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The impact of resistance training and collagen supplementation on joint stability and prevention of recurrent ankle sprains in amateur athletes: A Literature review

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Abstract

Introduction:

Ankle injuries are among the most common medical issues in the physically active population, accounting for nearly 15–30% of all sports-related injuries. The most frequent of these is the inversion sprain, which leads to damage of the lateral ligament complex, particularly the anterior talofibular ligament (ATFL). Although this injury is often downplayed in popular opinion, research indicates that improper treatment and a lack of rehabilitation lead to the development of chronic ankle instability (CAI) in nearly 40% of patients.

Aim:

The aim of this study is to review current literature regarding the role of sensorimotor training and collagen peptide supplementation in the process of strengthening ligamentous structures and improving the subjective perception of joint stability in athletes.

Background:

For the amateur athlete, recurrent sprains involve not only physical pain but, above all, a drastic decline in the Quality of Life (QoL), resulting from the necessity to interrupt training and increasing kinesiophobia—the fear of reinjury. Contemporary sports orthopedics is increasingly shifting away from a purely mechanical paradigm of injury treatment toward a holistic approach. The key pillars of this approach are resistance training focused on active stabilization and biochemical support through targeted collagen supplementation

Review methods:

A comprehensive analysis ofr esearch papers available on PubMed and GoogleScholar was conducted using keywords:

Keywords:

collagen, ankle joint, joint stability, resistance training, kinesiophobia

Introduction

1. Epidemiology and the Scale of the Problem

   Ankle injuries represent one of the most significant challenges in sports medicine, accounting for 15–30% of all injuries in the physically active population [1]. The most frequently diagnosed injury is an inversion sprain, which in most cases leads to damage to the lateral ligament complex, specifically the anterior talofibular ligament (ATFL) [2]. Despite their high incidence, these injuries are often downplayed, resulting in an inadequate revalidation process.

2. Pathophysiology and Chronic Ankle Instability (CAI)

   The lack of appropriate intervention after an initial sprain leads to the development of Chronic Ankle Instability (CAI) in nearly 40% of patients [3]. CAI is not merely a mechanical defect; it is a complex syndrome of disorders involving ligamentous insufficiency, proprioception deficits, and muscle weakness [4]. For the amateur athlete, this translates not only to pain but to a drastic reduction in quality of life (QoL) and the development of kinesiophobia—a pathological fear of re-injury that acts as a barrier to returning to activity [5, 6].

3. Modern Approach: Training and Biochemistry

   Contemporary sports orthopedics suggests moving away from passive treatment methods in favor of a holistic approach that integrates biomechanics with biochemistry. A key element of active stabilization is resistance and sensorimotor training, which stimulates neuromuscular adaptation [7]. However, for the remodeling process of damaged tissues to be effective, there must be an adequate availability of structural substrates.

4. The Role of Collagen Supplementation

   Research indicates that targeted supplementation with collagen peptides can significantly support the synthesis of the extracellular matrix in ligaments and tendons [8]. Crucially, the synergy between mechanical loading (training) and the availability of collagenous amino acids is vital for strengthening the collagen structure [9, 10]. Pioneering studies suggest that in athletes with CAI, regular collagen intake leads to both subjective and objective improvements in joint stability [11].

Methodology (Materials and Methods)

1. Search Strategy

Electronic databases, including PubMed, Google Scholar, the Cochrane Library, and Web of Science, were searched. To identify relevant publications, a combination of the following English keywords was utilized:collagen peptides AND joint stability

ankle sprain prevention AND resistance training

chronic ankle instability AND collagen supplementation

sensorimotor training AND ankle rehabilitation

2. Inclusion and Exclusion Criteria

Publications meeting the following criteria were included in the analysis:

Study Type: Meta-analyses, systematic reviews, randomized controlled trials (RCTs), and clinical trials.

Population: Athletes (both amateur and professional), individuals with a history of ankle sprains, or those diagnosed with Chronic Ankle Instability (CAI).

Intervention: Resistance training, sensorimotor training, and collagen/collagen peptide supplementation.

Language and Timeline: Publications in English and Polish, with a specific focus on works published after 2010 to ensure data currency.

Articles focusing exclusively on surgical treatment, injuries other than the ankle joint, and papers with low methodological reliability were excluded from the review.

3. Data Extraction

Selected articles were analyzed with regard to:

Biochemical mechanisms of collagen's influence on ligamentous structure.

The effectiveness of training protocols in improving joint stability.

The impact of combined interventions (training + supplementation) on the prevention of secondary injuries.

Refined Summary (Based on your suggestion)
If you need a more concise version for an abstract or introduction, you might use:

"The literature search was conducted across PubMed, Google Scholar, the Cochrane Library, and Web of Science. Key terms included 'collagen peptides', 'ankle instability', and 'resistance training'. Inclusion criteria focused on randomized controlled trials and systematic reviews involving athletes with chronic ankle instability (CAI). Data synthesis emphasized the synergy between mechanical loading and biochemical support in ligamentous remodeling."

Research Questions

1.Does the combination of collagen peptide supplementation and resistance training show greater efficacy in improving joint stability compared to a training protocol alone?

2.How does collagen supplementation affect the biomechanical and structural properties of damaged ligaments (specifically the ATFL) in amateur athletes?

3.What is the impact of improved joint stability (achieved through training and supplementation) on kinesiophobia levels and subjective quality of life in patients with chronic ankle instability (CAI)

4.What timing protocol and dosage of collagen peptides are most optimal for maximizing collagen synthesis in response to mechanical loading?.

Research Hypotheses

H1: Collagen supplementation acts synergistically with training, accelerating the remodeling process of the ligamentous extracellular matrix.

H2: The application of targeted biochemical support reduces the time to Return to Sport (RTS) and decreases the incidence of recurrent ankle sprains.

H3: The reduction of physical joint instability leads to a statistically significant decrease in the level of fear of re-injury (kinesiophobia).

Biomechanical and Molecular Foundations of Collagen Synthesis

3.1. Hierarchical Architecture and Histology of the Extracellular Matrix (ECM)

The anterior talofibular ligament (ATFL) is not merely a passive "tether" stabilizing the ankle joint; it is a highly specialized fibrous connective tissue with a unique hierarchical architecture. The primary structural determinant of this tissue is the extracellular matrix (ECM), which dictates the mechanical properties of the entire joint complex. In a healthy ligament, the dominant protein is Type I collagen (accounting for up to 85% of total dry collagen mass), organized in a linear, highly ordered longitudinal fashion [12].

On a molecular level, tropocollagen molecules align to form microfibrils, which aggregate into fibrils, eventually forming the fibers and fiber bundles visible in clinical imaging. This structural hierarchy enables a phenomenon known as "fiber recruitment." During low-load activities, the ligament exhibits a degree of elasticity (the "toe region" of the stress-strain curve). However, as inversion forces increase, the wavy collagen fibers straighten out, rapidly increasing the tissue's stiffness to protect the joint from luxation [13, 18].

In amateur athletes following a primary injury, the regeneration process is often compromised by the excessive production of Type III collagen. This collagen type is smaller, possesses fewer cross-links, and is characterized by a chaotic, disorganized arrangement—often referred to in literature as a "functional scar." While this tissue fills the anatomical gap, it lacks the appropriate Young’s modulus, which is a direct cause of mechanical ankle instability. Targeted collagen peptide supplementation aims to provide specific building blocks (primarily proline and hydroxyproline) that favor the synthesis of durable Type I collagen over Type III, effectively restoring the ligament's original biomechanical integrity [15, 20].

3.2. Fibroblast Biology and the Mechanotransduction Signaling Cascade

Fibroblasts are the sole resident cells of the ligaments, responsible for the constant metabolic turnover of the matrix. In a resting state, the anabolic activity of fibroblasts in an adult amateur athlete is minimal. A breakthrough in understanding soft tissue regeneration was the discovery of mechanotransduction—the process by which physical stimuli are translated into the language of cellular biochemistry [14].

This mechanism is initiated by mechanoreceptors located in the fibroblast cell membrane, such as integrins and stretch-activated ion channels (e.g., Piezo1 proteins). During resistance training, shear and compressive forces deform the ECM, which is transmitted to the cell's cytoskeleton. This triggers an intracellular signaling cascade, specifically activating the Mitogen-Activated Protein Kinase (MAPK) pathways and the ERK 1/2 pathway. These signals reach the cell nucleus, where they stimulate transcription factors responsible for the production of mRNA for procollagen [9, 21].

A crucial aspect to emphasize for amateur athletes is that fibroblasts exhibit "mechanical fatigue" or desensitization. After approximately 10–15 minutes of continuous loading, they cease to respond to the growth stimulus. Therefore, in regenerative protocols, short, high-intensity bouts of exercise (e.g., 10 minutes of sensorimotor drills) are more effective at "waking" the cells for synthesis than long-duration sessions. This allows for a concentrated anabolic phase in the presence of supplemented peptides [16, 19].

3.3. Interstitial Fluid Dynamics and Substrate Transport

Ligaments are characterized by extremely low vascularity, which causes repair processes to occur significantly slower than in muscles or skin. The transport of nutrients occurs primarily through diffusion and "forced convection" of interstitial fluid [14]. This is the precise intersection where collagen supplementation meets movement biomechanics.

During joint movement, extracellular fluid is literally "squeezed" out and "sucked" back into the dense matrix of the ligament, much like the action of a sponge. If an athlete ingests collagen peptides 60 minutes prior to training, their plasma concentration peaks exactly during the maximum activity of this "fluid pump" [10, 17]. Consequently, amino acids that would normally struggle to reach the core of the poorly vascularized ATFL are mechanically transported there. Without a movement stimulus, supplemented nutrients merely circulate in the peripheral capillaries, failing to reach the internal sites requiring structural remodeling [15, 20].

3.4. Enzymatic Helix Stabilization and the Role of Cofactors

The formation of collagen fibers does not end with the synthesis of polypeptide chains. For a collagen molecule to function, it must assume the form of a stable triple helix (superhelix). This process occurs within the endoplasmic reticulum of fibroblasts and is entirely dependent on the hydroxylation of proline and lysine residues. The enzymes responsible for this reaction—hydroxylases—require Vitamin C as an essential cofactor (an electron donor for the iron atom in the enzyme's active center) [16, 17].

A Vitamin C deficiency during the training window leads to the production of "immature" collagen, which is thermally unstable and degrades before even leaving the cell. From the perspective of an amateur athlete, supplementing collagen without simultaneous antioxidant (Vitamin C) intake is a fundamental error that prevents the strengthening of the ATFL structure. Additionally, Vitamin C protects fibroblasts from the oxidative stress induced by intense physical exertion, ensuring the continuity of anabolic processes [18, 21].

3.5. Matrix Maturation: Covalent Cross-linking and Young's Modulus

The final and most critical stage of enhancing joint stability is the process of cross-linking collagen fibers. Once procollagen molecules are secreted into the extracellular space, the enzyme lysyl oxidase (LOX) creates permanent covalent bonds between adjacent molecules [20].

The density of these links determines the mechanical properties of the ligament, including its Young's modulus (the ratio of stress to strain). In athletes with Chronic Ankle Instability (CAI), these bonds are often weakened or sparse. The synergy of resistance training and collagen supplementation significantly elevates LOX enzyme activity, leading to a "hardening" of the ligament. In practice, this means the ligament becomes capable of absorbing more energy during a sudden ankle twist (e.g., landing on uneven ground), preventing excessive tissue elongation and damage to the joint capsule. This structural reinforcement, rather than just muscle strength improvement, forms the foundation of lasting prevention for recurrent injuries in amateur athletes [11, 19, 21].

4: The STS Intervention Protocol – Integrating Training and Supplementation

4.1. Nutritional Periodization: Timing as a Success Determinant

The effectiveness of the STS (Synergy of Training and Supplementation) protocol is predicated on rigorous adherence to the chronobiology of nutrient delivery. In the context of amateur athletes, the most prevalent error identified in clinical practice is the ingestion of collagen at arbitrary times (e.g., morning or evening, regardless of activity levels). Research by Shaw and Baar has demonstrated that the peak plasma concentration (Cmax) of free amino acids—specifically glycine, proline, and hydroxyproline—occurs approximately 60 minutes after the ingestion of collagen hydrolysate [10, 17].

Under the STS protocol, the athlete ingests a precise dose of 15g of collagen peptides dissolved in a liquid enriched with a minimum of 50mg of Vitamin C. The 60-minute pre-training window is crucial, as it allows for the full absorption of di- and tripeptides from the gastrointestinal tract into the bloodstream. By the time the warm-up begins, the plasma is saturated with these essential substrates. This saturation, combined with the increased cardiac output and local periarticular hyperemia induced by exercise, facilitates the effective diffusion of these molecules into the dense, poorly vascularized matrix of the ATFL ligament [3, 31].

4.2. Biomechanics of Active Stabilization: Peroneal Muscle Resistance Training

The cornerstone of functional ankle stability lies in the proficiency of the peroneal muscles (longus and brevis). These muscles serve as "active braces," whose primary function is to counteract rapid foot inversion. In individuals suffering from Chronic Ankle Instability (CAI), a prolonged neuromuscular reaction time and disuse atrophy of these muscles are frequently observed [19, 22].

The STS protocol emphasizes resistance training with an eccentric focus. Exercises such as calf raises with a controlled, slow descent of the heel (a phase lasting 3–4 seconds) generate the highest internal tension within the tendons and ligaments. It has been shown that eccentric work induces a stronger anabolic response from fibroblasts than concentric work alone [20, 23]. Another vital element includes isolated foot eversion movements using resistance bands. The athlete performs 3 sets of 15–20 repetitions, ensuring a full range of motion. Such loading not only builds muscular strength but, more importantly, forces a collagenous remodeling of the tendon sheaths and lateral ligaments, thereby increasing their passive stiffness [30].

4.3. Recalibration of the Proprioceptive System: Sensorimotor Training

Damage to the ATFL ligament involves not only a disruption of fiber continuity but also the destruction of mechanoreceptors (Pacinian corpuscles and Ruffini endings). This results in a significant deficit in deep sensation—the athlete "loses the feel" for the foot's position, leading to subsequent sprains even on flat surfaces [7, 24].

Sensorimotor training within the STS protocol is divided into static and dynamic phases. The static phase involves single-leg standing on unstable surfaces (e.g., BOSU balls, balance discs, or foam pads) with both open and closed eyes. The objective is to force micro-corrections in joint alignment, which engages the mechanoreceptors within the collagenous matrix [25]. The dynamic phase, essential for a safe Return to Sport (RTS), includes drop jumps with single-leg landings and lateral plyometric hops. Performing these exercises within the optimal supplementation window allows for the structural changes in the tissue to support neurological function. The improved mechanical stability provided by the collagen reinforcement reduces the "informational noise" sent to the brain, resulting in superior motor control and coordination [26, 29].

4.4. Intermittent Loading: The Micro-dosing Concept

A unique aspect of the STS protocol, based on tissue engineering research, is the concept of intermittent loading. Ligamentous fibroblasts become unresponsive (mechanically saturated) after approximately 10–15 minutes of continuous mechanical stimulus [9, 14]. Therefore, instead of a single, long weekly training session, the protocol recommends short (15-minute) sessions repeated more frequently (e.g., 3–4 times per week).

This model allows for the repeated "awakening" of anabolic processes within the connective tissue. For the amateur athlete, these micro-sessions can be easily integrated into a daily routine: 60 minutes after collagen ingestion, they perform a series of stabilization exercises, providing the signal for new matrix synthesis. This approach is revolutionary as it moves away from the traditional bodybuilding principle of "high volume" toward a precise strike on fibroblast mechanoreceptors during the optimal biochemical window [3, 16].

4.5. Outcome Monitoring: The FAAM and CAIT Scales

The evaluation of the protocol's effectiveness in amateur athletes cannot rely solely on imaging studies, which rarely correlate perfectly with the patient’s functional experience. The STS protocol utilizes standardized questionnaires: the Foot and Ankle Ability Measure (FAAM) and the Cumberland Ankle Instability Tool (CAIT) [27, 28].

The FAAM scale allows for the assessment of daily activities and sports proficiency, measuring the subjective difficulty of tasks such as running on uneven terrain or jumping. The CAIT scale, on the other hand, precisely diagnoses the degree of chronic instability. Regular monitoring of these indicators (every 4 weeks) enables the objectification of results. It has been shown that combining training with collagen leads to a faster increase in scores on both scales than training alone. The reduction in perceived instability is directly linked to a decrease in kinesiophobia levels, finalizing the rehabilitation process and allowing the athlete a full return to activity without the debilitating fear of re-injury [5, 29, 31].

5: Discussion – English Version

5.1. Evolutionary Paradigm Shift: From Immobilization to Active Mechanotransduction

The traditional approach to treating ankle sprains in amateur athletes has for decades relied on the RICE protocol (Rest, Ice, Compression, Elevation), which emphasized passive recovery and immobilization. However, this analysis confirms a contemporary shift toward early mobilization and active mechanical loading. The research by Baar [9] and Kaux [18] sheds new light on ligament physiology, demonstrating that a lack of mechanical stimulus leads to extracellular matrix (ECM) atrophy and a weakening of the collagenous structure. Any discussion on the role of resistance training in recurrence prevention must acknowledge that joint stability depends not only on the mechanical strength of the ATFL but on the dynamic synergy of the neuromuscular system.

5.2. Controversies Surrounding Collagen Supplementation

For many years, the medical community remained skeptical of oral collagen supplementation, arguing that the protein is entirely broken down into individual amino acids during digestion, thereby losing its tissue specificity. However, modern isotope labeling techniques, utilized by Oesser [14] and others, have proven that specific collagen peptides (di- and tripeptides) are absorbed intact and accumulate selectively in connective tissues.

It is important to note, however, that the effectiveness of supplementation in amateurs is highly dependent on the quality of the preparation. Low molecular weight hydrolysates (below 3 kDa) exhibit significantly better bioavailability. In this discussion, it must be emphasized that "maintenance" supplementation (without training) shows no statistically significant impact on ligament stiffness in sedentary individuals, supporting the hypothesis that a motion-induced pressure gradient within the ECM is necessary for substrate uptake [10, 15].

5.3. Psychological Barriers: Kinesiophobia vs. Structural Integrity

A critical aspect addressed in this study is the correlation between physical joint stability and the athlete's psychological readiness (Return to Sport). In amateur athletes, unlike professionals, the fear of reinjury (kinesiophobia) often leads to a permanent cessation of physical activity. The analysis of works by Webster and Feller [29] suggests that improving deep sensation (proprioception) through sensorimotor training within the STS supplementation window shortens the time required to regain self-confidence. A more stable ligament sends a "cleaner" signal to the central nervous system, which reduces errors in joint position sense and minimizes the risk of "giving way"—the primary source of anxiety for CAI patients [5, 28].

5.4. Limitations of Current Research and Future Perspectives

Despite the promising results of the STS protocol, certain methodological limitations in the available literature must be acknowledged. Most clinical trials, such as those conducted by Dressler [7], involved follow-up periods of only 3 to 6 months. There is a lack of long-term prospective studies evaluating the permanence of collagenous structural changes after the cessation of supplementation. Furthermore, genetic variability regarding COL1A1 gene expression may cause some amateur athletes to respond to the STS protocol much more slowly. Another challenge is the standardization of Vitamin C dosage—while 50 mg is considered sufficient, some authors suggest higher doses to combat oxidative stress in older individuals engaging in amateur sports [16, 17].

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Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used Gemini Pro (Google) to improve grammar and language clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication