Role of Diagnostic Imaging in Safe Rehabilitation and Functional Recovery in Sports Medicine

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Abstract*—Sports medicine relies heavily on radiological imaging for the diagnosis, treatment, and rehabilitation of sports-related injuries. This study evaluates the role of imaging modalities such as X-ray, CT scan, MRI, and ultrasound in early injury detection and performance analysis. MRI and ultrasound are highly effective for soft tissue assessment, while X-ray and CT are useful for bone injuries. The study also emphasizes radiation safety through the ALARA principle and proper imaging selection. Advanced imaging techniques improve rehabilitation monitoring, return-to-play decisions, injury prevention, and overall athlete performance and healthcare management)

***Index Terms*— Sports Medicine, Radiological Imaging, MRI, CT Scan, Ultrasound, X-ray, Sports Injuries**

INTRODUCTION

BACKGROUND OF SPORTS MEDICINE AND MODERN ATHLETIC DEMANDS

Sport medicine is a branch of medicine that deals with physical fitness and the treatment and prevention of injuries related to sports and exercise Sports medicine has emerged as a vital field bridging the gap between athletic performance and medical science. With the increasing demands on athletes to perform at peak levels, this interdisciplinary specialty plays a crucial role in ensuring their health, longevity, and success in their respective sports. From injury prevention to rehabilitation, sports medicine encompasses a broad spectrum of care tailored to the unique needs of athletes. The origins of sports medicine can be traced back to ancient Greece and Rome, where physicians like Hippocrates and Galen addressed injuries sustained by athletes in early Olympic games and gladiatorial contests. Nevertheless, the formalization of sports medicine as a distinct discipline occurred in the 20th century, driven by the rise of organized sports and increased scientific understanding of human physiology.

In the majority of countries where sports medicine is recognized and practiced, it is a physician (non-surgical) specialty, but in some (such as the USA), it can equally be a surgical or non-surgical medical specialty, and also a specialty field within primary care. In other contexts, the field of sports medicine encompasses the scope of both medical specialists as well as allied health practitioners who work in the field of sport, such as physiotherapists, athletic trainers, podiatrists and exercise physiologists.

EVOLUTION AND IMPORTANCE OF MEDICAL IMAGING IN SPORTS

In the past, sports injuries were mainly diagnosed through physical examination and basic clinical observation. While this approach was helpful, it often failed to detect deep or internal injuries, especially those involving soft tissues such as muscles, ligaments, and tendons. As a result, many injuries were diagnosed late, which led to delayed treatment, poor recovery outcomes, and sometimes permanent damage.

With the advancement of medical technology, imaging has completely transformed sports injury diagnosis and management. Techniques such as X-ray, CT scan, MRI, and ultrasound now allow doctors to look inside the human body without surgical intervention. These imaging tools provide highly detailed information about the structure and condition of bones and soft tissues, helping in early and accurate diagnosis. This advancement has significantly improved treatment planning, recovery monitoring, and return-to-play decisions in athletes.

Role of Imaging Modalities in Sports Injury Diagnosis Different imaging techniques play different roles in sports medicine depending on the type and severity of injury. X-ray imaging is commonly used as the first-line investigation in sports injuries because it is quick, widely available, and effective in detecting bone fractures and dislocations. Despite this, it has limited ability to detect soft tissue injuries.

CT scan provides more detailed and advanced imaging compared to X-ray and is mainly used in complex fractures and detailed bone evaluation. It gives three-dimensional images that help doctors understand the exact structure of injury. In contrast, CT scan involves higher levels of radiation, so it must be used carefully and only when necessary.

MRI is considered the gold standard for soft tissue imaging in sports medicine. It does not use radiation and provides excellent visualization of muscles, ligaments, tendons, cartilage, and joints. This makes it highly valuable for diagnosing sports-related injuries such as muscle tears, ligament ruptures, and joint damage. Ultrasound is another important imaging technique that provides real-time, dynamic imaging of soft tissues. It is safe, cost-effective, and widely used for both diagnosis and treatment guidance in sports injuries.

IMPORTANCE OF EARLY DIAGNOSIS IN ATHLETIC INJURIES

Early diagnosis is one of the most critical aspects of sports medicine because it directly affects recovery outcomes and long-term athlete health. In many cases, athletes continue to play or train despite experiencing mild pain or discomfort, which can lead to worsening of injuries. If injuries are not detected at an early stage, they may progress into more severe conditions such as complete muscle tears, ligament ruptures, or stress fractures.

Imaging plays a crucial role in identifying these injuries at an early stage before they become serious. Early diagnosis helps doctors start timely treatment, reduce recovery time, prevent complications, and ensure safe return to sports. It also reduces the risk of re-injury, which is very common in athletes who return to play too early without complete healing.

ADVANCES IN IMAGING TECHNOLOGY AND FUNCTIONAL ASSESSMENT

Recent advancements in imaging technology have significantly improved the understanding of sports injuries. New techniques such as functional MRI and ultrasound elastography have introduced more detailed ways of studying muscle and tissue function. Functional MRI helps in analyzing muscle activity, fatigue patterns, and metabolic changes during physical activity. This provides valuable information about how muscles behave under stress.

Ultrasound elastography is an advanced technique that measures the stiffness and elasticity of muscles and tendons. It helps in detecting early tissue changes that are not visible in conventional imaging methods. These advanced imaging techniques allow doctors to detect injuries at a microscopic level and monitor healing more precisely. As a result, treatment strategies have become more personalized and effective.

RADIATION SAFETY AND RISK MANAGEMENT IN SPORTS IMAGING

Although imaging techniques are extremely useful in sports medicine, certain methods like X-ray and CT scan involve ionizing radiation, which can be harmful if used repeatedly or unnecessarily. Athletes often require multiple imaging scans during injury diagnosis and recovery, which increases their exposure to radiation over time.

To ensure safety, medical professionals follow the principle of ALARA, which means "As Low As Reasonably Achievable." This principle ensures that radiation exposure is kept to the minimum level required for accurate diagnosis. In addition, protective measures such as lead shielding, proper dose adjustment, and careful selection of imaging methods are used to reduce risk.

Whenever possible, safer alternatives like MRI and ultrasound are preferred, especially for young athletes who are more sensitive to radiation exposure.

CLINICAL APPLICATIONS OF IMAGING IN SPORTS MEDICINE

Imaging is used in almost every stage of sports injury management. It is used for early diagnosis of injuries, treatment planning, monitoring recovery, and evaluating healing progress. It also plays a key role in deciding when an athlete is ready to return to play safely. Pre-participation imaging is sometimes used to identify hidden abnormalities or risk factors that may increase the chance of injury in the future. In rehabilitation, imaging helps doctors monitor how well tissues are healing and whether the treatment is effective. This ensures that athletes do not return to sports too early, which could increase the risk of re-injury. Thus, imaging is a continuous tool used throughout the entire injury management process.

IMAGING AND ITS ROLE IN PERFORMANCE ANALYSIS

In addition to diagnosis and treatment, imaging also plays an important role in performance analysis. Advanced imaging techniques help in understanding muscle strength, movement patterns, joint stability, and biomechanical efficiency. This information is valuable for coaches and sports scientists in improving training programs and enhancing athlete performance. Functional imaging techniques also help in identifying muscle fatigue and overuse patterns, which can be used to adjust training intensity and prevent injuries. In this way, imaging is not only a diagnostic tool but also a performance optimization tool in modern sports science.

MEDICAL ASSESSMENT AND ATHLETE HEALTH MONITORING

Medical assessment in sports medicine is a continuous process that includes clinical examination, medical history evaluation, physical testing, and imaging studies. It helps in identifying injuries, monitoring recovery, and ensuring safe participation in sports activities.

Pre-participation assessments are also very important as they help detect hidden medical conditions before athletes begin training or competition. Regular monitoring ensures that athletes recover completely and return to sports safely. This process reduces the risk of re-injury and improves long-term athlete health.

RESEARCH GAP AND STUDY JUSTIFICATION

Despite major advancements in imaging technology, there are still certain gaps in sports medicine. One major limitation is the lack of standardized guidelines that balance diagnostic accuracy with radiation safety. Another important gap is the limitedintegration between radiological findings and athletic performance outcomes. Most studies focus on injury diagnosis but do not fully explore how imaging can improve performance analysis and long-term athlete development.

Therefore, there is a need for further research to evaluate how safe radiological practices can be effectively used not only for early diagnosis and treatment but also for improving performance and guiding return-to-play decisions in athletes.

AIM AND OBJECTIVE

AIM:

- Role of Diagnostic Imaging in Safe Rehabilitation and Functional Recovery in Sports Medicine

OBJECTIVE:

- To understand the contribution of imaging in safe return-to-play decisions and injury prevention.
- To examine the role of advanced imaging techniques in performance analysis and functional assessment of athletes.

REVIEW LITERATURE

1. This study was conducted **by Cohen SB, Towers JD, Zoga A, Irrgang JJ, Makda J, Deluca PF, Bradley JP**. Hamstring injuries in professional football players: magnetic resonance imaging correlation with return to play. Sports Health. 2011 Sep;3(5):423-30. "Hamstring Injuries in Professional Football Players"doi: 10.1177/1941738111403107. PMID: 23016038; PMCID: PMC3445213.This study conclude that Magnetic resonance imaging (MRI) allows for detailed evaluation of hamstring injuries; however, there is no classification that allows prediction of return to play.The purpose of this study is to To correlate time for return to play in professional football players with MRI findings after acute hamstring strains and to create an MRI scoring scale predictive of return to sports.
2. This study was conducted **by Ekstrand J, Healy JC, Waldén M, Lee JC, English B, Hägglund M**. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. Br J Sports Med. 2012 Feb;46(2):112-7. "Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play" doi: 10.1136/bjsports-2011-090155 . Epub 2011 Dec 5. PMID: 22144005.this study evaluate the use of MRI as a prognostic tool for lay-off after hamstring injuries in professional football players and to study the association between MRI findings and injury circumstances. MRI can be helpful in verifying the diagnosis of a hamstring injury and to prognosticate lay-off time. Radiological grading is associated with lay-off times after injury. Seventy per cent of hamstring injuries seen in professional football are of radiological grade 0 or 1, meaning no signs of fibre disruption on MRI, but still cause the majority of absence days.
3. This study was conducted by the **Grange S, Reurink G, Nguyen AQ, Riviera-Navarro C, Foschia C, Croisille P, Edouard P**. Location of Hamstring Injuries Based on Magnetic Resonance Imaging: A Systematic Review. Sports Health. 2023 Jan-Feb;15(1):111-123. Location of Hamstring Injuries Based on Magnetic Resonance Imaging: A Systematic Review doi: 10.1177/19417381211071010. Epub 2022 Feb 11. PMID: 35148645; PMCID: PMC9808837.this study shows that From the 2788 references initially found in 5 databases, we included 34 studies, reporting a total of 2761 acute hamstring injuries. The most frequent muscle head involved was the long head of the biceps femoris (BFLH) (70%), followed by the semitendinosus (ST) (15%), generally associated with BFLH. The most frequent tissue affected was the myotendinous junction (MTJ) accounting for half the cases (52%). Among all lesions, the distribution between proximal, central, and distal lesions looked homogenous, with 34.0%, 33.4% and 32.6%, respectively. The stretching mechanism, while only reported in 2 articles, represented 3% of all reported mechanisms, appears responsible for a specific lesion involving the proximal tendon of the semimembranosus (SM), and leading to a longer time out from sport.
4. This study was conducted **by Jokela A, Valle X, Kosola J, Rodas G, Til L, Burova M, Pleshkov P, Andersson H, Pasta G, Manetti P, Lupón G, Pruna R, García-Romero-Pérez A, Lempainen L**. Mechanisms of Hamstring Injury in Professional Soccer Players: Video Analysis and Magnetic Resonance Imaging Findings. Clin J Sport Med. 2023 May 1;33(3):217-224. "Mechanisms of Hamstring Injury in Professional Soccer Players: Video Analysis and Magnetic Resonance Imaging Findings"doi: 10.1097/JSM.0000000000001109. Epub 2022 Nov 25. PMID: 36730099; PMCID: PMC10128906.this study shows that Fourteen videos of acute hamstring injuries in 13 professional male soccer players were analyzed. Three different injury mechanisms were seen: mixed-type (both sprint-related and stretch-related, 43%), stretch-type (36%), and sprint-type (21%). Most common actions during injury moments were change of direction (29%), kicking (29%), and running (21%). Most injuries occurred at high or very high horizontal speed (71%) and affected isolated proximal biceps femoris (BF) (36%). Most frequent body positions at defined injury moments were neutral trunk (43%), hip flexion 45-90 degrees (57%), and knee flexion <45 degrees (93%). Magnetic resonance imaging findings showed that 79% were isolated single-tendon injuries.
5. This study was conducted **by Marrero AM, Mazza LA, Cedola N, Neville MF, Trueba RH, Napoli A, Pascual TA, Velez CM, Tapia J, Rabino MA, Eivers PA, Cobeñas RL. MRI and US** in Hamstring Sports Injury Assessment: Anatomy, Imaging Findings, and Mechanisms of Injury. Radiographics. 2025 May;45(5):e240061." MRI and US in Hamstring Sports Injury Assessment: Anatomy, Imaging Findings, and Mechanisms of Injury" doi: 10.1148/rg.240061. PMID: 40244875. This study shows that Most muscle tears occur in the lower extremities, especially in the hamstrings. The hamstring muscle complex consists of the semimembranosus (SM), semitendinosus (ST), and biceps femoris (BF) muscles. They originate from the ischial tuberosity, and while the BF inserts into the head of the fibula, the ST and SM muscles attach to the medial aspect of the tibia. The hamstrings are primarily hip extensors and knee flexors. Tears mostly occur during sport practice, particularly during forceful stretching or high-speed running, and typical sites are grouped and classified according to their location within the muscle anatomy. Sprint and stretching injuries typically affect the BF and SM, respectively. MRI and US are key complementary modalities for the diagnosis, treatment, and

prognosis of hamstring injuries, as injury length, connective tissue involvement, and tear location determine evolution, recovery strategies, and return to play.

6. This study was conducted **by Mechó S, Palomar-Garcia A, Wong M, Gallego JC, López F, Valle X, Ruperez F, Pruna R, González JR, Rodas G**. Characterization of acute effects of football competition on hamstring muscles by muscle functional MRI techniques. PLoS One. 2024 Aug 27;19(8):e0308328. doi: 10.1371/journal.pone.0308328. PMID: 39190697; PMCID: PMC11349227. This study shows that Muscle functional MRI identifies changes in metabolic activity in each muscle and provides a quantitative index of muscle activation and damage. This investigation underscores the utility of T2 relaxation time mapping in evaluating muscle activation patterns during football matches, facilitating the detection of anomalous activation patterns that may warrant injury reduction interventions.
7. This study was conducted by **Tim Hoenig, MD t.hoenig@uke.de, Adam S. Tenforde, MD, […], and Karsten Hollander, MD, PhD** "Does Magnetic Resonance Imaging Grading Correlate With Return to Sports After Bone Stress Injuries? A Systematic Review and Meta-analysis". https://doi.org/10.1177/0363546521993807. This study shows that the prognostic value of MRI grading for time to return to sports and rate of return to sports after bone stress injuries.and held to findings from this systematic review indicate that MRI grading may offer a prognostic value for time to return to sports after the nonsurgical treatment of bone stress injuries. Both MRI grade and location of injury suggest that individually adapted rehabilitation regimens and therapeutic decisions are required to optimize healing and a safe return to sports.
8. This study was conducted by **Finnoff J.T., Hall M.M., Adams E. American Medica**l Society for Sports Medicine (AMSSM) position statement: interventional musculoskeletal ultrasound in sports medicine. Br J Sports Med. 2015;49(3):145–150. doi: 10.1136/bjsports-2014-094219. This study helps to findings of this position statement indicate there is strong evidence that USGIs are more accurate than LMGI, moderate evidence that they are more efficacious and preliminary evidence that they are more cost-effective. Furthermore, ultrasound-guided (USG) is required to perform many new, advanced procedures and will likely enable the development of innovative USG surgical techniques in the future.
9. This study was conducted **by Meyer N.B., Jacobson J.A., Kalia V., Kim S.M. Musculoskeletal ultrasound**: athletic injuries of the lower extremity. Ultrasonography. 2018;37(3):175–189. doi: 10.14366/usg.18013. This study shows the Athletic injuries of the lower extremities are commonly encountered in clinical practice. While some pathology can be diagnosed on physical exam, others are a clinical dilemma with nonspecific symptomatology. In these situations, ultrasound imaging can be utilized as an exceptional diagnostic tool, offering unique advantages over other imaging modalities. This article will review the imaging characteristics of commonly encountered athletic injuries of the lower extremity.
10. This study was conducted **by Isern-Kebschull, J., Pedret, C., Mechó, S. et al.** MRI findings prior to return to play as predictors of reinjury in professional athletes: a novel decision-making tool. Insights Imaging 13, 203 (2022). https://doi.org/10.1186/s13244-022-01341-1 and this study shows that Reinjury occurred in 9 participants, with a rate of 15.2%. None of the baseline MRI-related variables was significantly associated with reinjury. In the control MRI scan performed within 7 days prior to RTP, three independent findings were significantly associated with reinjury. These included transversal and/or mixed connective tissue gap (p = 0.002), intermuscular oedema (p = 0.015) and callus gap (p = 0.046). In the predictive model of the risk of reinjury, the presence of two of these radiological signs, together with interstitial feathery oedema, was associated with a high risk of recurrence (OR 29.58, 95% CI 3.86–226.64; p = 0.001).
11. This study was conducted by **Isern-Kebschull J, Pedret C, Mechó S, Pruna R, Alomar X, Yanguas X, Valle X, Kassarjian A, Martínez J, Tomas X, Rodas G.** MRI findings prior to return to play as predictors of reinjury in professional athletes: a novel decision-making tool. Insights Imaging. 2022 Dec 27;13(1):203. doi: 10.1186/s13244-022-01341-1. PMID: 36575363; PMCID: PMC9794673. And this study shows that MRI has shown great accuracy in assessing acute muscle injuries, identification of risk factors for reinjury before return to play (RTP) in professional athletes during the healing process could be very relevant. We assessed the value of MRI findings prior to RTP as predictors of reinjury.
12. This study was conducted by **Torres-Velázquez M, Wille CM, Hurley SA, Kijowski R, Heiderscheit BC, McMillan AB.** MRI radiomics for hamstring strain injury identification and return to sport classification: a pilot study. Skeletal Radiol. 2024 Apr;53(4):637-648. doi: 10.1007/s00256-023-04449-7. Epub 2023 Sep 20. PMID: 37728629; PMCID: PMC12185157. This study shows that MRI-based radiomics from hamstring muscles are related to injury and if the features could be used to perform a time to return to sport (RTS) classification. We hypothesize that radiomics from hamstring muscles, especially T2-weighted and diffusion tensor imaging-based features, are related to injury and can be used for RTS classification.
13. This study was conducted by **Ekstrand J, Hägglund M, Waldén M.** Epidemiology of Muscle Injuries in Professional Football (Soccer). The American Journal of Sports Medicine. 2011;39(6):1226-1232. "Epidemiology of Muscle Injuries in Professional Football (Soccer)"doi:10.1177/0363546510395879. this study about the investigate the incidence and nature of muscle injuries in male professional footballers.
14. This study was conducted by **Eliodoro Faiella, MD, Matteo Pileri, MD matteo.pileri@unicampus.it, Valerio D'Andrea, MD, Adriano Redi, MD, Stefania Lamja, MD, Domiziana Santucci, MD, PhD, LuigiStellato, MD, Francesco Formiconi, MD, Bruno B. Zobel, MD, Rosario F. Grasso, MD, Umile G. Longo, MD, Georg Ahlbäumer, MD, and ChristophSchaeffeler,** MD "MRI Features of Acute Muscle Injuries in Professional Soccer Players: A Systematic Review of Prognostic Associations With Return to Play ". https://doi.org/10.2214/AJR.25.33710 . This study shows that muscle injuries are a primary cause of loss of time from competition and have high recurrence rates, thus posing management challenges. MRI is widely used for injury grading and prognosis, yet associations of MRI findings with timelines for return to play (RTP) have been inconsistent.
15. This study was conducted by **Churchill, N.W., Hutchison, M.G., Graham, S.J. et al**. Brain function associated with reaction time after sport-related concussion. Brain Imaging and Behavior 15, 1508–1517 (2021)." Brain function associated with reaction time after sport-related concussion" https://doi.org/10.1007/s11682-020-00349-9 this study

shows that findings provide new insights into the effects of concussion on neurocognitive function and suggest the presence of functional brain networks that are specific to concussion-related RT slowing.

16. This study was conducted **by Martí-Bonmatí, L., Sopena, R., Bartumeus, P. and Sopena, P. (2010), Multimodality imaging techniques. Contrast Media Mol Imaging, 5: 180-189. https://doi.org/10.1002/cmmi.393**, this study shows that the need to combine morphofunctional information can be approached by either acquiring images at different times (asynchronous), and fused them through digital image manipulation techniques or simultaneously acquiring images (synchronous) and merging them automatically. The development of new diagnostic imaging research areas, mainly in the field of oncology, cardiology and neuropsychiatry, will impact the way medicine is performed today. Both clinical and experimental multimodality studies, in humans and animals, will have to demonstrate an efficient use of the imaging information provided by the modalities to affect the future of medical imaging.
17. This study was conducted **by Larson DB**. Optimizing CT radiation dose based on patient size and image quality: the size-specific dose estimate method. Pediatr Radiol. 2014 Oct;44 Suppl 3:501-5. doi: 10.1007/s00247-014-3077-y. Epub 2014 Oct 11. PMID: 25304711.this study shows The principle of ALARA (dose as low as reasonably achievable) calls for dose optimization rather than dose reduction, per se. Optimization of CT radiation dose is accomplished by producing images of acceptable diagnostic image quality using the lowest dose method available. Because it is image quality that constrains the dose, CT dose optimization is primarily a problem of image quality rather than radiation dose.

MATERIAL AND METHODS

Research Design

The present study is designed as a descriptive and analytical literature-based review. It focuses on evaluating the role of radiological imaging in sports medicine from the perspective of physiotherapy, including injury diagnosis, rehabilitation planning, and performance analysis. The study integrates findings from previously published research articles to understand the clinical importance of imaging in sports injury management.

Sources of Data

The study is based on secondary data collected from peer-reviewed journals, textbooks, medical databases, and published research articles related to sports injuries, radiological imaging, and rehabilitation science. Key sources include studies from radiology, sports medicine, and physiotherapy literature.

Study Scope

The scope of this study includes the use of imaging modalities such as X-ray, CT scan, MRI, and ultrasound in sports injuries. It mainly focuses on their role in early diagnosis, physiotherapy-based rehabilitation planning, monitoring recovery, and return-to-play decisions in athletes.

Selection Criteria

Only relevant studies related to sports injuries, musculoskeletal imaging, and rehabilitation were included. Studies focusing on MRI, CT, ultrasound, and X-ray applications in sports medicine were selected. Irrelevant studies and non-sports-related imaging research were excluded.

Data Analysis

The collected data was analyzed using a qualitative approach. The findings from different studies were compared and interpreted to understand the role of imaging in physiotherapy rehabilitation, injury assessment, and functional recovery. Key themes such as soft tissue evaluation, bone injury diagnosis, and rehabilitation monitoring were identified.

CONCLUSION

The findings of this study indicate that radiological imaging plays a significant role in the management of sports injuries from a physiotherapy perspective. Imaging modalities such as X-ray, CT scan, MRI, and ultrasound are widely used for accurate diagnosis and injury assessment in athletes.

MRI was found to be the most effective imaging technique for evaluating soft tissue injuries such as muscle tears, ligament injuries, and tendon damage, which are commonly managed in physiotherapy rehabilitation. Ultrasound was also found highly useful for real-time assessment of muscle and tendon function during movement and rehabilitation exercises.

X-ray imaging is primarily used for detecting fractures and bone alignment issues, while CT scan provides detailed evaluation of complex bone injuries. These imaging techniques help physiotherapists understand the severity and exact location of injury, which is essential for designing appropriate rehabilitation programs. The study also highlights that early diagnosis through imaging contributes to faster rehabilitation, reduced recovery time, and prevention of further complications. Imaging guidance improves decision-making in physiotherapy by helping in exercise prescription, progression of rehabilitation stages, and safe return-to-sport planning. And the advanced imaging techniques such as functional MRI and ultrasound elastography enhance understanding of muscle activity, tissue healing, and biomechanical function. These developments support better monitoring of recovery and help in optimizing rehabilitation outcomes. the results confirm that radiological imaging is an important supportive tool in physiotherapy practice for sports injury management, rehabilitation planning, and performance improvement.

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