

ORIGINAL RESEARCH

The Impact of Advanced Imaging on Sports Medicine and Athlete Rehabilitation

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ABSTRACT

Objective:To evaluate the impact of advanced imaging technologies on the diagnosis, treatment efficacy, and rehabilitation outcomes of sports-related injuries. **Methodology:**A quantitative research design was employed, utilizing a retrospective analysis of medical records and imaging reports collected over the past 15 years. The study included data from professional, semi-professional, and amateur athletes who had undergone imaging-based injury assessment and rehabilitation. Clinical datasets were gathered from hospitals and sports rehabilitation centers, focusing on the effectiveness of various imaging technologies in diagnosing ligament tears, muscle strains, cartilage damage, and concussions. Statistical methods were applied to analyze the correlation between imaging modalities and recovery outcomes, while AI-based diagnostic tools were compared to conventional radiological assessments. **Results:**The results indicated that MRI and AI-assisted imaging exhibited the highest diagnostic accuracy, particularly in detecting ligament and cartilage injuries. AI-driven diagnostics significantly enhanced early detection, reduced diagnostic inconsistencies, and improved treatment precision. Professional athletes had greater access to advanced imaging technologies, while semi-professional and amateur athletes primarily relied on ultrasound and CT scans. Recovery timelines varied based on injury type, with ligament injuries requiring prolonged rehabilitation and muscle strains exhibiting the highest recurrence rates. AI-assisted imaging played a crucial role in predicting reinjury risks and optimizing rehabilitation strategies. **Conclusion:**This study reaffirmed the transformative role of advanced imaging technologies in sports injury management. The findings aligned with previous research, emphasizing the superiority of AI-enhanced diagnostics in improving clinical decision-making and expediting recovery. However, challenges such as accessibility and cost remained barriers to widespread implementation. Future research should focus on making AI-driven imaging more accessible in non-professional sports settings while exploring emerging imaging modalities for enhanced rehabilitation monitoring.

Keywords: Sports injuries, MRI, AI-assisted imaging, rehabilitation, diagnostic accuracy, treatment efficacy, athlete recovery.

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BACKGROUND

The field of sports medicine and athlete rehabilitation has undergone a remarkable transformation in recent decades, driven by rapid advancements in technology. Among the most significant of these innovations are advanced imaging techniques, which have redefined the landscape of injury diagnosis, treatment planning, and recovery monitoring. The integration of cutting-edge imaging modalities, such as Magnetic Resonance Imaging, Computed Tomography, ultrasound, and emerging technologies like 3D imaging and Artificial Intelligence-assisted diagnostics, has significantly enhanced the precision, efficiency, and accuracy of medical interventions in sports medicine(1).

In the dynamic world of sports, injuries are an unavoidable aspect of an athlete's career. Whether

stemming from acute trauma or the cumulative effects of overuse, timely and accurate diagnosis is paramount to facilitating a swift and effective recovery. Historically, diagnostic methods relied heavily on clinical assessments and conventional imaging techniques, which, while useful, often fell short in capturing the complexities of musculoskeletal injuries. The advent of advanced imaging has mitigated these limitations, offering high-resolution, detailed visualizations of anatomical structures, enabling early injury detection, and allowing for more personalized rehabilitation strategies tailored to individual athletes(2).

Among the most widely employed imaging modalities in sports medicine, MRI stands out for its exceptional soft tissue contrast, making it the gold standard for

detecting ligament tears, muscle strains, and cartilage damage. Unlike traditional X-rays, which primarily assess bone structures, MRI provides a comprehensive view of joints, muscles, and tendons, aiding in the diagnosis of conditions such as meniscal tears, rotator cuff injuries, and stress fractures. Furthermore, functional MRI has emerged as a pivotal tool in evaluating brain injuries, particularly concussions, offering valuable insights into the neurological impact of sports-related trauma(3).

Similarly, CT scans have proven indispensable in sports medicine by providing highly detailed cross-sectional images of bones and joints. While MRI is the preferred modality for soft tissue assessment, CT is particularly advantageous in evaluating complex fractures, bone contusions, and structural abnormalities. This technology is especially valuable for cases requiring intricate anatomical detail, such as the assessment of facial fractures, spinal injuries, and post-surgical evaluations of bone healing, ensuring optimal treatment outcomes(4).

Ultrasound imaging has also garnered widespread acceptance in sports medicine due to its portability, real-time imaging capabilities, and cost-effectiveness. Unlike MRI and CT, which typically require specialized imaging centers, ultrasound can be deployed directly on the field or in clinical settings, making it an invaluable tool for immediate diagnosis and guided interventions. It excels in assessing soft tissue injuries, tendon pathologies, and joint fluid accumulations. Additionally, advancements in Doppler ultrasound technology have facilitated the evaluation of blood flow and inflammation, providing deeper insights into injury recovery and the progression of rehabilitation(5).

The integration of AI and machine learning into advanced imaging has further revolutionized sports medicine by automating image analysis, enhancing diagnostic accuracy, and predicting injury risks with unprecedented precision(6). AI-driven algorithms can rapidly process extensive imaging datasets, identifying subtle abnormalities that might be overlooked by human interpretation. These breakthroughs have not only accelerated the diagnostic process but have also paved the way for personalized rehabilitation protocols based on predictive analytics and data-driven clinical decision-making, ushering in a new era of precision medicine in sports injury management(7).

Beyond diagnostics, advanced imaging plays an instrumental role in monitoring an athlete's rehabilitation journey. Serial imaging enables physicians and physiotherapists to track healing rates, assess tissue regeneration, and make informed decisions regarding an athlete's readiness to return to competition. Emerging imaging technologies, such as diffusion tensor imaging and elastography, have provided groundbreaking insights into muscle and tendon recovery, facilitating targeted rehabilitation

strategies that optimize healing while mitigating the risk of re-injury(8).

As the field of sports medicine continues to evolve, the role of advanced imaging is poised for further expansion, integrating pioneering innovations such as augmented reality-guided imaging, 3D-printed anatomical models for pre-surgical planning, and telemedicine applications for remote injury assessments. These cutting-edge developments will not only enhance the efficacy of sports injury management but also contribute to proactive preventive strategies aimed at reducing injury incidence among athletes(9).

Advanced imaging has profoundly transformed sports medicine and athlete rehabilitation by delivering real-time, high-resolution, and comprehensive insights into injuries and recovery processes. The continuous evolution of imaging technologies, coupled with AI-driven and data-centric approaches, holds immense potential for optimizing injury prevention, diagnosis, and treatment methodologies(9). As research and technological advancements progress, the future of sports medicine will undoubtedly witness even greater breakthroughs in imaging techniques, ultimately enhancing athlete health, performance, and longevity on a global scale(10).

Aim of the Study

To explore the transformative impact of advanced imaging technologies on sports medicine, emphasizing their role in precise injury diagnosis, treatment optimization, and enhanced rehabilitation outcomes.

Objective of the Study

To evaluate the role of AI-driven imaging in improving diagnostic accuracy and predictive injury assessments.

Methodology

This study employed a quantitative research design to systematically evaluate the impact of advanced imaging technologies on sports injury diagnosis, treatment efficacy, and rehabilitation outcomes. A retrospective analysis of medical imaging data was conducted to assess the diagnostic accuracy and clinical utility of modalities such as MRI, CT, ultrasound, and AI-assisted imaging in sports medicine. Statistical methods were applied to quantify the effectiveness of these technologies in enhancing early injury detection, optimizing treatment protocols, and expediting recovery processes. The study analyzed a sample of 500 athletes, selected through stratified random sampling from sports rehabilitation centers, hospitals, and professional sports organizations. The sample comprised both male and female athletes, aged 18 to 40 years, from various sports disciplines, including football, basketball, athletics, and tennis. The selected participants had undergone imaging-based diagnosis and rehabilitation

for sports-related injuries within the last 15 years. The dataset included medical records, imaging reports, and recovery timelines to ensure a comprehensive evaluation of imaging technologies' effectiveness in injury management.

Inclusion Criteria

The study established well-defined inclusion criteria to ensure the precision, relevance, and reliability of the findings. Athletes across professional, semi-professional, and amateur levels who had undergone imaging-based diagnosis and rehabilitation for sports-related injuries were included in the analysis. To maintain a comprehensive and data-driven approach, only medical records and imaging reports spanning the past 15 years were considered, with a specific focus on MRI, CT, ultrasound, and AI-assisted imaging as primary diagnostic and rehabilitative tools in sports medicine. Furthermore, clinical datasets were sourced from hospitals, specialized sports rehabilitation centers, and medical imaging facilities, ensuring that the study captured a broad spectrum of injury types, imaging methodologies, and recovery patterns. The inclusion of these diverse and systematically documented cases allowed for a robust evaluation of the impact of advanced imaging technologies on patient recovery, treatment accuracy, and overall rehabilitation effectiveness.

Exclusion Criteria

To maintain methodological rigor, the study excluded:

- Cases where imaging was not the primary diagnostic or rehabilitative tool.
- Studies lacking empirical data or statistical validation, including theoretical discussions and opinion-based reports.
- Athletes with pre-existing musculoskeletal conditions unrelated to sports injuries, which could confound the results.
- Imaging technologies that had become obsolete or were no longer in clinical practice.

Data Collection

Data was collected from hospital archives, sports injury registries, and electronic medical records,

ensuring a comprehensive dataset for analysis. Imaging reports and clinical assessments were retrieved to quantify the accuracy, efficiency, and predictive capabilities of different imaging modalities. Retrospective patient data, including injury types, imaging-based diagnoses, and rehabilitation timelines, was compiled to facilitate comparative analysis.

Data Analysis

Quantitative data was subjected to rigorous statistical evaluation using comparative analysis, regression modeling, and machine learning algorithms. Diagnostic precision, recovery durations, and treatment efficacy were statistically examined to determine correlations between imaging advancements and improved rehabilitation outcomes. AI-driven imaging datasets were analyzed to assess their predictive accuracy in injury prognosis. Comparative assessments between traditional and advanced imaging techniques were conducted to establish their respective contributions to sports medicine. The findings provided empirical evidence regarding the transformative role of advanced imaging in optimizing injury management and enhancing athlete rehabilitation strategies.

RESULTS

Table 1 presented a comprehensive demographic analysis of the study participants, categorized into professional, semi-professional, and amateur athletes. The total sample size comprised 1,000 athletes, with 200 classified as professional, 300 as semi-professional, and 500 as amateur athletes. The mean age distribution revealed that professional athletes had an average age of 27.5 years, semi-professional athletes 25.8 years, and amateur athletes 22.3 years. Gender representation indicated that 63% of the participants were male, while 37% were female. Furthermore, the table delineated the proportion of athletes engaged in contact and non-contact sports, with contact sports comprising 55% of the total sample. A higher prevalence of contact sports was observed among professional athletes, whereas non-contact sports were more common among amateur participants.

Table 1: Participant Demographics

Variable	Professional Athletes	Semi-Professional Athletes	Amateur Athletes	Total (%)
Sample Size (n)	200	300	500	1000 (100%)
Mean Age (Years)	27.5 ± 4.2	25.8 ± 3.9	22.3 ± 5.1	-
Gender (Male/Female)	130/70	180/120	320/180	630/370
Sport Type (%)				
- Contact Sports	120 (60%)	180 (60%)	250 (50%)	550 (55%)
- Non-Contact Sports	80 (40%)	120 (40%)	250 (50%)	450 (45%)

Table 2 provided a detailed overview of the frequency and distribution of different imaging modalities employed in diagnosing sports-related injuries across various levels of athletic participation. Magnetic Resonance Imaging emerged as the most frequently utilized imaging technique, accounting for 62% of total cases, with the highest prevalence among professional athletes (80%) and semi-professional athletes (70%). Computed

Tomography scans were employed in 47% of cases, predominantly among semi-professional (50%) and amateur (44%) athletes. Ultrasound, being a more accessible and cost-effective imaging modality, was used in 47% of cases, particularly among amateur athletes (60%). Notably, AI-assisted imaging was utilized in 28% of cases, with its highest adoption observed among professional athletes (35%), reflecting an increasing reliance on artificial intelligence-driven diagnostic technologies at the highest levels of competition.

Table 2: Imaging Modalities Utilized

Imaging Modality	Professional Athletes (%)	Semi-Professional Athletes (%)	Amateur Athletes (%)	Total (%)
MRI	160 (80%)	210 (70%)	250 (50%)	620 (62%)
CT scan	100 (50%)	150 (50%)	220 (44%)	470 (47%)
Ultrasound	50 (25%)	120 (40%)	300 (60%)	470 (47%)
AI-Assisted Imaging	70 (35%)	90 (30%)	120 (24%)	280 (28%)

Table 3 delineated the range of sports injuries identified through various imaging modalities, offering a comparative analysis of their diagnostic effectiveness. Ligament tears were most detected through MRI (90%) and AI-assisted imaging (80%), underscoring their superior sensitivity in assessing soft tissue injuries. Muscle strains exhibited high detection rates through ultrasound (80%) and MRI (70%), confirming the utility of these modalities in evaluating muscular damage. Bone fractures were primarily diagnosed via CT scans (90%), although AI-assisted imaging demonstrated considerable accuracy (70%) in fracture detection. Cartilage damage was predominantly identified using MRI (80%) and AI-assisted imaging (90%), signifying their essential role in diagnosing joint-related injuries. Concussions were mainly detected through CT scans (80%) and AI-assisted imaging (90%), highlighting the significance of these technologies in assessing traumatic brain injuries.

Table 3: Sports Injuries Diagnosed Using Imaging

Injury Type	MRI (%)	CT Scan (%)	Ultrasound (%)	AI-Assisted Imaging (%)	Total Diagnosed Cases
Ligament Tears	250 (90%)	40 (10%)	60 (20%)	220 (80%)	280
Muscle Strains	180 (70%)	30 (10%)	200 (80%)	160 (60%)	250
Bone Fractures	50 (20%)	280 (90%)	30 (10%)	200 (70%)	310
Cartilage Damage	160 (80%)	50 (20%)	40 (20%)	180 (90%)	200
Concussions	90 (60%)	120 (80%)	0 (0%)	130 (90%)	145

Table 4 provided a comparative assessment of the sensitivity, specificity, and overall accuracy of various imaging techniques. AI-assisted imaging exhibited the highest diagnostic accuracy (94%), with the lowest false positive (3.8%) and false negative (4.4%) rates, reinforcing its reliability in sports injury diagnostics. MRI demonstrated a high accuracy rate of 91.1%, with sensitivity and specificity values of 92.5% and 89.7%, respectively. CT scans followed closely, with an accuracy of 87%, primarily excelling in the detection of bone-related injuries. Although widely utilized for muscle and soft tissue assessments, ultrasound had the lowest accuracy (80.2%), with a relatively higher false negative rate (18.7%). These findings underscored the efficacy of AI-assisted imaging and MRI as the most precise modalities for sports injury diagnosis.

Table 4: Diagnostic Accuracy of Imaging Modalities

Imaging Modality	Sensitivity (%)	Specificity (%)	Accuracy (%)	False Positive Rate (%)	False Negative Rate (%)
MRI	92.5	89.7	91.1	5.3	7.5
CT Scan	88.2	85.4	87.0	7.8	11.8
Ultrasound	81.3	79.2	80.2	10.5	18.7
AI-Assisted Imaging	95.6	92.1	94.0	3.8	4.4

Table 5 provided a detailed analysis of treatment efficacy, recovery durations, recurrence rates, and the preferred imaging modalities for different types of sports injuries. Ligament tears exhibited the longest average recovery time of 12.4 weeks, with a treatment success rate of 90%, primarily diagnosed through MRI and AI-assisted imaging. Muscle strains had a comparatively shorter recovery period of 6.8 weeks but demonstrated a higher recurrence rate (12%), with ultrasound and MRI serving as the primary diagnostic tools. Bone fractures required an average healing duration of 9.2 weeks, with CT scans and AI-assisted imaging achieving high treatment

success rates (88%). Cartilage damage had the most prolonged rehabilitation period (14.3 weeks) and the highest recurrence rate (15%), indicating its complexity in clinical management. Concussions, on the other hand, had a relatively brief recovery time of 5.7 weeks and a treatment success rate of 87%, with MRI and CT scans playing pivotal roles in their diagnosis and management.

Table 5: Treatment and Rehabilitation Outcomes

Injury Type	Average Recovery Time (Weeks)	Treatment Success Rate (%)	Recurrence Rate (%)	Imaging Modality Most Used
Ligament Tears	12.4 ± 2.1	90	8	MRI, AI
Muscle Strains	6.8 ± 1.5	85	12	Ultrasound, MRI
Bone Fractures	9.2 ± 1.9	88	10	CT, AI
Cartilage Damage	14.3 ± 2.5	82	15	MRI, AI
Concussions	5.7 ± 1.2	87	9	MRI, CT

Table 6 showcased the diagnostic performance of various AI-driven imaging techniques in sports injury assessments. The study evaluated four AI algorithms: Deep Learning Convolutional Neural Networks, Machine Learning Support Vector Machines, AI-enhanced MRI analysis, and automated CT scan review. AI-enhanced MRI analysis demonstrated the highest diagnostic accuracy (95.2%) with the shortest processing time (3.8 seconds), achieving an exceptional diagnostic agreement with expert radiologists (93.5%). Deep Learning CNN exhibited a similarly high accuracy rate (94.5%), with a processing time of 4.2 seconds. The Machine Learning SVM model performed slightly lower, with an accuracy of 91.3% and a processing time of 5.5 seconds. Automated CT scan review achieved an accuracy of 92.7%, reinforcing the role of AI in enhancing diagnostic precision and efficiency in sports medicine. These findings underscored the potential of AI-driven imaging in revolutionizing sports injury diagnostics by providing rapid and highly accurate assessments.

Table 6: AI-Assisted Imaging Performance in Sports Medicine

AI Algorithm Used	Number of Cases Analyzed	Average Processing Time (Seconds)	Accuracy (%)	Diagnostic Agreement with Radiologists (%)
Deep Learning CNN	500	4.2	94.5	92.8
Machine Learning SVM	300	5.5	91.3	90.2
AI-Enhanced MRI Analysis	400	3.8	95.2	93.5
Automated CT Scan Review	350	4.0	92.7	91.0

DISCUSSION

The findings of this study provided an in-depth evaluation of the transformative role of advanced imaging technologies in diagnosing, managing, and rehabilitating sports-related injuries. The results unequivocally demonstrated that MRI and AI-assisted imaging exhibited the highest diagnostic accuracy, particularly in detecting ligament tears, cartilage damage, and concussions. These findings were in alignment with previous studies by Gog et al., that underscored the superior sensitivity of MRI in soft tissue assessments and the rapidly emerging role of AI in enhancing diagnostic precision and efficiency (11). A notable trend observed in this study was the differential utilization of imaging modalities among athletes at various levels of competition. Professional athletes were significantly more likely to undergo MRI and AI-assisted diagnostics, whereas semi-professional and amateur athletes predominantly relied on ultrasound and CT scans. This pattern corroborated prior research by Finnoff et al., which highlighted the greater accessibility of sophisticated imaging technologies among elite athletes, driven by the necessity for precise diagnostics and expedited

recovery.(12) Moreover, the increasing reliance on AI-enhanced imaging among professional athletes signified a paradigm shift towards data-driven decision-making in sports medicine, aligning with the findings of Guglielmi et al., who emphasized the transformative potential of AI in radiological assessments(13).

Injury distribution analysis revealed that ligament tears and cartilage damage were the most frequently diagnosed conditions, with MRI and AI-assisted imaging proving to be the most effective diagnostic modalities. These results reinforced prior investigations by McCurdie established MRI as the gold standard for detecting soft tissue injuries due to its unparalleled resolution and detailed visualization capabilities(14). Furthermore, AI-assisted imaging demonstrated remarkable accuracy, reducing diagnostic inconsistencies and facilitating early detection of micro-injuries, findings that were consistent with recent advancements in AI-driven radiological assessments (15).

The study also explored treatment efficacy and rehabilitation timelines across different injury types, revealing that ligament injuries necessitated the most

prolonged recovery periods, whereas muscle strains exhibited the highest recurrence rates. These findings agreed with previous literature, which identified ligamentous injuries as particularly challenging due to their extended healing duration and heightened reinjury risk (16). Additionally, the high recurrence rates of muscle strains aligned with the research of El Demellawy et al., who attributed such patterns to suboptimal rehabilitation strategies and insufficient muscle conditioning(17). AI-assisted imaging played a pivotal role in identifying micro-tears and predicting injury recurrence, further validating its emerging significance in sports medicine.

A particularly noteworthy aspect of this study was the evaluation of AI-driven imaging methodologies, which demonstrated that AI-enhanced MRI analysis and deep learning convolutional neural network models outperformed traditional radiological assessments in terms of diagnostic precision and processing efficiency. These findings were congruent with the work of Davidson and Jayaraman reported that deep learning algorithms significantly surpassed conventional imaging techniques in detecting musculoskeletal injuries with enhanced accuracy and speed(18). The results underscored the growing integration of AI in medical imaging, particularly in elite sports settings where rapid and precise diagnostics are imperative for optimizing treatment pathways.

Beyond diagnostics, this study reinforced the indispensable role of advanced imaging technologies in injury monitoring and rehabilitation. Serial imaging assessments facilitated a meticulous evaluation of healing progress, enabling clinicians to make data-driven decisions regarding an athlete's readiness to return to competition. Emerging imaging modalities, such as diffusion tensor imaging and elastography, demonstrated substantial potential in assessing tissue recovery, findings that echoed the work of Bell et al., who emphasized the utility of novel imaging techniques in refining rehabilitation protocols and mitigating reinjury risks(19).

However, despite the undeniable advantages of AI-assisted imaging, this study also acknowledged certain limitations. The accessibility of AI-driven diagnostic tools remained a significant challenge in non-professional sports settings due to financial constraints and the requirement for specialized expertise. These challenges were previously highlighted by McCalden et al., who posited that while AI exhibited immense promise, its widespread adoption was contingent upon infrastructural advancements and cost reductions(20). Additionally, the retrospective nature of this study posed inherent constraints, as variations in historical medical records and imaging documentation introduced inconsistencies, a limitation that was similarly noted in the research of Zhou et al., (21).

CONCLUSION

This study reaffirmed the transformative impact of advanced imaging technologies in sports medicine, establishing MRI and AI-assisted imaging as the most reliable modalities for injury diagnosis and rehabilitation monitoring. The findings were consistent with prior research, reinforcing the role of AI in augmenting diagnostic accuracy, minimizing misdiagnoses, and optimizing recovery outcomes. Moving forward, future research should prioritize the expansion of AI accessibility in amateur and community-level sports, alongside the development of cost-effective AI-driven imaging solutions to facilitate broader clinical implementation. As technological advancements continue to evolve, the integration of AI and emerging imaging modalities is poised to revolutionize sports medicine, paving the way for more personalized, precise, and proactive approaches to injury management and athletic performance optimization.

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