis, the specific effort is:

- submaximal and maximal. The intensity of effort in tennis involves the phased alternation of submaximal and maximal efforts;
- considerable in terms of volume, as reflected in a large number of motor actions performed at high speed;
- complex and diversified. The effort complexity is often considered a bridge between the physical and the technical-tactical component;
- aerobic, intertwined with numerous anaerobic moments.

Speed

This motor quality is constantly required during the game of tennis. Modern tennis does not allow players any shortcoming in this regard, be it repetition speed or reaction speed, but especially the latter. Tennis is an anaerobic sport, characterised by short and intense bursts of energy interspersed with periods of low-intensity activity. Its physical demands include rapid changes of direction, acceleration and deceleration, as well as multiple high-intensity strokes of varying durations, with an average match duration of approximately 90 minutes (Simion, 2020).

At age 10, step frequency reaches its peak, after which it declines sharply (especially among boys), only to increase again at age 17. The practical conclusions are relatively easy to draw. It is pointless to insist in the case of children older than 10 if their speed slows down day by day. This does not mean that speed exercises are not useful at ages 12–13, especially when performed without additional weights. A high speed of side steps over a distance of 3–5 metres is essential for returning the ball and quickly resuming the starting position to get ready for the next stroke. Side movements are critical when reacting and changing direction, enabling players to hit the ball at the right moment. Therefore, it is not surprising that tennis associations have included side movements in testing protocols to assess the stability levels of tennis players (Fernandez-Fernandez et al., 2012).

It can be said that, based on a high level of the body's morpho functional indicators and the possibility of performing motor actions with high speed and force, using coordinated movements over a longer period, the technical-tactical components corresponding to the requirements of tennis can be improved. Linear and side sprints performed for 15–20 minutes, 2–3 times per week, improve players' capacity to react and increase their speed, supporting the concepts of movement specificity and speed adjustment. Like athletes in other sports, tennis players must move forwards, backwards, and to the sides with great speed, agility, and jumping skills, in order to accomplish their main tasks on the court (Scanlan et al., 2012).

Figure 1. Developing agility using methodical cones

Strength

Since tennis is a sport that develops players unilaterally, strength exercises must be combined in such a way that, together with other means of multilateral physical training, they contribute to children's harmonious development. Therefore, in my opinion, the development of strength in children should not be an end in itself but should be integrated into the broader set of means we use, while respecting the aim of forming healthy, well-balanced young people. The most effective motor skills of tennis players appear to be agility and speed (Weineck, J., 2000). To improve strength in children who play tennis, one of the most recommended and widely used methods is plyometrics. This type of training is of particular interest because it improves performance and mitigates the risk of injury among athletes. Plyometric training increases strength and explosive force through exercises that condition the neuromuscular system and allow rapid changes of direction, all of them specific to tennis. This method involves quickly stretching a muscle group (an eccentric contraction before its shortening – a concentric contraction) in order to obtain maximum strength (Tudurache & Cojocariu, 2025). Specialised research has highlighted relevant findings on the impact of plyometric training on tennis performance. Following such training, improvements in players' agility have been observed. Plyometric and explosive training can positively impact various physical attributes of junior tennis players, such as serving performance and rapid movement on the court, thus helping to optimise overall tennis performance (Fort-Vanmeerhaeghe, A., 2016).

Figure 2. The use of plyometrics leads to improved agility

In the 12–18 age range, physical training should focus primarily on developing strength and endurance through systematic training routines. After the age of 16, the use of training periodisation and individualised physical training schedules is recommended (Simion, 2020).

Endurance

Concerning endurance in tennis, it is worth noting endurance for intense efforts and for high-volume efforts. It can be assessed by monitoring the number of repetitions and the duration of the effort. Specialists point out that the judicious use of endurance training does not have negative effects on the bodies of junior athletes. According to N. Ozolin, the body's physiological limit increases most effectively through low-intensity, long-duration effort. We should not forget that at the age of 11–12, athletes run around 14 kilometres per week, but for the development of general endurance, apart from the uniform method, the most commonly used method is the alternating one, namely speed work performed in the form of short repetitions separated by short rest intervals.

Specialists such as A. Kirsch have shown that the systematic development of general endurance can begin at the ages of 8–9. From his point of view, during the period of human growth, there are no stages in which, for medical reasons, covering long distances should be prohibited. Around the age of 16, excellent results were observed in developing the endurance required of tennis players through functional training programmes, at the expense of traditional training methods aimed at developing this motor quality (Xiao, 2024).

Mobility

Regarding mobility development, the most sensitive period for its improvement is considered to be between 6 and 12. After 12 years of age, improvements in joint range of motion decrease dramatically in the absence of special measures in training, and the differences between active and passive values also decrease significantly. It has been shown that mobility develops most rapidly between ages 8 and 10 in boys and between ages 9 and 11 in girls (Polevoy, 2024). After age 12, the use of a structured programme to optimise tennis-specific mobility becomes imperative to achieve sports performance and prevent injuries related to players' flexibility (Tudurache & Cojocariu, 2025).

Guzhalovsky, the author of several physiology books, noted in 1986 that flexibility develops best during primary school age (that is, between 6 and 10 years of age), but that there is another favourable period later – 11–13 years in girls and 13–15 years in boys. In 2021, Matveev, a renowned specialist in the field of Physical Education and Sport and the author of hundreds of articles and specialised books, systematised and synthesised data on favourable periods for the development of motor qualities. Thus, the author argues that the optimal periods for boys to develop mobility are 8–9 and 12–13 years of age, while for girls these periods are 7–10, 11–13, and 14–15 years of age (Matveev, 2021).

Coordination

Coordination generally concerns an individual's ability to find easily and execute accurately, as quickly as possible, certain movements in complex situations; in other words, to find the best solution in the shortest possible time. Its physiological foundation is the plasticity of the cerebral cortex, as well as the unity between the central nervous system and other organs. Knowing all these aspects, we understand why coordination is involved in learning new, challenging, and complex executions. Coordination is expressed, as I have shown, whenever unforeseen factors arise during the unfolding of an action. We may therefore deduce that this motor quality should undergo both quantitative and qualitative transformations through targeted training. We do not doubt that this is an innate quality and that it reifies more evidently in some sports and less so in others. However, a person who has good coordination for football will not necessarily also have good coordination for tennis.

Tennis requires children's coordination to a great extent. From a biomechanical point of view, the execution of an effective serve involves the proper use of body mechanics. For instance, the involvement of the lower limbs through the flexion and extension of the knees and ankles plays a significant role. Touzard and his colleagues argue that an effective leg push is essential for generating force in the serve through efficient lower-limb movement (Touzard et al., 2023). This aspect is also supported by Myers et al. (2016), who emphasise that a powerful and consistent serve derives from the player's capacity to coordinate the movements of the trunk and the upper and lower limbs.

Specific coordinative skills required over time:

- Rhythm**:** the ball is the metronome of the players' movements; can they adapt to the tempo of the ball?
- Balance**:** can the player maintain their centre of gravity while moving?

• Dissociation**:** can the player keep different body segments working separately at different rhythms without interfering with one another? (for instance, while serving, the hand tossing the ball and the hand holding the racket);

Figure 3. The development of coordination using the training ladder

3. Conclusions

Currently, tennis involves a specific set of skills that includes, first and foremost, a multifaceted training approach and great freedom for creativity and tactical inventiveness, which can only be expressed by individuals who have reached a high level of technical, physical, and psychological mastery. The relevance of physical training is universally recognised, as it constitutes the support system for players' activity, enabling them to exploit their technical-tactical and psychological capabilities. Young athletes represent a distinct group whose physical development is prone to significant fluctuations, with periods of rapid growth and change during adolescence.

At the children's level, the development of speed is a key component of physical training, with emphasis placed on movement over short distances (3–5 metres), forwards, backwards, and to the sides, without the use of weights. Regarding strength development, one of the most effective and widely used methods is plyometrics. Through plyometric exercises, players develop agility, a highly significant skill for efficient movement on the court.

Generally, at younger ages, developing endurance is not a priority for tennis players, but after age 11–12, they are ready to focus on this motor quality. The use of functional training is considered one of the most effective methods applicable to children.

Regarding the development of coordination, as with speed, it can be addressed from early ages, in both its general and specific forms. In this respect, exercises may be used to develop hand-eye coordination, spatial-temporal orientation, balance, sense of rhythm, and the capacity to combine movements. Mobility can also be developed from an early age, predominantly through stretching exercises, while after age 12, the application of a structured programme for developing tennis-specific mobility is recommended.

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Research article

EXERCISE CAPACITY IN YOUTH 3X3 BASKETBALL: A COMPARATIVE ANALYSIS BETWEEN U15 AND U17 CATEGORIES

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Abstract

Analyzing effort parameters in 3x3 basketball is necessary due to game intensity, providing coaches with an accurate perspective on the physical components that require optimization in athlete training. This study compares the heart rate and movement profiles of U17 (n = 10, born 2009) and U15 (n = 10, born 2011) players from the ACS MADMAX Iași club in Romania. The players were monitored with Polar GPS chest straps during two training sessions on October 31, 2025. The analyzed metrics are effort distribution across zones Z1–Z5, individual player variation, and movement efficiency. The U15 group showed higher physical stress during training: an average Cardio Load (CL) of 42.1 vs. 17.2, time in Z4+Z5 of 26.1% vs. 0.5%, and an average heart rate (HR Avg) of 71.9% vs. 59.4% of maximum heart rate (HR max). The distance-to-Cardio Load ratio (km/CL) was higher in the U17 group (0.081 vs. 0.040 km/unit), showing better movement efficiency. Analyzing these two age groups reveals how physical growth changes a player's response to the same training exercises. The data help identify specific individual needs within each category to optimize game-based conditioning.

***Keywords**: 3x3 basketball, youth athletes, heart rate monitoring, training intensity zones, athletic periodization.*

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1. Introduction

For athletic structures and youth training frameworks to be considered genuinely sustainable, they must achieve a balanced integration of four fundamental dimensions: social impact, environmental preservation, economic viability, and institutional integrity (Yang et al., 2020). The fast growth of 3x3 basketball worldwide, especially after its Tokyo 2020 Olympic debut, has changed how young players develop and compete. Its specific rules, such as the fast pace, 12-second shot clock, and continuous play (Sansone et al., 2023), create intense physical demands that differ significantly from traditional 5x5 basketball. Elite 3x3 games keep players at near-maximal heart rate (HR) responses and cause neuromuscular fatigue (Sansone et al., 2023).

In modern sports training management, the accurate quantification and monitoring of training load are essential for optimizing athletic performance and reducing health-related risks. This issue is particularly important in youth sports, where inappropriate workloads may impair development and increase the risk of injury and psychological stress (Bergeron et al., 2015). Additionally, the morphofunctional characteristics of young athletes contribute to substantial inter-individual variability in responses to training stimuli (Clemente et al., 2020). More specifically, the transition from the Under-15 (U15) to the Under-17 (U17) category is associated with rapid bone and muscle growth, cardiovascular development, and metabolic adaptations (Montgomery & Maloney, 2018), further emphasizing the need for individualized workload management.

The personal contribution of the author is the direct, synchronized field-monitoring of youth physical output within a real competitive framework. Therefore, the purpose of this study is to compare the physiological and locomotor profiles of U17 and U15 youth 3x3 basketball players. To achieve this, I recorded the players' live cardiac responses across five intensity zones and calculate their distance to load ratios during high-intensity tournament simulations.

2. Material and method

I studied 20 male youth basketball players from the same sports club, ACS MADMAX Iași, Romania. The players were divided into two groups based on their competitive age category: the U17 group (n = 10) and the U15 group (n = 10). This study is limited by its small size involving 20 total subjects (n = 10 per group) and its focus on a single session, applying this monitoring protocol across a full competitive season would provide a more comprehensive dataset and allow for stronger generalizations.

Both teams followed the same training schedule of four sessions per week. We collected all data on October 31, 2025, in the same basketball gymnasium to ensure identical indoor conditions. To avoid the influence of different times of day, the groups played back-to-back: the U17 group started at 11:47 (session duration: 28 min., 10 s.), and the U15 group started at 13:31 (session duration: 31 min., 52 s.). Before playing, all participants completed a regular 15 minute warm-up consisting of running, dynamic stretching, and ball-handling drills.

The integration of GPS-based monitoring systems and physiological parameters, including heart rate (HR), maximum heart rate (HRmax), and Cardio Load, has become essential in modern sports science. These technologies provide accurate, individualized insights into athletes' internal and external training loads, thereby supporting performance optimization, fatigue management, and injury prevention (Impellizzeri et al., 2019; Peake et al., 2018; Martins et al., 2021)

During the games, each player wore a wireless cardio-GPS sensor secured to the chest with an elastic strap (Polar Team Pro). The devices tracked real-time movement and cardiac parameters, transmitting the data to a sports performance analysis platform to generate individual and group reports.

Fig. 1- Real-time physiological monitoring of the U17 team

The monitored parameters included session duration, calories consumed (kcal), Cardio Load (CL), average heart rate (HR Avg), maximum heart rate (HR Max), total distance covered (km), and the percentage distribution of time and distance across five cardiac effort zones (Z1–Z5).

Fig. 2- Individual physiological data – L.T.

Fig. 3- Individual physiological data – A.P

Fig.4 Individual physiological data – M.R.

Fig. 5 -Individual physiological data – D.A.

Figures 2 and 3 illustrate these individual physiological profiles for the U17 category, while Figures 4 and 5 represent the U15 category, all generated by the Polar Team Pro platform (Polar Electro Kempele, Finland). Each report provides a comprehensive overview of the athlete's workload.

3. Findings

Individual physiological profile – U17/2009 Group

Table 1 presents the individual physiological parameters of players in the U17/2009 Group

Player	No.	Kcal	C.Load	Level	HR Avg%	HR Avg BPM	HR Max%	HR Max BPM	Dist (km)	Z5t%	Z4t%	Z3t%	Z2t%	Z1t%
S.T.	12	158	20	Low	65	129	78	155	1.093	0	0	19	40	18
V.A.	6	127	9	Very low	50	100	65	129	1.167	0	0	0	2	48

Player	No.	Kcal	C.Load	Level	HR Avg%	HR Avg BPM	HR Max%	HR Max BPM	Dist (km)	Z5t%	Z4t%	Z3t%	Z2t%	Z1t%
R.R.	8	166	20	Low	64	127	74	148	1.022	0	0	11	56	18
C.C.	11	138	12	Medium	55	109	64	127	1.074	0	0	0	8	71
P.M.	17	225	26	Very low	65	130	80	159	1.259	0	0	27	50	23
L.T.	15	171	25	Very low	69	138	105	211	1.132	0	3	35	29	6
B.D.	20	215	28	Very low	68	135	81	161	1.122	0	1	28	59	7
A.P.	14	146	11	Very low	51	113	64	140	1.587	0	0	0	5	55
J.S.	20	137	11	Low	55	110	75	150	0.973	0	0	2	10	58
D.S.	18	115	10	-	52	105	89	177	0.768	0	1	0	7	49
MEAN		**159.80**	**17.20**		**59.40**	**119.60**	**77.50**	**155.70**	**1.12**	**0.00**	**0.50**	**12.20**	**26.60**	**35.30**

Table 1. Individual physiological parameters and effort zone distribution – U17/2009 Group (n=10, duration 28:10 min)

Individual physiological profile – U15/2011 Group

Table 2 presents the individual physiological parameters of players in the U15/2011 Group, using the same indicators as in Table 1.

Table 2. Individual physiological parameters and effort zone distribution – U15/2011 Group

Player	No.	Kcal	C.Load	Level	HR Avg%	HR Avg BPM	HR Max%	HR Max BPM	Dist (km)	Z5t%	Z4t%	Z3t%	Z2t%	Z1t%
D.A.	19	422	72	Medium	83	166	96	192	1.645	39	27	13	15	3
L.D.	2	337	67	Medium	82	164	97	193	1.602	21	43	19	13	1
H.I.	5	339	55	Medium	76	152	97	194	1.307	22	16	24	29	9
T.C.	10	195	31	Medium	63	125	94	188	1.465	9	14	5	10	31
C.R.	6	320	60	Medium	81	161	99	197	2.022	27	15	37	11	2
M.R.	9	319	42	Medium	70	154	89	195	2.613	0	23	27	24	18
M.D.	3	270	31	Medium	69	138	82	164	1.345	0	4	39	50	5
D.T.	19	149	22	Very low	69	137	80	159	1.075	0	0	34	29	8
P.S.	16	125	14	Low	58	117	84	167	0.883	0	0	4	37	20
A.I.	17	224	27	Medium	68	135	81	161	1.502	0	1	36	38	16
MEAN		**270.00**	**42.10**		**71.90**	**144.90**	**89.90**	**181.00**	**1.55**	**11.80**	**14.30**	**23.80**	**25.60**	**11.30**

4. Discussions

A comparative analysis of the mean physiological parameters between the two teams is presented in Table 3, highlighting the distinct cardiovascular and metabolic profiles exhibited by each group during training.

Table 3. Comparison of mean physiological parameters – U17/2009 Group vs. U15/2011 Group

Parameter	**G2009/U17 (n=10)**	**G2011/U15 (n=10)**	**Difference (G2−G1)**
Session duration	28:10 min	31:52 min	**+3:42**
Mean calories (kcal)	159.80	270.00	**110.2**
Mean Cardio Load	17.20	42.10	**24.9**

Parameter	G2009/U17 (n=10)	G2011/U15 (n=10)	Difference (G2−G1)
Mean HR Avg %	59.40	71.90	**12.5**
Mean HR Avg BPM	119.60	144.90	**25.3**
Mean HR Max %	77.50	89.90	**12.4**
Mean HR Max BPM	155.70	181.00	**25.3**
Mean distance (km)	1.12	1.55	**0.430**
% time Z5 (maximal)	0.00	11.80	**11.8**
% time Z4 (high)	0.50	14.30	**13.8**
% time Z3 (medium)	12.20	23.80	**11.6**
% time Z2 (moderate)	26.60	25.60	**-1.0**
% time Z1 (light)	35.30	11.30	**-24.0**

Data from the training session reveals a clear age-based disparity: the younger group (G2011/U15) sustained a much higher physical and cardiovascular load compared to the older G2009/U17 athletes. Although the difference in session duration was minor (+3:42 min for U15), the U15 players registered a 69% higher energy expenditure (270.00 vs. 159.80 kcal) and a mean Cardio Load nearly 2.5 times greater than the U17 group (42.10 vs. 17.20). This massive discrepancy is directly supported by the heart rate metrics, where the U15 group operated at a mean of 71.90% HRmax and reached a peak of 89.90% HRmax, while the U17 group remained in a predominantly submaximal zone (59.40% HRmax mean). The distribution of time across intensity zones clearly explains this polarization: while the U17 athletes completely avoided the maximal zone (Z5) and spent a combined 61.9% of the session in light and moderate brackets (Z1-Z2), the U15 players spent over a quarter of the training volume under high-intensity and maximal thresholds (Z4-Z5), while also covering a greater absolute distance (1.55 km vs. 1.12 km).

From a physiological standpoint, the variations between the U17 and U15 teams are related to biological developmental stages. While the older players showed stable cardiac responses to submaximal workloads due to an age-related improvement in managing their own pacing, the U15 team operated under intense cardiovascular strain. Younger, less mature athletes frequently sustain efforts within peak cardiovascular thresholds (Z5 > 90% HR max) often lacking the pacing efficiency required to regulate internal load during uniform team constraints.

Table 4. Inter-individual variability indicators – U15/2011 Group

Parameter	Mean	Min	Max	Range (Max−Min)	CV% (est.)
Calories (kcal)	270.00	125.00	422.00	297.00	55.0%
Cardio Load	42.10	14.00	72.00	58.00	68.9%
HR Avg %	71.90	58.00	83.00	25.00	17.4%
HR Avg BPM	144.90	117.00	166.00	49.00	16.9%
HR Max %	89.90	80.00	99.00	19.00	10.6%
HR Max BPM	181.00	159.00	197.00	38.00	10.5%
Distance (km)	1.55	0.90	2.60	1.70	54.8%

Table 4 highlights the large individual variations within the U15 team, demonstrating that identical training constraints generated highly unequal physical and metabolic responses. This dispersion is most prominent in the internal workload metrics. Cardio Load varied by 58.00 (CV = 68.9%), separating the least taxed player (14.00 units) from the most physically challenged one (72.00 units), with a parallel 297.00 kcal gap in energy expenditure (CV=55.0%). Mechanical volume also differed significantly (CV= 54.8%), as total distance more than doubled from a minimum of 0.883 km to a maximum of 2.613 km. Meanwhile, relative heart rate parameters remained highly uniform, showing lower variability in both mean (CV = 17.4% HRavg) and peak cardiovascular values (CV= 10.6%

HRmax). These indicators demonstrate that while the entire group consistently achieved near-maximal cardiac recruitment, the mechanical work performed and the resulting total internal costs were highly asymmetric.

Categorizing this intensity into distinct heart rate zones provides a precise method for monitoring internal load, revealing substantial inter-individual variability across both teams. This wide dispersion reflects the marked individual variations in biological maturation typical around 14 years of age. Within the U15 group alone, individual CL ranged from 14 (P.S.) to 72 (D.A.), while total distance ranged from 0.883 km to 2.613 km. This demonstrates the critical importance of individualized internal load monitoring.

This approach is heavily supported by recent acute profiling which indicates that recreational 3×3 basketball structures can elicit similar or even superior physiological stimuli and enjoyment levels compared to traditional high-intensity interval training (HIIT) protocols (Buchheit, M., & Laursen, P.B. 2013). However, while such indicators have been predominantly validated in active young adults with established tactical experience, their direct translation to younger subjects remains a critical area of investigation. The pronounced physiological stress observed in the U15 team is indicated by a substantially higher Cardio Load and an average heart rate of 71.9% of their maximum. This reflects the inherent, high-density nature of half-court play. Official medical tracking and performance tests confirm that the work-to-rest density in 3x3 basketball is twice as high as in traditional 5v5 basketball (Montgomery et al., 2018). Adolescent athletes within early developmental stages, such as the U15 group, do not possess a fully developed aerobic capacity required to rapidly clear the metabolic by products and lactic acid accumulated during these phases of continuous, explosive effort. This physiological limitation explains why their heart rates remain effectively "locked" in the upper intensity zones (Z4–Z5) throughout the short training sessions.

Therefore, training strategies must be individualized. The U17 team requires targeted intensity progression, shifting more volume into the Z3–Z4 through fast-paced bilateral play (Sansone et al., 2023). Meanwhile, outlier profiles like V.A. and D.S. suggest a need for targeted aerobic conditioning; integrating high-intensity interval training (HIIT) or specific small-sided games can enhance their maximal oxygen uptake (VO2max) and cardiovascular efficiency, allowing them to effectively tolerate higher competitive demands (Buchheit & Laursen, 2013).

5. Conclusions

This study highlights differences in how U17 and U15 players respond to 3x3 basketball, showing that integrated cardio-GPS monitoring provides a reliable, objective method for tracking training loads. The U15 group experienced higher cardiovascular stress, spending more time in high-intensity zones (Z3–Z5). The distance to cardio-load ratio indicates that U17 players possess better locomotor efficiency and a more developed movement economy. As a result, youth 3x3 basketball coaching requires continuous, standardized workload tracking rather than a uniform approach. Training plans must be adapted to match each athlete's biological maturity and individual internal effort profile.

Furthermore, this investigation underscores that looking only at team averages can be misleading. Coaches must account for the high intra-group dispersion in mechanical volume and metabolic costs, particularly within younger teams where biological maturation rates vary. Practically, field practitioners should implement targeted interventions, such as high-intensity interval training (HIIT) or rule conditioned small-sided games to accelerate aerobic conditioning in outlier profiles. At the same time, training for older athletes should be structured to intentionally push them into higher intensity zones (Z3–Z4) through fast-paced bilateral structures.

In conclusion, this study highlights the importance of individualized workload monitoring during short 3x3 basketball sessions and provides a clearer understanding of the physical demands experienced by young athletes. Longitudinal monitoring across an entire competitive season could offer deeper insight into how players gradually adapt their pacing strategies, heart rate responses, and movement patterns to the sustained demands of competitive basketball (Stojanović et al., 2018).

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Research article

OVERCOMING ARTHROKINETIC DEFICITS IN POST-TRAUMATIC KNEE AND ANKLE INJURIES: A COMBINED PNF AND SOFT-TISSUE TECHNIQUES

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Abstract

Post-traumatic lower limb injuries frequently impair joint mobility, muscle strength, proprioception, balance, and gait, requiring comprehensive rehabilitation strategies to restore functional capacity and independence. This study aimed to evaluate the effectiveness of a multimodal rehabilitation program combining therapeutic exercise with Instrument-Assisted Soft Tissue Mobilization (IASTM), cupping therapy, kinesiotaping, and Proprioceptive Neuromuscular Facilitation (PNF) techniques in patients with post-traumatic lower limb conditions. Ten patients with lower limb musculoskeletal injuries participated in the study. Functional assessment was performed before and after the intervention using somatoscopy, anthropometric measurements, goniometry, manual muscle testing, and gait phase analysis. The rehabilitation protocol included RICE principles during the acute stage, immobilization and postural management when indicated, therapeutic massage, PNF techniques, IASTSTM, cupping therapy, stretching, kinesiotaping, and individualized therapeutic exercises based on the Analytical Therapeutic Exercise (ATE) system. Following treatment, all participants demonstrated improvements in joint range of motion, muscle strength, gait mechanics, and overall functional performance, accompanied by reduced pain and enhanced locomotor control. Restoration of the physiological gait phases contributed to improved walking efficiency and functional independence. The findings suggest that integrating contemporary soft tissue mobilization techniques with evidence-based therapeutic exercise enhances post-traumatic recovery and represents an effective rehabilitation strategy for optimizing functional outcomes and facilitating the return to daily activities in patients with lower limb injuries.

***Keywords**:* Physical Therapy, Lower Limb, IASTM, PNF Techniques, Gait Rehabilitation.

1. Introduction

Post-traumatic lower limb injuries represent one of the leading causes of temporary disability and functional impairment worldwide, affecting individuals of all ages and activity levels. Damage to the musculoskeletal structures of the hip, knee, ankle, or foot frequently results in pain, joint stiffness, muscle weakness, impaired proprioception, and altered gait mechanics, significantly limiting functional independence and delaying the return to daily, occupational, and sports-related activities. Because normal locomotion depends on the coordinated interaction of the musculoskeletal and neuromuscular systems, rehabilitation following lower limb trauma should aim not only to restore tissue integrity but also to re-establish efficient movement patterns and dynamic stability.

Contemporary physical therapy emphasizes an evidence-based and patient-centered approach that integrates therapeutic exercise with complementary rehabilitation techniques to optimize tissue healing and functional recovery. Therapeutic exercise remains the cornerstone of post-traumatic rehabilitation by improving joint mobility, muscle strength, neuromuscular coordination, and functional performance. In recent years, increasing attention has been directed toward multimodal rehabilitation protocols that combine conventional therapeutic exercise with adjunctive interventions designed to enhance soft tissue healing, reduce pain, improve circulation, and facilitate neuromuscular re-education.

Among these interventions, Proprioceptive Neuromuscular Facilitation (PNF) has been widely recognized for its ability to improve neuromuscular control, proprioception, flexibility, and muscle activation through specific movement patterns and facilitation techniques. Likewise, Instrument-Assisted Soft Tissue Mobilization (IASTM) has demonstrated beneficial effects in reducing fascial restrictions, improving soft tissue mobility, and increasing joint range of motion. Cupping therapy has been increasingly incorporated into rehabilitation programs because of its potential to enhance local blood circulation, decrease pain, and promote tissue regeneration, whereas kinesiotaping provides continuous sensory stimulation and biomechanical support without restricting physiological movement.

Despite the growing popularity of these therapeutic modalities, evidence regarding their combined application within a structured rehabilitation program remains limited, particularly in patients with post-traumatic lower limb injuries. Most published studies have investigated these interventions individually, while relatively few have evaluated their synergistic effects when integrated into a comprehensive rehabilitation protocol.

Therefore, the aim of the present study was to evaluate the effectiveness of a multimodal physical therapy program combining therapeutic exercise, Proprioceptive Neuromuscular Facilitation (PNF), Instrument-Assisted Soft Tissue Mobilization (IASTM), cupping therapy, and kinesiotaping in improving joint mobility, muscle strength, gait function, and overall functional recovery in patients with post-traumatic lower limb injuries. It was hypothesized that the combined rehabilitation approach would produce clinically meaningful improvements in functional outcomes following the intervention period.

2. Material and method

2.1. Study Design

This prospective observational clinical study was conducted to evaluate the effectiveness of a multimodal physical therapy program in patients with post-traumatic lower limb injuries. The rehabilitation protocol combined evidence-based therapeutic exercise with complementary rehabilitation techniques, including Proprioceptive Neuromuscular Facilitation (PNF), Instrument-Assisted Soft Tissue Mobilization (IASTM), cupping therapy, therapeutic massage, stretching, and kinesiotaping. Functional outcomes were assessed before and after completion of the rehabilitation program.

2.2. Participants

The study included ten patients diagnosed with post-traumatic musculoskeletal injuries of the lower limb who were referred for physical rehabilitation. The participants presented knee and ankle disorders resulting from grade II or III ligament sprains, conservatively treated fractures, or stabilized musculotendinous injuries. All patients completed the rehabilitation program and participated in both the initial and final assessments.

2.3. Outcome Measures

Each participant underwent a standardized functional assessment before and after the rehabilitation program. The evaluation protocol included:

- somatoscopic examination for postural assessment;
- anthropometric measurements;
- joint range of motion assessment using universal goniometry;
- manual muscle testing according to the Medical Research Council (MRC) grading system;
- observational gait analysis focusing on the four physiological phases of gait: initial contact (shock absorption), midstance, propulsion, and swing phase.

The primary outcome measures were joint mobility and muscle strength, whereas gait quality and functional recovery represented secondary outcome measures.

2.4. Rehabilitation Protocol

The rehabilitation program was individualized according to the clinical presentation of each patient while maintaining a standardized therapeutic structure. The intervention was implemented progressively according to the biological stages of tissue healing.

During the acute phase, the RICE protocol (Rest, Ice, Compression, and Elevation) was applied to control pain, edema, and inflammation. Immobilization and therapeutic positioning were prescribed whenever clinically indicated to ensure adequate tissue protection and maintain anatomical alignment. As pain and inflammation subsided, proprioceptive neuromuscular facilitation techniques, including Slow Reversal, Slow Reversal Hold, and Repeated Contractions, were introduced using Kabat diagonal movement patterns to improve neuromuscular recruitment and motor control.

Soft tissue management included therapeutic massage, Instrument-Assisted Soft Tissue Mobilization (IASTM), and cupping therapy to improve fascial mobility, decrease soft tissue restrictions, stimulate local circulation, and reduce pain. The exercise component consisted of individualized therapeutic exercises developed according to the Analytical Therapeutic Exercise (ATE) system, emphasizing progressive restoration of joint mobility, muscle strength, proprioception, balance, and functional movement patterns. Static and dynamic stretching exercises were incorporated to improve flexibility and restore normal muscle length. Kinesiotaping was applied according to the functional deficit identified during clinical evaluation, providing proprioceptive stimulation, biomechanical support, and pain modulation throughout the rehabilitation process.

The final stage of rehabilitation focused on gait re-education through progressively loaded walking exercises, treadmill training, and functional activities designed to restore symmetrical gait mechanics and improve dynamic stability.

3. Discussions

The functional outcomes of the rehabilitation program were assessed by comparing the initial and final evaluations performed for all ten participants. The analysis focused on joint mobility, muscle strength, pain intensity, and gait performance, providing an overall perspective on the functional evolution achieved following the multimodal rehabilitation protocol.

1.Joint Mobility Evaluation

Goniometric measurements targeted the main post-traumatic deficient movements (knee flexion and extension, ankle dorsiflexion and plantarflexion). The average values obtained by the sample of 10 patients indicate a significant recovery of the range of motion (ROM):

Table 1. Dynamics of the sample's average goniometric values (n=10)

JOINT / MOVEMENT	INITIAL VALUE (AVERAGE)	FINAL VALUE (AVERAGE)	RESIDUAL DEFICIT
Knee - flexion	85°	130°	Absent
Knee - extension	-10° (deficit)	0° (complete)	Absent
Ankle - dorsiflexion	8°	20°	Absent
Ankle - plantarflexion	25°	45°	Absent

2. Muscle Strength Evaluation (Manual Muscle Testing - 0-5 Scale)

Table 2. Manual Muscle Testing according to the Medical Research Council (MRC) Scale

Muscle group	Initial Assessment	Final Assessment
Quadriceps	2+	4
Hamstrings	2	4
Gastrocnemius	2+	4+
Gluteus maximus	3	4+

Before starting treatment, due to immobilization and antalgic phenomena, the average muscle strength of the large groups (quadriceps, hamstrings, gastrocnemius, gluteus maximus) was between grades 2 and 3. The application of Repeated Contractions (RC) techniques and Kabat diagonals allowed overcoming these strength "gaps". Manual Muscle Testing demonstrated a substantial increase in muscle strength across all evaluated muscle groups. Initial assessments indicated moderate muscle weakness following injury, whereas final evaluations showed recovery to near-normal muscle strength, suggesting improved neuromuscular activation and functional stability.

- **Initial Evaluation:** Average muscle strength of the lot = **2+** (movements possible through the full range only with gravity eliminated or with minimal resistance).
- **Final Evaluation:** Average muscle strength of the lot = **4+** (ability to execute movement against maximum resistance, close to the values of the healthy limb).

3. Functional Gait Analysis

Table 3. Observational gait analysis before and after rehabilitation

Gait Parameter	Initial Assessment	Final Assessement
Initial contact (shock absorption)	Painful heel strike, reduced shock absorption	Normal heel strike with effective shock absorption
Midstance	Reduce weight-bearing on affected limb	Symmetrical weight-bearing
Propulsion	Weak push-off, decreased ankle plantarflexion	Effective propulsion with adequate push-off
Swing phase	Reduced limb advancement and asymmetrical gait	Symmetrical swing phase and coordinated limb advancement

Gait analysis demonstrated progressive normalization of the locomotor pattern throughout the rehabilitation period. At baseline, all participants presented an antalgic gait characterized by reduced stance time on the affected limb, diminished shock absorption during initial contact, and impaired propulsion. Following completion of the rehabilitation program, symmetrical weight-bearing, restoration of the physiological gait cycle, and improved dynamic stability were observed in all participants. Walking speed and functional mobility also improved, reflecting successful reintegration of coordinated locomotor mechanics

4. Conclusions

The present study explored the potential contribution of a multimodal physical therapy program integrating therapeutic exercise, Proprioceptive Neuromuscular Facilitation (PNF), Instrument-Assisted Soft Tissue Mobilization (IASTM), cupping therapy, kinesiotaping, therapeutic massage, and stretching in the rehabilitation of patients with post-traumatic lower limb injuries.

The rehabilitation protocol was associated with improvements in joint range of motion, muscle strength, pain reduction, and gait performance, suggesting a progressive restoration of lower limb function following conservative treatment. The combination of active therapeutic exercise with complementary rehabilitation techniques provided a comprehensive approach addressing both musculoskeletal impairments and functional limitations commonly observed after lower limb trauma.

Although therapeutic exercise remains the cornerstone of post-traumatic rehabilitation, adjunctive interventions such as PNF, IASTM, cupping therapy, and kinesiotaping may contribute to optimizing clinical recovery when incorporated according to individual patient needs and the stage of tissue healing.

The findings of this study should be interpreted in light of its limitations, including the small sample size, the absence of a control group, and the illustrative nature of the presented data. Consequently, the results cannot establish the superiority of the multimodal protocol over conventional rehabilitation but rather support its potential clinical applicability.

Future research involving larger patient populations, randomized controlled designs, standardized intervention protocols, and long-term follow-up is required to further clarify the effectiveness of multimodal rehabilitation strategies in the management of post-traumatic lower limb injuries.

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Review article

THE EVOLUTION OF THE ROMANIAN WOMEN'S NATIONAL HANDBALL TEAM AT THE IHF WOMEN'S WORLD CHAMPIONSHIPS: A HISTORICAL ANALYSIS (1957–2025)

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Abstract

Women's handball is one of the most successful and representative sports in Romania, having made a significant contribution to the country's international sporting prestige. The aim of the present study was to analyse the participation and competitive achievements of the Romanian women's national handball team at the IHF Women's World Championships between 1957 and 2025 and to compare these results with those of the other Balkan national teams. The research was conducted as a systematic review following the PRISMA 2020 guidelines for the identification, selection, and evaluation of relevant literature. A total of 20 sources were included in the review, comprising 12 scientific studies and 8 official documents published by the International Handball Federation (IHF) and the Romanian Handball Federation (FRH). Historical, comparative, and descriptive statistical methods were applied, and the findings were synthesized using tables and graphical representations.

The results indicate that Romania is the only national team to have participated in every edition of the IHF Women's World Championship, recording a total of 22 appearances during the analysed period. The comparative analysis showed that Romania ranks first among the Balkan countries in terms of participation continuity, whereas the former Yugoslavia achieved the highest number of World Championship medals. The evolution of Romania's final rankings reflects both periods of outstanding success, including the silver medal won in 2005 and the bronze medal obtained in 2015, and periods of reconstruction and adaptation to the increasing level of international competition.

In conclusion, the study confirms Romania's historical role as the leading representative of the Balkan region in international women's handball and highlights the importance of continuity, tradition, and long-term development in maintaining elite sporting performance. Furthermore, the review provides an updated synthesis of the historical evolution of Romanian women's handball and may serve as a valuable reference for future comparative studies investigating the international performance of women's national handball teams.

Keywords: women's handball, Romania, World Championships, performance analysis, Balkan countries, sports history.

1. Introduction

Handball represents one of the most popular sports disciplines in Europe and one of the team sports characterized by the highest dynamism and technical-tactical complexity. Defined by a rapid alternation between offensive and defensive phases, high physical demands, and the necessity for permanent cooperation among teammates, handball contributes to the harmonious development of practitioners' motor, cognitive, and socio-affective abilities (Bompa & Buzzichelli, 2019). Currently, this sport is practiced at a professional level across all continents under the governance of the International Handball Federation (IHF), an organization that promotes the development and standardization of international competitions.

In Romania, handball holds a special place in the history of national sport, being one of the disciplines that has yielded the most significant international achievements. The development of Romanian handball is closely linked to the modernization process of physical education and sports during the first half of the 20th century. The first organized forms of handball practice were introduced in Transylvania in the early 1920s, through the influence of physical education teachers trained in Germany, where the game had already experienced considerable development (Romanian Handball Federation [RHF], 2024).

Over time, handball has become one of the most important team sports in Romania, benefiting from a broad base of practitioners and a well-organized competitive system. Beginning in the 1950s, Romania emerged as one of the great powers of world handball, both in the men's and women's categories. The national teams have secured numerous world titles, Olympic medals, and European trophies, contributing to the consolidation of the prestige of Romanian sports on the international stage (IHF, 2024).

The period between the 1960s and 1980s is considered by many specialists to be the "golden age" of Romanian handball. During this era, the Romanian men's team won four world titles (1961, 1964, 1970, and 1974), an achievement unmatched by many of the world's leading handball nations. Concurrently, the women's team achieved remarkable results, culminating in the world title won in 1962 and the silver medals obtained at the World Championships in 1973 and 2005 (IHF, 2024).

However, the importance of handball to Romanian sports extends beyond the realm of competitive performance. Practicing this game contributes to the development of essential competencies such as teamwork, discipline, responsibility, communication skills, and psychological resilience. Studies in the field of sports sciences highlight that participation in collective sports fosters social integration and the development of prosocial behaviors, aspects that are particularly important in the educational process of young people (Weinberg & Gould, 2019).

In the context of sports globalization and rising international competitive standards, Romanian handball has undergone numerous transformations. The economic and social changes that occurred after 1990 influenced the structure of the national sports system, generating both challenges and opportunities for the development of athletic performance. Nevertheless, Romania has continuously maintained its presence at the most important international competitions, preserving its status as a nation with a rich tradition in women's handball. A relevant argument in this regard is that the Romanian women's national representative is the only team to have participated in all editions of the IHF Women's World Handball Championship organized to date (IHF, 2024).

The evolution of Romanian women's handball is closely linked to the contribution of exceptional athletes who have left their mark on the history of this sport. Players such as Cristina Neagu, Luminița Dinu, Valentina Ardean-Elisei, Narcisa Lecușanu, or Aurelia Brădeanu have contributed to achieving major results and have served as role models for future generations of athletes. In particular, Cristina Neagu is widely considered one of the most valuable handball players in the history of the sport, having been named World Handball Player of the Year four times by the International Handball Federation (IHF, 2024).

The analysis of the evolution of Romanian handball and the participation of the women's national team in the World Championships is of particular importance from both a historical perspective and a sports performance standpoint. Studying the results obtained over time allows for the identification of factors that influenced the success or decline of performance, while also highlighting the role that Romania has played in the development of international handball. Furthermore, such analyses can contribute to the formulation of future development strategies and to leveraging the experience accumulated by previous generations.

Therefore, handball represents one of the most critical components of the Romanian sports heritage, and the analysis of its evolution provides a relevant perspective on how athletic performance can influence a nation's identity and global image. Within this context, the present article aims to conduct a review analysis on the evolution of Romanian handball and the participation of the women's national team in the World Championships, highlighting the main historical milestones and performances that have contributed to consolidating Romania's status within the elite of world handball.

The purpose of this research was to analyze and evaluate the participation and performance of the Romanian women's national handball team at the World Championships organized by the International Handball Federation (IHF) during the 1957–2025 period, as well as to compare the results obtained with those of other representative teams from the Balkan region.

The research was conducted in accordance with the PRISMA 2020 methodology recommendations for systematic reviews. The research process involved identifying, selecting, and evaluating relevant scientific studies, as well as collecting and verifying official statistical data regarding the participations and performances of the Romanian women's national handball team and other Balkan countries at the IHF Women's World Handball Championships.

The studies included in the analysis were methodologically evaluated and qualitatively analyzed, while the historical and statistical data were organized into comparative tables and graphical representations. Subsequently, the information was processed using descriptive and comparative methods to highlight the evolution of participations, athletic performances, and Romania's position within the context of Balkan and world women's handball.

2. Main text

Material and Methods

The present research was conducted in accordance with the recommendations of the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology and was based on the documentary and statistical analysis of the Romanian women's national handball team's participation in the IHF Women's World Handball Championships during the 1957–2025 period. The study aimed to integrate information from specialized literature with official statistical data in order to perform a comparative analysis regarding Romania's position within the context of Balkan and world women's handball.

Research Material

The material utilized in this research consisted of documentary and statistical sources concerning the evolution of women's handball and the participation of the Romanian women's national handball team in the World Championships. The process of identifying and selecting the studies was carried out in accordance with the PRISMA 2020 methodology by consulting the Google Scholar, Scopus, Web of Science, and ResearchGate databases, as well as official documents published by the International Handball Federation (IHF) and the Romanian Handball Federation (RHF).

The documentary material included:

- specialized literature regarding the history and evolution of handball;
- scientific articles published in peer-reviewed journals;
- official databases and statistics from the International Handball Federation;
- documents and materials published by the Romanian Handball Federation;
- official standings and results of the IHF Women's World Handball Championships;
- bibliographical sources concerning the development of women's handball in Romania and the Balkan region.

The source selection process comprised the stages of identification, removal of duplicate records, screening, eligibility assessment, and inclusion in the final analysis, in accordance with the PRISMA 2020 methodology recommendations (Figure 1). Following the application of the inclusion and exclusion criteria, 20 relevant sources were selected; among these, 12 scientific studies were included in the qualitative literature analysis, and 8 official documents published by the International Handball Federation (IHF) and the Romanian Handball Federation (RHF) were utilized to verify and supplement the historical and statistical data analyzed in the present study.

The unit of analysis consisted of the participations and results of the Romanian women's national handball team at the World Championships held between 1957 and 2025, alongside the performances of the women's national representative teams from other countries in the Balkan region.

The bibliographical study method

The bibliographical study method consisted of identifying, selecting, and critically analyzing scientific studies related to women's handball, the World Championships, and national team performance. Eligible studies were selected in compliance with the PRISMA 2020 methodology and formed the theoretical foundation of the research.

The historical method

The historical method was employed to present the chronological evolution of Romanian women's handball and to highlight the pivotal moments that influenced the development of this sport. Concurrently, this method enabled the analysis of the evolution of the Romanian women's national handball team's participations and performances at the World Championships throughout the analyzed period.

The comparative method

The comparative method was utilized to analyze Romania's participations and performances in relation to the other national representative teams from the Balkan region. The comparison was carried out based on the following indicators:

- the total number of participations in the World Championships;
- the number of medals obtained;
- the number of qualifications for the semifinals and finals;
- the final standings achieved throughout the analyzed period.

The Statistical Analysis Method

The collected data were centralized and processed using descriptive statistics methods. Absolute and relative frequencies of participations and performances were calculated, and the information was organized into synthetic tables and comparative graphical representations. The statistical analysis enabled the identification of evolutionary trends in the performances of the Romanian women's national handball team and their comparison with those of the other Balkan representatives.

The graphical method

To facilitate the interpretation of the results, graphical representations were constructed regarding the participations, standings, and performances of the analyzed teams at the IHF Women's World Handball Championships. The graphs allowed for a visual highlight of the evolution of athletic performance and a comparison of the results achieved by Romania with those of the other Balkan countries.

Research organization

The research was carried out in three main stages:

- Stage I – Documentation: which involved identifying and selecting relevant scientific studies and official documents according to the PRISMA 2020 methodology;
- Stage II – Data Collection and Processing: which consisted of centralizing statistical information regarding the participations and results of the analyzed teams and organizing them into tables and graphical representations;
- Stage III – Analysis and Interpretation of Results: during which statistical comparisons between Romania and the other Balkan countries were performed, followed by the formulation of the research conclusions.
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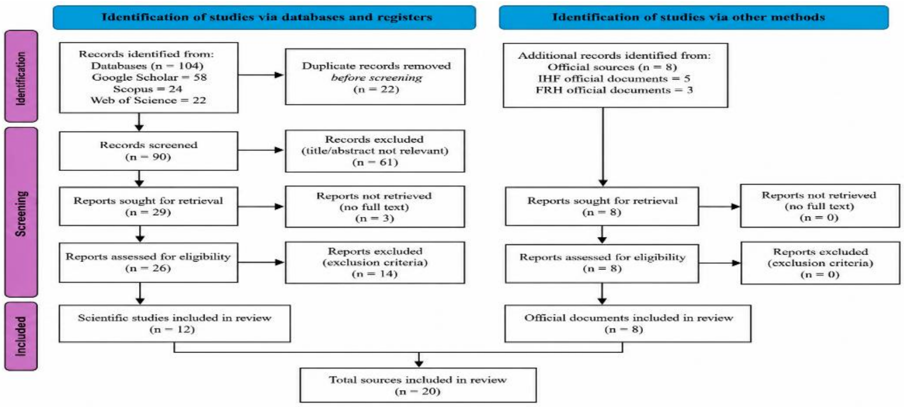

Figure 1. PRISMA diagram

By utilizing these methods, the study aimed to provide a comprehensive overview of the evolution of Romanian women's handball and to highlight Romania's standing within world and Balkan women's handball during the 1957–2025 period.

Figure 1 presents the PRISMA 2020 flow diagram illustrating the identification, screening, eligibility assessment, and inclusion of the sources considered relevant for the present review. The selection process involved the removal of duplicate records, title and abstract screening, full-text eligibility assessment, and final inclusion of the eligible sources. Following the application of the predefined inclusion and exclusion criteria, a total of 20 sources were included in the review, comprising 12 scientific studies and 8 official documents provided by the International Handball Federation (IHF) and the Romanian Handball Federation (FRH). The application of the PRISMA 2020 methodology ensured a transparent, systematic, and reproducible selection process for the literature and official statistical data included in this review.

Table 1. Methodological Quality Assessment of the Studies Included in the Review

Reference	Score	%	Quality	Argument
Leuciuc (2012)	8/10	80%	High	The study is relevant to Romania's performance at the 2011 Women's World Championship; however, its applicability is limited because it focuses on a single tournament edition.
Leuciuc (2018)	9/10	90%	High	The study provides a comprehensive comparative analysis of European and non-European teams, offering valuable evidence for positioning Romania within the international context.
Skoufas et al. (2019)	9/10	90%	High	The study examines several Women's World Championship editions and identifies technical and tactical performance indicators associated with competitive success.
Gheorghe et al. (2020)	8/10	80%	High	The study contributes to the analysis of Romania's performance at the 2019 Women's World Championship but focuses primarily on attacking efficiency rather than overall team performance.
Laporta et al. (2021)	8/10	80%	High	The study provides valuable information on offensive performance indicators in elite women's handball, although its relevance to the Romanian national team is indirect.
Gómez-López et al. (2023)	9/10	90%	High	The study employs a contemporary analytical approach to offensive performance and provides strong theoretical support for interpreting competition results.
Konstantinos et al. (2018)	9/10	90%	High	The study demonstrates the relationship between performance indicators and final ranking, supporting the use of statistical analysis in the present research.
Daza et al. (2017)	8/10	80%	High	The study highlights the predictive value of match statistics for competitive success, although it is not exclusively focused on women's World Championships.
Ferrari et al. (2018)	8/10	80%	High	The study identifies key characteristics of World Championship-winning teams and provides useful benchmarks for evaluating Romania's performance.
Krawczyk et al. (2025)	9/10	90%	High	The study offers an up-to-date analysis of elite women's handball performance indicators, although it focuses on the European Championship rather than the World Championship.
IHF (2025)	9/10	90%	High	The official source provides reliable historical and statistical information essential for verifying participation records and competition results, although it does not include scientific analysis.
IHF Activity Report (2021–2023)	8/10	80%	High	The report contains official competition statistics and organizational information but has a documentary rather than a research-oriented methodological approach

The quality assessment of the included sources was conducted using ten predefined criteria related to the clarity of the objective, appropriateness of the methodology, relevance of the material analysed, quality of data presentation, and usefulness for the present review. The scores ranged between 80% and 90%, indicating that all selected sources were of high methodological or documentary relevance. Scientific studies received higher scores when they presented clear objectives, appropriate statistical or comparative methods, and results directly connected to women's handball performance, while official reports were considered highly reliable for statistical verification but less detailed from a methodological perspective.

Table 2. Characteristics of the sources included in the review

Author, year	**Study objective**	**Methodology**	**Sample/Material**	**Main findings**	**Relevance to the present study**
Leuciuc (2012)	Analysis of Romania's participation in the 2011 Women's World Championship	Statistical analysis	Romanian national team at the 2011 World Championship	Main strengths and limitations of the team were identified	Provides data on Romania's performance at the world level
Leuciuc (2018)	Comparison of European and non-European teams in the Women's World Championship	Comparative and statistical analysis	Teams participating in the Women's World Championship	European teams dominated the competition	Supports the analysis of Romania's position in the international context
Skoufas et al. (2019)	Analysis of the last five Women's World Championships	Technical-tactical analysis	International matches	Performance indicators associated with competitive success were identified	Supports the interpretation of sports performance
Gheorghe et al. (2020)	Analysis of Romania's attacking efficiency at the 2019 Women's World Championship	Observational analysis	Romanian national team	Attacking efficiency influences final results	Complements the evaluation of recent performances
Laporta et al. (2021)	Offensive indicators of Spain at the 2019 Women's World Championship	Statistical analysis	Spanish national team	Key offensive indicators were identified	Allows comparisons with elite teams
Gómez-López et al. (2023)	Analysis of offensive performance in handball	Spatial analysis	Elite handball teams	Offensive organization influences success	Supports the interpretation of World Championship performances
Konstantinos et al. (2018)	Relationship between performance indicators and ranking	Statistical analysis	Handball teams	Certain indicators predict final ranking	Justifies the use of statistical analysis
Daza et al. (2017)	Predictive indicators of performance	Statistical analysis	International competitions	Match statistics can predict success	Supports the study methodology
Ferrari et al. (2018)	Analysis of World Championship winning teams	Comparative analysis	Senior and junior world champions	Characteristics of elite performance were identified	Provides benchmarks for evaluating Romania's performance
Krawczyk et al. (2025)	Performance analysis at the 2022 Women's European Championship	Statistical analysis	Participating teams	Significant differences were found between winning and losing teams	Provides a modern perspective on performance analysis
IHF (2025)	Romania's profile at the Women's World Championship	Documentary analysis	Official IHF statistics	Historical participation and performance data	Supports verification of statistical information

Author, year	**Study objective**	**Methodology**	**Sample/Material**	**Main findings**	**Relevance to the present study**
				were presented	
IHF Activity Report (2021–2023)	Analysis of international handball competitions	Documentary analysis	Official IHF reports	Official competition statistics were reported	Validates historical and statistical data used in the review

Table 2 summarizes the main characteristics of the sources included in the present review. For each study, information regarding the author(s), publication year, study objective, methodology, sample or material analyzed, principal findings, and relevance to the present research was extracted and synthesized. The selected literature comprises statistical, comparative, observational, and documentary studies focused on women's handball performance, World Championship participation, and competitive success. In addition, official documents published by the International Handball Federation (IHF) were included to verify and complement the historical and statistical information analyzed. Overall, the selected sources provide a comprehensive scientific and documentary basis for evaluating Romania's participation and achievements in the IHF Women's World Championships within the Balkan context.

Table 3 summarizes the participation records and medal achievements of the Balkan countries at the IHF Women's World Championships between 1957 and 2025. Romania recorded the highest number of participations, demonstrating remarkable continuity at the highest international level. Although Yugoslavia participated in fewer editions, it achieved the greatest number of medals, reflecting its exceptional competitive success during the analysed period. Serbia remains the only other Balkan nation to have won a World Championship medal, while the remaining countries have experienced more limited international achievements. These findings underline Romania's leading role in terms of continuity and highlight the historical competitive strength of Yugoslavia in women's handball.

Table 3. Participation and medal achievements of Balkan countries at the IHF Women's World Championships (1957–2025)

Country	Participations	Gold	Silver	Bronze	Total medals
Romania	22	0	2	2	4
Yugoslavia	13	2	2	2	6
Croatia	8	0	0	0	0
Serbia	7	0	0	1	1
Montenegro	6	0	0	0	0
North Macedonia	5	0	0	0	0
Slovenia	5	0	0	0	0
Bulgaria	3	0	0	0	0
Greece	2	0	0	0	0
Bosnia & Herz.	1	0	0	0	0
Albania	1	0	0	0	0
Türkiye	4	0	0	0	0

Figure 2 illustrates the distribution of World Championship participations among the Balkan countries during the period 1957–2025. Romania clearly leads the region with the highest number of appearances, confirming its long-standing presence in elite international women's handball. Yugoslavia ranks second, followed by Croatia and Serbia, whereas the remaining Balkan countries have participated considerably less frequently. The figure emphasizes the substantial differences in competitive continuity across the region and highlights Romania's consistent qualification for the World Championship over nearly seven decades.

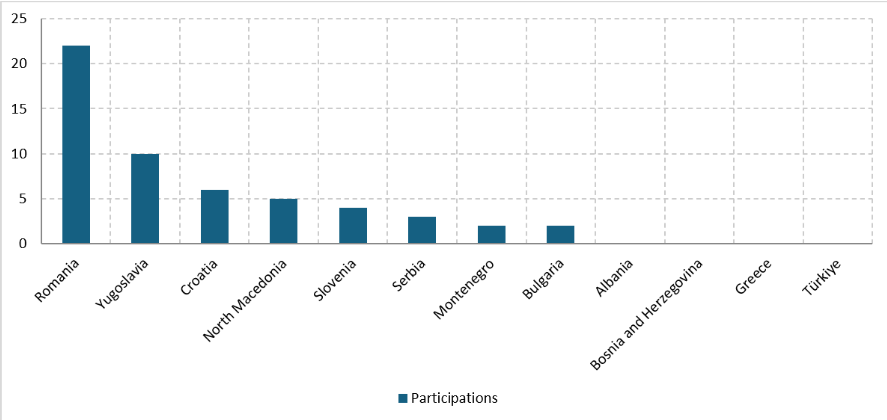

Figure 2. World Championship Participation

Results

The comparative analysis of the historical participation and competitive achievements of the Balkan countries in the IHF Women's World Championships between 1957 and 2025 reveals substantial differences regarding continuity, international competitiveness, and long-term sporting success

The statistical data presented in Table 3 demonstrate that Romania has recorded the highest number of participations among all Balkan countries. This finding confirms the long-standing tradition and continuity of Romanian women's handball at the highest international level. Romania has been consistently represented in the World Championship throughout almost seven decades, reflecting the stability of its national handball program and its ability to qualify for elite international competitions across different generations of athletes. By comparison, Yugoslavia occupies the second position in terms of total participations, while Croatia, North Macedonia, Slovenia, Serbia, Montenegro, Bulgaria, Albania, Bosnia and Herzegovina, Greece, and Türkiye have participated considerably less frequently.

Although Romania achieved the greatest continuity of participation, the distribution of medals presents a different competitive perspective. As illustrated in Figure 2, Yugoslavia obtained the largest number of World Championship medals, benefiting from an exceptionally successful period during the second half of the twentieth century. Romania follows closely, with multiple podium finishes that confirm its historical status as one of the strongest women's handball nations worldwide. Serbia remains the only other Balkan country to have secured a World Championship medal during the analysed period, whereas the remaining national teams have not reached the medal positions.

The comparative graphical analysis further highlights the unequal competitive development of women's handball across the Balkan region. Romania and the former Yugoslavia clearly dominate the historical rankings, while the remaining countries have generally experienced sporadic participation or limited competitive success. These differences may be explained by variations in the historical development of handball, national investment in elite sport, coaching traditions, and the continuity of youth development systems.

The evolution of Romania's final rankings throughout the analysed period demonstrates several distinct competitive phases. During the early decades of the Women's World Championship, Romania consistently occupied leading positions and established itself among the world's strongest national teams. Subsequently, the team experienced periods of fluctuating performance, alternating between top-eight finishes and lower rankings. Nevertheless, Romania has maintained a constant presence at the World Championship, illustrating the resilience and long-term competitiveness of its women's handball programme despite the increasing level of international competition.

The historical analysis also indicates that the balance of power within women's handball has gradually shifted over time. While Romania and Yugoslavia dominated the early editions of the World Championship, recent decades have witnessed the emergence of new leading nations outside the Balkan region. Despite this increased global competitiveness, Romania has continued to qualify regularly for the tournament, preserving its position as the most consistently represented Balkan nation.

The comparison between participation frequency and medal achievements suggests that continuity alone does not necessarily guarantee competitive success. Although Romania participated in more World Championships than any other Balkan country, Yugoslavia converted a larger proportion of its appearances into medals. This observation highlights the importance of performance efficiency in addition to participation continuity. At the same time, Romania's sustained presence at the highest competitive level represents an important indicator of the country's long-term sporting tradition and organizational stability.

Overall, the results confirm the leading position of Romania within the Balkan region regarding participation in the IHF Women's World Championships, while also emphasizing the exceptional historical achievements of Yugoslavia in terms of medal success. The findings support the view that Romania has played a fundamental role in the development and international recognition of women's handball in the Balkan area and continues to represent one of the region's most successful national team

Discussion

The present review aimed to evaluate Romania's participation and competitive achievements at the IHF Women's World Championships between 1957 and 2025 and to compare these results with those of the other Balkan countries. The findings confirm Romania's leading position in the region regarding the number of participations, highlighting the country's remarkable continuity in elite international women's handball. This sustained presence over nearly seven decades reflects the long-standing tradition of Romanian handball, the consistency of its qualification process, and the historical importance of the sport within the national sporting system.

Although Romania recorded the highest number of World Championship appearances, the results also demonstrate that Yugoslavia achieved greater efficiency in terms of medal success. This finding suggests that continuity of participation alone does not necessarily translate into superior competitive outcomes, as the quality of performance during each tournament remains a decisive factor. Similar observations have been reported by Nikolaidis et al. (2018), who emphasized that successful international teams are characterized not only by regular participation but also by superior competitive performance and efficiency in decisive matches.

The comparative analysis is also consistent with the conclusions reported by Leuciuc (2018), who highlighted the historical competitiveness of European women's handball and the dominant role of several Balkan nations in international competitions. Likewise, the studies conducted by Skoufas et al. (2019) and Laporta et al. (2021) demonstrated that technical and tactical efficiency, together with offensive performance indicators, represent essential determinants of success at major international tournaments. Although the present study did not analyse match statistics directly, the historical comparison of participations and final rankings complements these findings by providing a broader perspective on long-term competitive performance.

Recent research has increasingly focused on performance analysis in elite women's handball. Gómez-López et al. (2023) and Krawczyk et al. (2025) reported that modern match analysis and advanced performance indicators provide valuable information for understanding success at the highest competitive level. The present review extends these perspectives by integrating historical records, official statistics, and comparative analyses to evaluate the evolution of Balkan women's handball over an extended period. In addition, the inclusion of official documents published by the International Handball Federation ensured the accuracy and reliability of the historical data used throughout the study.

An important strength of the present review is the combination of scientific evidence with official documentary sources, allowing a comprehensive evaluation of Romania's historical achievements within the Balkan context. Furthermore, the application of the PRISMA 2020 methodology increased the transparency and reproducibility of the literature selection process. Nevertheless, several limitations should be acknowledged. The review relied primarily on historical and documentary evidence and did not include advanced statistical modelling or detailed match-performance indicators for every World Championship edition. Future studies should integrate technical, tactical, and physiological performance variables to provide a more comprehensive understanding of the factors contributing to long-term international success in women's handball.

Overall, the findings confirm Romania's historical importance in international women's handball and reinforce its status as the most consistently represented Balkan nation at the IHF Women's World Championships. The study also demonstrates that combining systematic literature review methods with official statistical documentation provides a robust framework for analysing the historical evolution of elite team sports.

3. Conclusions

The present study provides a comprehensive historical and comparative analysis of Romania's participation in the IHF Women's World Championships between 1957 and 2025, placing the national team's achievements within the broader context of the Balkan region. By combining evidence from scientific publications with official statistical documents issued by the International Handball Federation (IHF) and the Romanian Handball Federation (FRH), the review offers a systematic overview of the evolution of Romanian women's handball at the highest international level.

The findings demonstrate that Romania occupies a leading position among the Balkan countries regarding the number of participations in the Women's World Championships. This continuity reflects the country's long-standing tradition in women's handball, the stability of its national programme, and its sustained ability to qualify for elite international competitions over several decades. Although Yugoslavia achieved a higher number of World Championship medals, Romania remains the most consistently represented Balkan nation throughout the analysed period, confirming its historical importance in international women's handball.

The comparative analysis further revealed considerable differences in competitive success among the Balkan countries. While Romania and the former Yugoslavia established themselves as the dominant representatives of the region, the remaining national teams recorded fewer participations and more limited international achievements. These findings emphasize the unequal historical development of women's handball across the Balkan area and highlight the importance of long-term investment in athlete development, coaching expertise, and organizational continuity.

The systematic review of the literature showed that the selected scientific studies consistently identify technical, tactical, statistical, and organizational factors as key determinants of international success. The integration of these findings with official historical statistics strengthened the interpretation of Romania's competitive evolution and provided a comprehensive understanding of the country's sporting achievements. The application of the PRISMA 2020 methodology also contributed to a transparent and reproducible process of source identification, selection, and evaluation, increasing the methodological rigor of the present review.

Despite its contributions, the study has several limitations. The analysis was based primarily on historical records, official statistics, and published scientific literature, without incorporating detailed match-performance indicators or advanced statistical modelling for each World Championship edition. Consequently, future research should combine historical analyses with technical, tactical, physiological, and performance-related variables in order to obtain a more comprehensive understanding of the factors influencing long-term success in elite women's handball.

In conclusion, the present review confirms Romania's significant historical contribution to international women's handball and reinforces its status as the most consistently represented Balkan nation in the history of the IHF Women's World Championships. Beyond documenting historical achievements, the study provides an updated scientific synthesis that may serve as a valuable reference for researchers, coaches, sports historians, and national federations interested in the development and international performance of women's handball. The methodological approach adopted in this review may also represent a useful framework for future comparative analyses involving other regions, competitions, or team sports.

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Review article

OSTEOPENIA AND VIBRATION THERAPY: A BRIEF NARRATIVE REVIEW

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Abstract

The skeleton is a tissue that undergoes constant remodelling throughout one's life. This is necessary to allow the skeleton develop during growth, respond to the stresses placed on it, and repair structural damage caused by structural fatigue or fracture.

There are three major phases throughout which bone mass changes during one's life: growth, consolidation, and involution. Involutional bone loss starts between the ages of 35 and 40 in both sexes, but in women it is accelerated after the menopause begins.

Osteopenia refers to the reduced bone mineral density below normal values without passing the diagnostic limit for osteoporosis.

Vibration therapy uses mechanical vibrations to contract and relax the muscles. Vibrations pass through the body while the patient stands, sits or lies on a machine. Generally, it can take two forms: Whole-Body Vibration (WBV) or Focal Vibration (FV). During vibration, skeletal muscles rapidly contract and relax at a certain chosen frequency, which promotes muscle anabolism and improved stretch reflex through the activation of one's muscle spindles.

While some studies show that it promotes increases in the bone density, alongside stimulating bone remodelling and generally being an innovative exercise alternative that has a potential use in metabolic disease and in situations in which patients are unable to perform traditional exercises, the evidence is still mixed or contradictory.

The purpose of this article is to review the recent literature regarding the use of vibration therapy in treating bone metabolic disorders and outline potential avenues for future investigation and clinical implementation.

***Keywords**:* Osteopenia, Vibration therapy, Whole-Body Vibration

1. Introduction

Bone is a living, dynamic tissue that undergoes constant remodelling throughout life. This is necessary to allow the skeleton to increase in size during growth, respond to the physical stresses placed on it, and repair structural damage caused by structural fatigue or fracture. The processes of bone resorption and bone formation are usually closely coupled, but bone formation exceeds resorption during skeletal growth, allowing the skeleton to increase in size and density. Later in life resorption outstrips bone formation, leading to involutional bone loss.

Bone mass changes throughout life in three major phases: growth, consolidation, and involution. Up to 90% of the ultimate bone mass is deposited during skeletal growth, which lasts until the closure of the epiphyses. There is then a phase of skeletal consolidation lasting for up to 15 years, when bone mass increases further until the peak mass is achieved in the mid-30s. Involutional bone loss then starts between the ages of 35 and 40 in both sexes, but in women there is an acceleration of bone loss in the decade after the menopause (Fillit et al., 2016, p. 565).

Osteopenia, or low bone mass, refers to reduced bone mineral density below normal values without fulfilling the diagnostic threshold for osteoporosis. Bone mineral density is determined by dual-energy x-ray absorptiometry (DXA). According to the World Health Organization, osteopenia corresponds to a T-score between -1.0 and -2.5, while a T-score less than -2.5 indicates osteoporosis. Osteopenia arises from an imbalance between bone resorption and formation, influenced by aging, estrogen deficiency, inadequate calcium and vitamin D intake, cigarette smoking, a sedentary lifestyle, and certain medications such as glucocorticoids (Varacallo et al., 2026).

The human skeleton is not a static structure; it a metabolically active tissue in a state of continuous remodelling. This ongoing remodeling serves several essential functions: ensuring skeletal growth, adapting to different types of mechanical load, and repairing microdamage before it progresses to an actual fracture.

Under normal circumstances, bone resorption and bone formation are 2 complementary processes. During growth, however, the formation is the main process, allowing the skeleton to expand in both size and mineral density. With advancing age, this balance scales in the opposite direction, and resorption begins to outpace formation which in time leads to bone loss.

Skeletal mass evolves across three broad phases. The first, the growth phase, accounts for roughly 90% of the eventual bone mass formation, ending with the epiphyseal closure. A consolidation phase follows, extending up to 15 years after this point, during which bone mass continues to rise toward its peak, which is typically reached in the mid-30s for both males and females. After that, involutional loss sets in gradually in both men and women from around the age of 35–40. Women, however, face an additional challenge: the years immediately following menopause are associated with an accelerated phase of bone loss that substantially compounds this age-related decline (Fillit et al., 2016, p. 565).

Vibration therapy uses mechanical vibrations to contract and relax the muscle fibers. Vibrations pass through the body while the patient stands, sits or lies on a specific machine. Usually, it can be used in two ways: Whole-Body Vibration (WBV) or Focal Vibration (FV) (Physiopedia, n.d.; Royal Osteoporosis Society, n.d.).

During vibration, muscles oscillate rapidly between contraction and relaxation at a certain calculated frequency, which in turn promotes muscle anabolism and eventual improved stretch reflex through the activation of the targeted muscle spindles.

While some studies show that it promotes increases in the bone density, alongside stimulating bone remodeling and generally being an innovative exercise alternative that has a potential use in metabolic disease and in situations in which patients are unable to perform traditional exercises (National Library of Medicine, n.d), the evidence is still mixed or contradictory (Harvard Health Publishing, 2011).

This narrative review synthesizes findings from 40 different sources containing randomized controlled trials, systematic reviews, meta-analyses, animal/ in vitro studies, and one book chapter examining the effects of vibration therapy on bone health. It must be noted that the literature on axial vibration therapy for osteopenia specifically is still limited, thus, this review extrapolates from the pre-existing adjacent studies: studies on osteoporosis and on WBV more broadly (axial vibration is a mechanistically equivalent delivered through the lower limbs). These extrapolations are mentioned in their given chapters.

We address six main questions: (1) What are the general trends and findings across the present literature and the given sources? (2) What can we extrapolate to osteopenia and axial vibration from the literature? (3) What are the main characteristics of the study populations and which are the most vulnerable groups? (4) What mechanisms does vibration therapy act with on the bone? (5) What are the main limitations and scientific gaps in knowledge at this point? (6) What are the clinical implications of these findings for practice and future research?

2. Main text

1. General trends and findings

Across the sources reviewed, the general image is mixed. Vibration therapy appears capable of slowing or even vaguely reversing bone density decline specifically at the proximal femur and lumbar spine, but the actual effect varies considerably depending on the chosen vibration protocol, population characteristics, intervention duration, and the measurement tools used.

1.1 BMD outcomes: stabilization more reliable than reversal

The most consistent finding across the given studies, including the meta-analyses and the systematic reviews is that vibration therapy is more effective at maintaining the bone mass density compared to actually increasing it in a notable way.

For example, Yin et al. (2024), in a comprehensive overview of 15 systematic reviews involving thousands of participants, explicitly conclude that WBV should be recommended for maintaining bone mass density (BMD) in postmenopausal women rather than improving it. This is a conclusion with direct clinical relevance for the management of osteopenia, where preventing progression to osteoporosis is the primary goal.

That said, several sources show notable positive BMD changes under specific conditions. Regina Dantas Jales de Oliveira et al. (2022), in the largest meta-analysis in the reviewed corpus (23 RCTs, n=2,089), found significant improvements in lumbar spine and trochanter BMD specifically for the protocol combining low frequency (~30 Hz) and low magnitude (~0.3 g) over a high cumulative dose (>7,000 minutes, equivalent to daily 20-minute sessions for approximately one year). Li et al. (2024), in a meta-analysis of 13 RCTs, found significant improvements in both lumbar spine and femoral neck BMD at 6 months, though these effects were not sustained at 12-month follow-up, suggesting either a physiological adaptation plateau or insufficient protocol duration.

Importantly, Sen et al. (2020), one of the few direct RCTs in the osteopenic range (T-score −2.0 to −3.0), found significant BMD gains at the femoral neck (+5.0%, p=0.003) and L2–L4 (+1.3%, p=0.005) after 6 months, alongside functional and quality-of-life improvements, providing evidence that positive BMD effects are achievable in this population.

1.2 Site-specificity: the axial transmission pattern

A mechanical pattern of site-specificity emerges consistently across the literature. Chen et al. (2026), confirmed that the most responsive skeletal sites are those closest to the vibration source: Ward's triangle, the greater trochanter, femoral neck, and L2–L4; all located in the lower axial chain. Effects diminish when it comes to distal sites and are inconsistent at the lumbar spine in aggregate analyses, though subgroup analyses under optimal conditions show some effects.

This pattern is mechanically predictable: vibration enters the body through the feet and is progressively attenuated as it travels up the skeleton. Chen et al. (2026) quantify this precisely, noting that vibration transmissibility peaks at the ankle (10–40 Hz), knee (10–25 Hz), and hip/spine (10–20 Hz), with transmitted power dropping to as little as 1/1000th of platform output at higher frequencies or distal sites. Qin et al. (2019), studying axial vibration through the foot in a bed-rest disuse model, demonstrated significant protective effects specifically at the calcaneus but not at the femoral neck, further confirming the mentioned pattern.

This site-specificity has direct implications for axial vibration therapy design: targeting the calcaneus, tibia, and proximal femur is mechanically sound, while expecting significant lumbar spine effects from standing-platform protocols requires high cumulative doses and optimal transmission conditions (e.g., semi-flexed knees, which Oliveira et al. (2016) and de Oliveira et al. (2022) identify as superior to extended-knee postures for maintaining transmissibility to the spine).

1.3 Protocol heterogeneity: A field-wide challenge

The biggest challenge across the given literature is the high heterogeneity of vibration protocols used across studies. Frequencies range from 8 to 90 Hz, magnitudes from 0.15 g to 12 g, session durations from 1 minute to 1 hour, session frequencies from twice weekly to daily, and intervention durations from 4 weeks to 22 months. This variability means that aggregating results across studies often produces null or highly uncertain pooled effects that hide the real effects found within specific protocol subgroups.

Fratini et al. (2016) demonstrate this exact problem: when all WBV studies are pooled indiscriminately, the weighted mean difference is near zero. But when studies are grouped by a specific parameter, clear significant effects emerge (e.g side-alternating platforms (Bemben, 2020) or magnitudes above 3 g). DadeMatthews et al. (2022), in a meta-analysis of 40 RCTs, found that frequency across the 6–90 Hz range was not a significant moderator of BMD outcomes, suggesting that within the clinically used range, frequency alone is insufficient to predict efficacy, and protocol combinations (e.g. platform type x magnitude x frequency x total cumulative dose) determine outcomes.

1.4 Measurement tool sensitivity

A reccuring theme is the insensitivity of dual-energy X-ray absorptiometry (DXA), which is the most commonly used measurement tool, to the microstructural bone improvements that vibration therapy intends to produce. Rajapakse et al. (2021), in a double-blind RCT, found significant improvements in tibial stiffness (+1.31% vs −2.55% in placebo, $p=0.01$), trabecular bone volume fraction, and vertebral marrow fat fraction by MRI, yet no significant DXA-measured BMD differences between the groups. Bilek et al. (2024) similarly found significant per-protocol benefits using CT-based biomechanical computed tomography (BCT) that were absent on the DXA evaluations. Both studies explicitly attribute this to DXA's inability to detect microstructural changes that are clinically significant for bone strength.

This measurement issue has important implications for the interpretation of the literature: The many studies reporting null DXA results for vibration therapy may be underestimating the effects of vibration therapy rather than accurately characterising the biological effects of the intervention. More sensitive imaging modalities (pQCT, HR-pQCT, BCT, MRI-based stiffness) and biochemical markers are needed for a detailed picture.

1.5 Secondary benefits: consistent and clinically meaningful

Even in studies where BMD effects are equivocal or absent, improvements in musculoskeletal function, balance, and fall-related outcomes are reported with notable consistency. This is clinically significant because, for osteopenic patients, fall prevention is at least as important as BMD improvement. Falls are the proximate cause of over 90% of hip fractures (Beck et al., 2022, Ma et. al., 2016).

Dutra et al. (2016), in 122 osteopenic postmenopausal women over 12 months, found significant improvements in hip flexor strength (+36.7%), back extensor strength (+36.5%), grip strength, arm curl test, flexibility, and Timed Up and Go (TUG) mobility while using low-intensity vibration (<1 g) alone. Guedes De Aguiar et al. (2023), reviewing 8 RCTs with 1,095 participants, found consistent improvements in muscle strength, jump performance, balance, and chair rise performance. Luo et al. (2017), despite finding null BMD results, reported significant improvement in maximal isometric knee extensor strength. Sen et al. (2020) found significant TUG improvements, quality-of-life gains, and a significant reduction in depressive symptoms.

Another element characteristic for vibration therapy would be the pain-reduction potential; Li et al. (2024) found a significant reduction in pain scores in osteoporotic patients. This may be particularly relevant for osteopenic patients with early vertebral loading pain.

2. Extrapolation from adjacent literature

2.1 From osteoporosis to osteopenia

The majority of the clinical literature addresses osteoporosis (T-score ≤ −2.5) rather than osteopenia (T-score −1.0 to −2.5). Direct osteopenia-specific evidence comes from a subset of sources: Kienberger et al. (2022), Dutra et al. (2016), He et al. (2022), Bilek et al. (2024), Rajapakse et al. (2021), parts of Myint Swe et al. (2016) (specifically the Slatkovska and Stolzenberg sub-studies), parts of Oliveira et al. (2016), Tan et al. (2016) (which included 92 participants with osteopenia), and Sen et al. (2020), (with T-scores spanning the osteopenic-osteoporotic boundary).

Extrapolation from osteoporosis to osteopenia can be made given several clinical reasons. First, osteopenia and osteoporosis represent points on a continuum of the same pathological process which is accelerated net bone resorption over bone formation, thus interventions that modify this balance are applicable across the full spectrum. Second, the underlying mechanisms (osteoblast-osteoclast coupling, OPG/RANKL signaling, mechanotransduction) are the same, regardless of disease severity. Third, evidence suggest that the response to vibration therapy may actually be greater in osteopenic than in healthy bone: Fratini et al. (2016) find that the skeleton's sensitivity to WBV is inversely related to baseline BMD, and Steppe et al. (2020) show that in the animal models, the OVX-induced osteoporotic bone shows greater responsiveness to LMHFV than healthy bone.

Marini et al. (2021), in a systematic review focused on combined physical and pharmacological treatment in osteopenia and osteoporosis, found that only one eligible RCT existed in the literature whis is an illustration of how understudied the osteopenia-specific combination therapy space is, and of why extrapolation from the broader osteoporosis literature is currently necessary.

2.2 From Whole-Body Vibration to Axial Vibration

All WBV platform studies reviewed are functionally axial vibration studies in terms of the primary transmission pathway: oscillations enter through the feet and travel upward through the lower limbs to the pelvis and spine. Fratini et al. (2016) specifically notes that vibration delivered through the lower limbs cannot reach the upper body with sufficient intensity to produce meaningful effects there, confirming that WBV is a lower-limb and axial-skeleton therapy.

The most directly analogous studies for axial vibration therapy are those using low-magnitude, low-frequency (≤40 Hz) standing-platform protocols with foot contact as the entry point (Rajapakse et al., 2021; de Oliveira et al.(2022); Qin et al., (2019); Tan et al., (2016), and the Bilek et al. (2024) study of the OsteoBoost wearable belt; the latter being the only study in the current set to apply targeted vibration directly to the lumbar spine and hips rather than through the feet.

The OsteoBoost findings are important for bridging WBV platform evidence to direct axial vibration. In a 12-month RCT of 126 osteopenic postmenopausal women, Bilek et al. (2024) found that adherent users (≥3 sessions/week) experienced 83% less vertebral strength decline and significant preservation of vertebral volumetric BMD compared to sham controls with compliance being the dominant variable. Akbar et al. (2025) confirm that OsteoBoost is now FDA-cleared specifically for osteopenia (T-score −1.0 to −2.49) of the lumbar vertebrae or total hip, delivered at 20–40 Hz with low amplitude. Bilek et al. (2025) additionally report 82% adherence in a real-world home-use context with high usability scores, addressing the practical feasibility concern that has historically limited WBV adoption.

3. Demographics, vulnerable populations, and incidence

3.1 Overview of study populations

Table 1. The demographic characteristics in the key studies reviewed

Study (Year)	n	Age range	% Female	Primary condition
Singh & Varma (2023)	9 trials reviewed	55–84 yrs	~100%	Postmenopausal osteoporosis + geriatric age
Kienberger et al. (2022)	65	56–63 yrs	100%	Osteopenia (T-score −1.0 to −2.5)
Rajapakse et al. (2021)	80	45–65 yrs	100%	Osteopenia / low bone mass
Dutra et al. (2016)	122	≥55 yrs (~63 mean)	100%	Osteopenia (specifically recruited)
He et al. (2022)	67	55–90 yrs (~72–73 mean)	85%	Osteopenia post-TKA
Bilek et al. (2024)	126	~61 yrs mean	100%	Osteopenia (T-score −1.0 to −2.5)
de Oliveira et al. (2022)	2,089 (23 RCTs)	53–82 yrs	100%	Postmenopausal (mixed T-scores)

Study (Year)	n	Age range	% Female	Primary condition
Massini et al. (2025)	202 (7 RCTs)	55–93 yrs	94%	Older adults at fracture risk
DadeMatthews et al. (2022)	~2,000+ (40 RCTs)	7–82 yrs	Predominantly female	Mixed: healthy, postmenopausal, chronic conditions
Zhang et al. (2022)	8,502 (97 RCTs)	Middle-aged to elderly	86%	Osteoporosis / osteopenia (mixed)
Sen et al. (2020)	49 completers	40–65 yrs (~54 mean)	100%	Osteopenia to mild osteoporosis (T-score −2.0 to −3.0)
Ebid et al. (2021)	95	~51 yrs mean	0%	Osteopenia / osteoporosis (male cohort)
Qin et al. (2019)	29	25–48 yrs	41%	Disuse/bed-rest osteopenia (healthy baseline)
Tan et al. (2016)	114	45–≥65 yrs	56%	Osteopenia (n=92) + osteoporosis (n=22)

3.2 Most vulnerable population: postmenopausal women

Across all the sources reviewed, postmenopausal women consistently emerge as both the most studied and most clinically vulnerable population. The biological basis is clear: estrogen withdrawal at menopause accelerates bone resorption by disinhibiting osteoclast activity, leading to bone loss rates of 3–5% per year in the initial postmenopausal years (Singh & Varma, 2023). Tomašević-Todorović et al. (2024) note that osteoporotic vertebral fractures affect approximately 1 in 3 women over 50, compared to 1 in 5 men, establishing the gender disparity in fracture risk.

Within the postmenopausal population, a critical age threshold is identified at 65 years. Marín-Cascales et al. (2018) find that significant femoral neck BMD improvements from WBV are specific to women under 65, with no significant effect in the older subgroup. Tan et al. (2016)similarly find that osteogenic responses to WBV diminish in the ≥65 age group. This suggests that the optimal intervention window for vibration therapy in postmenopausal women is the 50–65 year range coinciding with the highest bone loss rate and greatest potential for intervention to change the trajectory.

3.3 Men: underrepresented but responsive

Men are generally underrepresented in the literature. Zhang et al. (2022), in a network meta-analysis of 97 RCTs with 8,502 participants, counted only 1,174 men versus 7,328 women. Myint Swe et al. (2016) explicitly state that evidence for WBV benefits in elderly men remains insufficient. Chen et al. (2026) note that only 4% of participants across their 14 included RCTs were male.

The notable exception is Ebid et al. (2021), which studied an all-male cohort of 95 men (mean age ~51 years) with osteopenia or osteoporosis. Combined PEMF and exercise (including WBV at 30–40 Hz) produced significant increases in lumbar spine and total hip BMD at 12 weeks, with effects sustained at 6-month follow-up, demonstrating that the pathophysiology and therapeutic response in men are comparable, even if the epidemiological burden is lower. Men with secondary osteoporosis risk factors like hypogonadism, prolonged corticosteroid use or low activity levels) represent a rarely researched group.

3.4 Younger and mixed-sex populations

Qin et al. (2019), studying disuse-induced osteopenia in a bed-rest model with 29 volunteers aged 25–48 (41% female), demonstrate that axial vibration through the foot significantly halves the rate of calcaneus BMD loss compared to controls in a population without age-related osteopenia. This is relevant because it isolates the mechanical effect of vibration from the hormonal side present in postmenopause, suggesting that the osteogenic mechanism is broadly applicable across age and sex. Flores (2018), studying 51 premenopausal women aged 18–26, found significant trochanter BMD increases after just 4 weeks of WBV, establishing that vibration can modulate bone even before peak bone mass is reached with implications for primary prevention guidelines.

3.5 Risk factors and incidence

Tomašević-Todorović et al. (2024) provide a detailed enumeration of osteopenia and osteoporosis risk factors relevant to understanding the target population for vibration therapy:

- Non-modifiable: age ≥50, female sex, Caucasian or Asian ethnicity, genetic predisposition, and slender physique
- Hormonal: estrogen deficiency (menopause, surgical oophorectomy), early menopause (<45 years), androgen deficiency in men
- Lifestyle: sedentary lifestyle, smoking, excess alcohol consumption, low calcium and vitamin D intake
- Medical: prolonged corticosteroid use, rheumatoid arthritis, hyperthyroidism, malabsorption syndromes, and chronic immobilization

Chłystek et al. (2018) note that physical inactivity is among the most modifiable and prevalent risk factors, which is why vibration therapy (which mimics the skeletal loading effects of weight exercise without requiring high amounts of physical effort) is attractive for elderly or mobility-limited patients who cannot engage in conventional exercise programs.

4. Mechanisms of action

Understanding how vibration therapy affects bone at the cellular and molecular level is essential for interpreting clinical findings and creating detailed guidelines. The literature reviewed provides converging evidence for several interacting mechanisms.

4.1 Mechanotransduction and osteocyte signaling

Bone is a mechanosensitive tissue that adapts its mass and architecture in response to mechanical loading. Osteocytes the main and the most abundant cells are the primary mechanosensors. They detect shear stress and transduce mechanical signals into biochemical responses that coordinate osteoblast and osteoclast activity (Olçum et al., 2016, Steppe et al., 2020).

Steppe et al. (2020) review 51 studies of LMHFV(Low-Magnitude High-Frequency Vibration) effects on bone cells and confirm that vibration at low magnitudes (<1 g) and frequencies of 20–90 Hz consistently promotes osteogenesis and suppresses bone resorption at the cellular level. Key osteocyte responses include: downregulation of sclerostin (SOST), a potent inhibitor of the Wnt/β-catenin bone formation pathway, increased gap junctional communication between osteocytes and altered secretory profiles that influence neighbouring osteoblasts and osteoclasts.

4.2 Osteoblast activation and bone formation

Vibration at 30–60 Hz and 0.25–0.5 g increases osteoblast proliferation, matrix mineralization, and upregulates bone-formation markers including alkaline phosphatase (ALP), osteocalcin (OCN), Runx2, bone morphogenetic protein (BMP), Osterix, collagen type I, and OPG (Steppe et al., 2020). He et al. (2022) confirm this in a clinical context, finding significant increases in the bone formation markers P1NP and osteocalcin in osteopenic patients receiving WBV following knee arthroplasty.

Runge et al. (2018), in a rat model, identified prostaglandin E2 (PGE2) elevation at a +74% in the highest vibration group as a key biochemical mediator of vibration-induced bone anabolism, implicating the COX-2 pathway. This provides a distinct mechanistic route from the usual osteocyte-sclerostin pathway and suggests that vibration instead engages in multiple parallel anabolic mechanisms.

4.3 Osteoclast suppression and bone resorption reduction

Aside from the anabolic effects, vibration at 45 Hz and 0.3 g also inhibits osteoclast differentiation, reduces actin ring formation, and suppresses several main resorption genes including cathepsin K, MMP-9, and TRAP (Steppe et al., 2020). Kostyshyn et al. (2023) demonstrate in an obese/immobile rat model that WBV at 50 Hz significantly reduces RANKL expression while increasing OPG expression, shifting the OPG/RANKL ratio toward bone formation and away from resorption.

4.4 Mesenchymal stem cell lineage switching

Rajapakse et al. (2021) identify an additional mechanism with particular relevance to ageing bone: LIV significantly decreased vertebral marrow fat fraction in their RCT, suggesting a shift from adipogenic to osteoblastic differentiation of bone marrow mesenchymal stem cells (MSCs).

In ageing and oestrogen-deficient bone marrow, MSCs increasingly differentiate into adipocytes rather than osteoblasts, a process driven in part by PPAR-γ upregulation. Vibration appears to suppress adipogenesis and redirect MSC differentiation toward osteoblastogenesis. Steppe et al. (2020) also confirm this in multiple cell culture models. Sassi (2024), studying osteocyte-cancer cell interactions, further demonstrates that vibration-stimulated osteocytes alter their secretory profiles in ways that change their cellular environment which is consistent with the notion that osteocytes are active regulators of bone marrow biology instead of passive bystanders.

4.5 The LINC complex and cytoskeletal mechanotransduction

Olçum et al. (2016) describe the role of the LINC complex (Linker of Nucleoskeleton and Cytoskeleton) as an internal mechanical amplification mechanism: low-magnitude external vibration is amplified within cells through cytoskeletal remodeling, allowing signals that appear too weak to generate significant bone strain to trigger intracellular signaling cascades. This mechanism explains the apparent paradox that low-magnitude vibration (0.1–0.3 g notably lower than the habitual physical activity loads) can produce measurable osteogenic effects.

5. Limitations and gaps in the literature

5.1 Extreme protocol heterogeneity

As documented throughout this review, the vibration therapy literature is characterised by a high protocol heterogeneity across essentially every parameter: frequency (8–90 Hz), magnitude (0.1–12 g), session duration (1–60 min), session frequency (2/week up to daily), platform type (synchronous vs. side-alternating; standing vs. wearable), posture during vibration (static vs. Exercising, or the angle knee), and total intervention duration (4 weeks to 22 months).

This makes cross-study comparison unreliable and meta-analytic pooling problematic, as Fratini et al. (2016) and Oliveira et al. (2016) demonstrate. Without consensus protocol standards, the field cannot determine optimal parameters or make clear and reliable clinical recommendations.

5.2 DXA insensitivity as a measurement limitation

DXA measures BMD: a two-dimensional projection of a three-dimensional structure; and is relatively insensitive to changes in bone microarchitecture, trabecular connectivity, cortical thickness, and bone stiffness. Multiple studies in this review (Bilek et al., 2024,DadeMatthews et al., 2022,Rajapakse et al., 2021) demonstrate that vibration therapy can produce significant improvements in bone quality metrics detectable by MRI, CT, or BCT while showing no significant DXA changes.

This means the field might be repeatedly underestimating the efficacy of vibration by relying on the wrong measurement tool. Future studies should make more use of pQCT, HR-pQCT, or BCT as primary or co-primary outcomes.

5.3 Paucity of osteopenia-specific studies

Only a minority of the sources reviewed specifically target osteopenic populations. The majority studied osteoporosis or mixed populations troughout the T-score values. This means that most evidence for vibration therapy's effects on osteopenia is extrapolated from adjacent populations. Given that the response to treatment, and the clinical goals differ between osteopenia and osteoporosis (prevention of progression vs. fracture prevention and reversal), further dedicated osteopenia studies are needed.

Marini et al. (2021) make this point starkly: their systematic review of combined physical-pharmacological treatment in osteopenia and osteoporosis found only a single eligible RCT in the world literature.

5.4 Underrepresentation of men

Men are profoundly underrepresented across the corpus, comprising a small fraction of study participants in most reviews and being entirely excluded from many trials. Given that men do develop osteopenia and osteoporosis (at lower rates but with potentially higher fracture mortality), and that secondary causes (hypogonadism, corticosteroid use) are common, this represents a significant evidence gap.

5.5 Short intervention durations and follow-up periods

Many studies in the reviewed literature used intervention durations of 12 weeks to 6 months which is potentially insufficient for the bone remodeling cycle which takes usually around 3–6 months per cycle to produce detectable BMD changes.

Massini et al. (2025) find that protocols of less than 18 weeks are most probably insufficient. Li et al. (2024) observe that significant BMD effects at 6 months were not sustained at 12 months, though this may reflect a treatment plateau rather than reversal. Long-term follow-up (more than 2 years) and durability of effect data remain scarce.

5.6 Small sample sizes and statistical power

Many individual RCTs lack the necessary evaluation procedures to detect the small BMD effect sizes expected from vibration therapy. Massini et al. (2025) note that low certainty of evidence at the femoral neck and lumbar spine is partly attributable to small sample sizes across individual studies. The largest meta-analyses (de Oliveira et al., 2022, Zhang et al., 2022) obtain partial results through aggregation of data, but the methodological quality of primary studies still remains variable.

5.7 Adverse effects and long-term safety

The short-term safety profile of low-magnitude vibration therapy is well-supported: de Oliveira et al. (2022) report an adverse event rate of only 2.8% across 2,089 participants. Furthermore, no serious adverse events were reported in the 15 systematic reviews included in Yin et al. (2024). However, high-magnitude WBV (≥1 g) in osteopenic or osteoporotic individuals is explicitly cautioned against by de Oliveira et al. (2022) due to fracture risk.

6. Clinical implications and recommendations

6.1 Evidence-based protocol parameters

Based on the data obtained in this review, the following vibration therapy parameters are best supported for osteopenic patients seeking bone density maintenance or modest improvement. It must be noted that exercising during vibration sessions appears to reduce osteogenic efficacy compared to static standing (Fratini et al., 2016), though combined vibration-exercise programs may better address the functional and neuromuscular goals of osteopenia management.These are presented as a practical reference and should be individualised based on patient characteristics.

Table 2. Relevant vibration therapy parameters

Study	Frequency	Magnitude	Session	Duration	Platform
Rajapakse (2021)	30 Hz	0.3 g	10 min/day	12 months	Standing, feet
Beck / VIBMOR (2022)	30 Hz	0.4 g	10 min/day	9 months	Standing, feet
Qin / VIBE (2019)	30 Hz	0.3 g	10 min/day	90 days	Supine, feet
Tan (2016)	35 Hz	0.25 g	15 min/day	4 weeks	Standing, feet
Bilek / Osteoboost (2024)	20–40 Hz	0.1–0.3 g	30 min/day	12 months	Wearable belt
Dutra (2016)	60 Hz	0.6 g (<1mm)	20 min/day	12 months	Vertical platform
Sen (2020)	30–40 Hz	2–4 mm amp.	Not specified	6 months	WBV platform
He (2022)	8–10 Hz	2 mm amp.	5 min, 2×/wk	24 weeks	WBV platform
Kienberger (2022)	18–20 Hz	2 mm amp.	~6 min, 2×/wk	12 months	Galileo, side-alt.

6.2 Target population and timing

The strongest evidence for vibration therapy effectiveness is in postmenopausal women aged 50–65 which is the population experiencing the highest bone loss rate and greatest potential for BMD modification. The evidence for the >65 age group is more equivocal, and both Marín-Cascales et al. (2018) and Tan et al. (2016) identify diminished osteogenic response after this threshold. However, functional benefits such as strength, balance and the reduction of fall risk are consistently demonstrated across all age groups, making vibration therapy an acceptable intervention in older cohorts even if BMD gains are not the main target.

Patients with lower BMD within the osteopenic range may respond better, given the inverse relationship between baseline BMD and vibration response (Fratini et al., 2016; Rajapakse et al., 2021). Body weight should also be considered: de Oliveira et al. (2022) find that women under 65 kg show greater lumbar spine BMD responses.

6.3 Use of DXA vs. advanced imaging for monitoring

In light of DXA's demonstrated insensitivity to the microstructural benefits of vibration therapy (Bilek et al., 2024, Rajapakse et al., 2021;), clinicians and researchers monitoring patients receiving vibration therapy should consider supplementing annual DXA with bone quality assessments where feasible, including vertebral fracture assessment, FRAX score updates, and, where available, pQCT or CT-based bone strength measures. Absence of DXA improvement does not rule out clinically meaningful bone quality benefits.

6.4 Safety considerations

Low-magnitude vibration therapy (≤0.3–0.4 g) delivered through the feet via standing platforms or wearable devices has an excellent short-term safety profile across multiple large studies. Key safety considerations include: avoiding high-magnitude protocols (>1 g) in osteopenic and osteoporotic patients due to fracture risk.

On the same note, ensuring appropriate posture during vibration sessions (such as semi-flexed knees preferred over fully extended), screening for contraindications (e.g. recent fractures, implanted hardware, active deep vein thrombosis, and severe inner ear disorders) and using frequencies ≤50 Hz in frail or elderly populations, are alo important, given that Massini et all's (2025) cautions against higher frequencies which increase adverse event risk.

6.5 Priorities for future research

This review identifies the following as important areas for future research in vibration therapy for osteopenia:

- Dedicated RCTs in osteopenic (not osteoporotic) populations, with sufficient sample size and duration (≥12 months) to detect BMD effects with adequate power
- Male-specific trials and sub-group analyses in mixed-sex studies, given the current near-total absence of male data
- Protocol standardisation studies comparing frequency x magnitude x duration combinations systematically in controlled designs
- Use of advanced imaging (HR-pQCT, BCT, MRI) as primary or co-primary outcomes alongside DXA
- Biomarker studies with standardised timing protocols to resolve the apparent disconnect between structural and biochemical markers of bone response
- Long-term studies (≥24 months) examining durability of effect and optimal maintenance protocols after initial benefit is achieved
- Studies combining targeted axial vibration (wearable devices) with pharmacological agents in osteopenic populations

3. Conclusions

This narrative review, synthesising 40 sources on vibration therapy and bone pathology, supports a relatively optimistic assessment of vibration therapy's role in osteopenia management. The evidence is strongest for three main conclusions:

The first one, that low-magnitude vibration therapy (approximately 30 Hz, 0.3 g) applied axially through the lower limbs has the highest-quality evidence for BMD stabilisation and modest improvement in postmenopausal women; The second is that functional benefits such as muscle strength, balance, fall risk reduction are more consistent and robust than BMD effects and are clinically important. The third one is that the OsteoBoost wearable belt, now FDA-cleared specifically for osteopenia, represents a significant clinical advance in targeted axial vibration delivery and suggests a future direction for non-platform vibration therapy.

Key limitations that temper these conclusions include the protocol variety across studies, DXA's technical insensitivity to microstructural improvements, the lack of dedicated osteopenia studies, the near-total absence of male-specific evidence, and the short duration of most trials. These limitations mean that the current evidence, while promising, does not yet support a definite clinical recommendation of vibration therapy as a primary treatment of osteopenia

The prospects are encouraging. The development of wearable axial vibration devices, the increasign number of meta-analyses on low-magnitude protocols, the growing mechanistic understanding of osteocyte and MSC biology under vibration, and the consistent demonstration of functional benefits across diverse populations all point toward a possible clinically viable modality that requires continued investigation and, in specific clinical contexts, implementation under supervision.

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