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# Application of nuclear medicine techniques in sports medicine

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## Abstract

**Introduction and purpose:** To briefly introduce the reader to the application of nuclear medicine studies in the diagnosis and treatment of musculoskeletal disorders developed among athletes.

**Materials and methods:** To prepare this review, publications indexed in the PubMed and Google Scholar databases were analyzed. Special attention was given to full-text articles published in English between 2015 and 2023, as well as to the references cited by the authors of selected publications.

**Description of the state of knowledge:** Nuclear medicine is applied in the diagnosis and therapy of orthopedic conditions. Commonly used nuclear medicine techniques include planar bone scintigraphy (WBS), single-photon emission computed tomography (SPECT) combined with computed tomography (CT), and positron emission tomography (PET) combined with computed tomography (CT).

**Summary:** The utilization of nuclear medicine techniques allows for proper diagnosis and early treatment of musculoskeletal disorders, including pathologies resulting from sports-related physical activity.

**Keywords.** fusion imaging; hybrid imaging; musculoskeletal diseases; scintigraphy; single-photon emission tomography.

**Abstrakt**

**Wprowadzenie i cel pracy:** Zwięzłe przybliżenie czytelnikowi tematu wykorzystania badań medycyny nuklearnej w diagnostyce i leczeniu schorzeń układu ruchu powstałych u sportowców.

**Opis stanu wiedzy:** Medycyna nuklearna znajduje zastosowanie diagnostyce i terapii zmian w schorzeniach ortopedycznych. Do technik medycyny nuklearnej powszechnie wykorzystywanych zalicza się m.in. planarną scyntygrafię układu kostnego (WBS), scyntygrafię emisyjną pojedynczego fotonu połączoną z tomografią komputerową (SPECT/CT) oraz pozytonową tomografię emisyjną z tomografią komputerową (PET/CT).

**Materiały i metodyka:** Aby przygotować niniejszy przegląd poddano analizie publikacje zindeksowane w bazach wyszukiwarek PubMed oraz Google Scholar. Szczególną uwagę poświęcono artykułom pełnotekstowym opublikowanym w latach 2015 – 2023 w języku angielskim oraz pracom przytaczanym przez autorów wybranych publikacji.

**Wnioski:** Wykorzystanie technik medycyny nuklearnej pozwala na właściwą diagnostykę i wczesne podjęcie leczenia schorzeń układu ruchu, w tym patologii powstałych w wyniku sportowej aktywności fizycznej.

**Słowa klucze:** obrazowanie fuzyjne; obrazowanie hybrydowe; choroby mięśniowo-szkieletowe; scyntygrafia; tomografia emisyjna pojedynczych fotonów

## Introduction

Many pathological conditions of the musculoskeletal system are directly related to sports activities. Available data indicate that every tenth athlete participating in the Olympic Games suffers an injury requiring medical intervention.[1] Most injuries affect the lower limbs, with a smaller percentage affecting the upper limbs, head, and trunk. [1,2] Contact sports and athletics are characterized by the highest frequency of injuries.[2] Most sports injuries result from excessive overload, leading to acute or chronic pathological changes in the musculoskeletal system.[3] A significant portion of these injuries requires medical intervention.

Nuclear medicine has been used in orthopedics for many years, including the diagnosis and treatment of changes resulting from physical activity. Common nuclear medicine techniques include planar bone scintigraphy (WBS), single-photon emission computed tomography combined with computed tomography (SPECT/CT), and positron emission tomography combined with computed tomography (PET/CT). Hybrid imaging methods provide information not only about anatomical changes, like radiological imaging methods, but also allow the detection of functional changes in the examined organ/system. This is important because changes in the function of a particular organ often precede the development of anatomical pathology.[2]

## Aim

A concise overview is presented to the reader regarding the utilization of nuclear medicine research in the diagnosis and treatment of musculoskeletal disorders occurring in athletes.

## Material and methods

To prepare this review, publications indexed in PubMed and Google Scholar search engine databases were analyzed. Special attention was paid to full-text articles published between 2015 and 2023 in English, as well as papers cited by authors of selected publications.

**Analysis of the literature**

*Bone scintigraphy*

WBS, due to its simplicity and clinical significance, is the most commonly used imaging method for the musculoskeletal system in nuclear medicine. The patient is intravenously administered a radioisotope combined with an appropriate ligand that integrates into the bones. The most commonly used is technetium-99m in combination with one of the commonly available ligands/biphosphonates, such as methylene diphosphonate (MDP).[2,4,5]

Studies have shown that 99mTc-labeled biphosphonates are absorbed by the mineral phase of bones during active bone formation or remodeling.[2] Additionally, three-phase scintigraphy allows visualization of increased blood flow in the analyzed organ. Along with planar bone scintigraphy, this allows the diagnosis of inflammatory conditions and the visualization of certain growth processes.[5,6]

*SPECT/CT*

Hybrid SPECT/CT devices allow for increased sensitivity of nuclear imaging by overlaying an anatomical image created by computed tomography (CT) onto the functional image created by SPECT. The fusion method enables obtaining images in different anatomical planes, which allows for a better assessment of bones and their pathologies.[7,8]

For example, the radiological assessment of the ankle joint is relatively difficult due to its complex anatomy. Compared to anatomical imaging methods and clinical evaluation, the use of hybrid imaging improves diagnosis and modifies the management of patients in approximately 48-62% and 40-79% of cases where other imaging methods are inconclusive or treatment does not improve the condition. [9,10]

*PET/CT*

The fundamental principle of PET imaging is the detection of high-energy photons produced in the annihilation process of positrons. Fluorine-18 (18F) is one of the main emitters of these particles in nuclear medicine.[11] Glucose labeled with 18F (18F-FDG) forms a complex that is taken up by cells with increased glucose metabolism.[12] After entering the cytoplasm

through glucose transporters, this complex is metabolized into FDG-6-phosphate.[2] PET imaging is particularly useful in oncology for detecting tumors and evaluating disease progression. [2,12,13] It also allows for the evaluation of the musculoskeletal system. [12,13]

Technology involved in hybrid diagnostics is continuously evolving. Currently, NaF-PET (18F-Sodium Fluoride PET) is gaining importance. [22] Sodium fluoride in nuclear medicine imaging was first used in the 1960s. Initially, it was used in skeletal scintigraphy. It is characterized by high bone uptake and rapid clearance from the body, additionally allowing for obtaining scans with high contrast. [22] Compared to 99mTc-diphosphonates the 18F-NaF has approximately twice the uptake and a faster blood clearance rate, resulting in an increased bone-to-background activity ratio. [2]

*Overload syndrome of the medial tibial area*

In runners and individuals engaged in dynamic sports, there is a risk of overloading the muscles of the lower limbs and experiencing structural changes within the feet (pathological pronation or supination).[14] This condition is associated with pain and reduced training efficiency.[15] Scintigraphy can differentiate this syndrome from stress fractures in the tibia. Overload syndrome is characterized by increased linear accumulation of the radiotracer, whereas stress fractures typically exhibit focal or spindle-shaped accumulation.[2] Additionally, in three-phase scintigraphy, increased blood flow is not observed at the site of radiotracer accumulation in cases of overload syndrome.[2]

In a 2023 study, authors described the case of an 18-year-old athlete who complained of pain in the right lower leg for 10 days, which he attributed to intense physical exercise. Radiological examination did not reveal any deviations from the norm, such as suspected fractures or cortical cracks. Planar scintigraphy was performed, which was expanded with SPECT/CT. The obtained images revealed the coexistence of stress fractures in the tibia and cortical bone changes characteristic of overload syndrome.[16]

A similar case was described by a group of doctors in 2013. Their patient complained of leg pain induced by intense physical exertion. Anatomical imaging did not reveal any abnormalities. Performing bone scintigraphy combined with SPECT/CT uncovered the presence of two coexisting pathologies: stress changes that led to stress fractures.[17]

*Loosening of prostheses*

When a clinician suspects ongoing loosening of an implant in a patient, it is necessary to confirm the diagnosis and determine its background, which can be aseptic or related to infection. Increased radiotracer accumulation and intensified tissue perfusion confirm an infectious process.[5] Conversely, when blood flow is not increased, aseptic loosening of the prosthesis is more likely.[4]

Furthermore, in a 2021 study, authors reviewed and analyzed imaging studies conducted on patients with persistent pain following knee and hip prosthesis surgeries. They found that SPECT/CT imaging demonstrated high diagnostic accuracy for detecting prosthesis loosening in these cases.[11]

*Stress fractures*

Three-phase bone scintigraphy (3-PBS) also allows for the diagnosis of stress fractures, occult injuries, and bone and adjacent tissue infections, which is particularly important in the diagnosis of injuries in athletes treated conservatively or surgically.[1,3] Stress fractures are associated with severe pain that can lead to a limitation of physical activity. They occur due to repetitive suboptimal loading of the musculoskeletal system, exceeding the adaptive and regenerative capacities of healthy bone.[1] Importantly, insufficient diagnosis and lack of appropriate treatment can lead to the progression of the disorder, resulting in complete fractures, failure of bone union, bone instability, and persistent pain.[18] Early recognition enables the implementation of proper therapy, significantly shortening the treatment period and facilitating a quick return to training.

In a 2018 case report, the authors described the case of a 39-year-old male athlete who sought medical attention for the diagnosis of knee pain.3-PBS was performed, revealing pathological hyperemia in the left knee joint a few days after the onset of symptoms. Expanding the examination to include SPECT/CT uncovered a stress fracture in the proximal part of the tibia.[11]

Moreover, recent studies suggest the superiority of NaF-PET/CT over conventional methods in detecting pathological fractures, stress fractures, and occult fractures.[19]

*Joint imaging*

Increased osteoblastic activity resulting from ligament injuries can be visualized in SPECT/CT imaging, as demonstrated by authors in a study published in 2019.[20] Additionally, three-phase bone scintigraphy shows increased blood flow in the joint and

surrounding soft tissues in cases of synovial membrane inflammation.[2,19] Studies conducted by Jeon et al. using NaF-PET/CT accurately diagnosed 95 patients with fractures, 12 with Achilles tendon rupture, 12 with ligament injury, and 2 with complex regional pain syndrome in a group of patients with ankle pain that occurred on average 290 days before the examination and was not visible in a typical radiological examination.[19] Injuries to the ankle joint account for 16-25% of all musculoskeletal injuries in sports.[21] Therefore, it seems justified to expand the diagnostic options to include NaF-PET/CT in patients with persistent post-traumatic pain of unclear origin.[19]

**Radiosynovectomy**

Radiosynovectomy (*RSO*) is a well-established method for treating conditions characterized by synovial membrane overgrowth and recurrent joint effusions, such as rheumatoid arthritis, reactive arthritis, joint inflammation in hemophilia, joint effusion after joint replacement surgery, Lyme disease, and Behçet's disease. This technique involves intra-articular injections of radioisotopes emitting β radiation. For the treatment of inflammation in large joints, Itrium-90 (Y-90) is commonly used, while Rhenium-186 (Re-186) is utilized for medium-sized joints. Erbium-169 (Er-169) is reserved for the treatment of small joints. [2] By administering these radioisotopes in colloid form, they are unable to penetrate the joint capsule, enter the bloodstream, or form long-term associations with intra-articular structures. [23]

**Conclusion**

Molecular medicine techniques, especially modern hybrid imaging, enable the diagnosis of various disorders commonly occurring in athletes. They can be helpful in visualizing injuries that are not visible in typical radiological examinations. Additionally, they find application in diagnosing skeletal overload conditions and joint injuries. The increasing popularity of these methods may contribute to establishing an accurate diagnosis in individuals experiencing long-lasting pain of unclear origin.

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### *Author contributions*

Conceptualisation, P.Z.; Methodology, P.Z.; Software, M.S.; Validation, D.M.; Formal Analysis L.A.; Investigation, P.Z.; Resources, P.Z., M.S.; Data Curation, D.M.. L.A.; Writing – Original Draft Preparation, P.Z.; Writing – Review & Editing, P.Z., M.S.; Visualisation, N.I., L.A.; Supervision, P.Z.; Project Administration: N.I., P.Z.

### *Conflicts of interest*

The authors declare no financial or commercial conflicts of interest.

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