NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Quality in Sport. eISSN 2450-3118.

Journal Home Page
https://apcz.umk.pl/QS/index

KOŁODZIEJ-SIERADZ, Marta, TERLECKA, Anna Magdalena, ĆWIEK, Hubert, GRYZ, Paulina Klaudia, KOMOROWSKI, Kacper, PILARSKA, Karolina Jolanta, SZWANKOWSKA, Anna Aleksandra, BACZYŃSKA, Anna, BORUSZCZAK, Błażej, and ROŻENEK, Adam Wiktor. A Symptom-Driven Imaging Protocol for Temporomandibular Disorders in Elite Athletes: Integrating AI and Conventional Modalities. Quality in Sport. 2026;54:70643. eISSN 2450-3118. https://doi.org/10.12775/QS.2026.54.70643

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a Unique Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).
The authors declare that there is no conflict of interest regarding the publication of this paper.
Received: 07.04.2026. Revised: 12.04.2026. Accepted: 20.04.2026. Published: 26.04.2026.

A Symptom-Driven Imaging Protocol for Temporomandibular Disorders in Elite Athletes: Integrating AI and Conventional Modalities

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Abstract

Background. Temporomandibular disorders (TMDs) affect the TMJ, masticatory muscles, and related structures. They are critical in sports medicine, as athletes face unique stressors—from facial trauma to exertional bruxism—impacting postural stability and quality of life. Despite their clinical significance, standardized imaging protocols for professional athletes are lacking.
Aim. This narrative review presents an evidence-based, symptom-oriented algorithm for selecting efficient imaging modalities for TMDs in athletes. It combines conventional imaging (MRI, CBCT) with cutting-edge AI and DL screening methods to establish a contemporary diagnostic protocol.
Material and methods. A literature search (2018–2026) was conducted across PubMed/MEDLINE, Scopus, WOS, and IEEE Xplore. It included studies on biomechanics, neurophysiology, sports medicine, imaging techniques (MRI, CBCT, US), and DL applications in orofacial diagnostics.
Results. Diagnostic protocols should be tailored to athletes' specific clinical signs and sport-related risks. While MRI remains the gold standard for soft tissue, disc derangements, and early

inflammation, CBCT offers superior resolution for osseous degeneration and fractures. Furthermore, recent DL models (e.g., TMJ-PanoNet) enable sensitive prescreening using widely available 2D panoramic radiographs.

Conclusions. A symptom-oriented, AI-assisted imaging protocol improves diagnostic speed, accuracy, and treatment outcomes. Early detection of TMJ dysfunctions helps control TMD progression, reduce chronic pain, and restore biomechanical balance, potentially preventing premature career termination in professional athletes.

Keywords: Temporomandibular joint, TMD, Sports medicine, Magnetic resonance imaging, Cone beam computed tomography, Deep learning, Artificial intelligence, Orthopantomogram, Exertional bruxism, Postural stability

1. Introduction

Temporomandibular disorders (TMD) are a heterogeneous group of clinical entities, pain and dysfunction of the masticatory muscles, temporomandibular joint (TMJ) and related orofacial, fascial and neurological structures [1, 2, 3, 4]. The prevalence of symptomatic TMD ranges between 5% and 12% of the adult population globally, with significantly higher prevalence rates observed amongst elite and professional athletes [5]. The higher prevalence of TMD in the athletic population compared to the general population is attributed to the high-impact nature of their occupations, high-intensity training, occupational parafunctions and specific sport-related trauma [5].

The stomatognathic system in modern athletic medicine is not solely regarded as a dental issue but is of great importance for the overall neuromuscular and biomechanical performance of the body. The TMJ has anatomical and physiological relations with the upper cervical spine and the vestibular system, with its fascial connections to the entire body [6]. Due to its close relationship with the trigeminocervical nucleus, the sensory information from the TMJ and masticatory muscles is intimately related with the information from the cervical spine [7]. TMDs such as anterior disc displacement and unilateral masseter hypertrophy can therefore clinically manifest in athletes with postural instability, poor core stability, chronic suboccipital pain and reduced dexterity [6, 7]. Although the stomatognathic system is of great importance to the overall performance of an athlete, there is a current lack of information amongst sports medicine practitioners regarding an evidence-based, protocol-driven approach to the selection of an appropriate imaging modality in the assessment of TMJ dysfunction or pathology in an athlete. This often leads to delayed or inappropriate management of TMJ pathologies with associated chronic pain, and inappropriate, low-yield imaging for the diagnosis of the disorder.

Research objective. This narrative review aims to provide a multi-tiered, evidence-based protocol for the selection of an appropriate imaging modality (OPG, CBCT, MRI and USG) for TMJ pathologies in athletes.

Research problems. This study will investigate the specific limitations and strengths of individual imaging modalities in the assessment of sports-related orofacial injuries. It will also investigate how the different physiological requirements of various sporting disciplines (contact sport, strength training and endurance) affect the selection of the optimal imaging modality for the diagnosis of TMJ pathologies. Furthermore, it will assess the role of artificial intelligence (AI) and deep learning in enhancing early screening and triage for joint damage in high-performance athletes.

Research hypothesis. It is hypothesized that a symptom-led imaging protocol, in conjunction with AI and deep learning enhanced pre-season screening, will reduce time to definitive diagnosis, reduce unnecessary radiation, optimize health care costs and reduce the time for return to play (RTP) in athletes.

2. Research materials and methods

2.1. Participants

The target population for the theoretical and clinical model discussed in this review are professional, semi-professional and high-intensity amateur athletes. For the purpose of this theoretical discussion, these athletes will be broadly classified into three categories based on the biomechanical nature of their sport:

1. **Contact and Combat Sports** (e.g. rugby, American football, boxing, mixed martial arts and ice hockey): High risk for acute macrotrauma, mandibular trauma, traumatic condylar fractures and acute disc displacements.
2. **Strength and Power Sports** (e.g., weightlifting, powerlifting, shot put, sprinting): This is characterised by the presence of high-intensity, explosive muscle contractions, often accompanied by concomitant exertional bruxism (maximal teeth clenching). This results in excessive joint loading, increased intra-articular pressure and micro-traumatic cartilage damage.

3. **Endurance and Precision Sports** (e.g., marathon running, biathlon, gymnastics): This is characterised by repetitive loading, muscle fatigue and spasms, and an increased dependence on postural balance and cervical-stomatognathic inter-relationship.

Due to the relative absence of large-scale, longitudinal imaging studies conducted exclusively in elite athletes, this narrative review is also informed by cross-sectional data drawn from general dental, orthodontic and maxillofacial populations.

2.2. Methodology and Search Strategy. This study is structured as a comprehensive narrative literature review. The search was performed using the following databases: PubMed/MEDLINE, Scopus, Web of Science Core Collection and the IEEE Xplore Digital Library.

The search terms were combined using Boolean operators as follows: ("Temporomandibular Joint" OR "TMJ" OR "Temporomandibular Disorders" OR "TMD") AND ("Sports Medicine" OR "Athletes" OR "Exertional Bruxism" OR "Postural Balance" OR "Quality in Sport") AND ("Magnetic Resonance Imaging" OR "Cone Beam Computed Tomography" OR "CBCT" OR "Ultrasound" OR "Deep Learning" OR "Artificial Intelligence" OR "Neural Networks").

Studies were included if they were peer-reviewed articles published in English, randomised control trials, observational studies, reviews, meta-analyses, and technical engineering papers describing AI diagnostic models in maxillofacial radiology published between 2018 and 2026. Exclusion criteria included single case reports (unless describing a novel imaging technique), non-peer reviewed articles, non-English articles, and those published before 2018. Exceptions to the date exclusion criteria were made for foundational anatomical texts and universally accepted diagnostic criteria (e.g., DC/TMD).

2.3. Data collection and analysis

2.3.1. Statistical analysis As a narrative review, this study did not involve the statistical calculation of primary raw data or meta-analysis. Instead, data extraction focused on identifying key clinical themes, diagnostic protocols, and synthesizing recommendations based on the findings reported in the included primary studies.

2.3.2. Use of artificial intelligence (AI) In accordance with current academic and ethical standards, artificial intelligence tools (in the form of large language models) have been used as ancillary tools during the preparation of this manuscript. Their use has been limited to structural organisation, language editing and formatting. All conceptual ideas, clinical analysis, diagnostic pathways and medical validation have been conceived and verified by the author alone. AI has not been used to produce or alter any primary medical data or clinical fact.

2.3.3. Statistical Methods This literature analysis includes a critical evaluation of the diagnostic accuracy metrics reported in the primary studies. For the evaluation of imaging techniques and AI models (e.g., TMJ-PanoNet), key diagnostic accuracy metrics such as Sensitivity, Specificity, Area Under the Receiver Operating Characteristic Curve (AUC-ROC), and classification accuracy were extracted and qualitatively compared.

3. Research results.

3.1. The Postural-Kinematic Chain and TMJ Biomechanics

The TMJ is one of the most complex joints of the human body. Classified as a bilateral, diarthrodial, ginglymoarthrodial joint, it is unique in that it simultaneously performs hinge-like rotations (in the inferior compartment) and gliding translations (in the superior compartment). The articular disc, a dense, avascular, and a-neural biconcave fibrocartilaginous structure, is the key biomechanical element of the TMJ. It splits the joint space, functioning as an essential shock absorber and stabilizer, which reduces the friction between the condyle of the mandible and the articular eminence of the temporal bone [4, 8].

In contemporary sports medicine, the human body should be considered as a linked kinetic chain. The stomatognathic system is biomechanically related to the cervical spine through the accessory masticatory muscles (suprahyoid and infrahyoid muscles) and the deep fascial planes. Therefore, any TMJ disorders (such as disc displacement or capsulitis) will cause immediate, reflex changes in the resting tone of the sternocleidomastoid, trapezius, and deep cervical stabilizers. In some cases, particularly in sports that require precision (e.g., biathlon or gymnastics), the asymmetric muscle tone may affect the fine motor skills, hand-eye coordination, and vestibular balance [6, 9].

3.2. Exertional Bruxism and Dynamic Overload in Elite Athletes

The TMJ is subjected to non-physiological stresses in competitive sports. For example, weightlifters and sprinters exhibit involuntary teeth clenching during high-intensity effort. This condition is called exertional bruxism and has a clear biomechanical role: during powerful clenching of the jaw, the concurrent activation potentiation effect is activated, engaging the core and neck muscles for spinal stabilization and force generation. However, this mechanism has a high biomechanical cost for the TMJ.

The studies that employed intra-articular pressure monitoring and finite element analysis (FEA) have shown that, during peak isometric contractions, occlusal forces may reach 900 to 1200 Newtons. This significant increase in intra-articular pressure pushes the synovial fluid out of the joint compartments, determining a local hypoxic environment, and causes shear stress in the fibrocartilage of the articular disc. Through this repetitive microtrauma, the progressive release of pro-inflammatory cytokines and matrix metalloproteinases (MMPs) is stimulated, leading to the progressive alterations of the articular surfaces [8, 10].

3.3. Panoramic Radiography (OPG): The Pre-Screening Phase

The orthopantomogram (OPG) is a traditional imaging method used for dental and maxillofacial diagnostics. It offers a two-dimensional image of the dental arches of the maxilla and mandible, alveolar bone, and both mandibular condyles. The most important advantages of OPG are its wide availability, low costs, fast execution time, and low dose of ionizing radiation.

However, in the complex diagnosis of TMD, conventional OPG has several limitations. It is prone to geometric distortion, magnification errors, and overlap of dense anatomical structures (skull base, zygomatic arches, and cervical spine) over the TMJ [11, 12, 13]. In modern sports medicine, a noncontrast OPG is not a definitive diagnostic imaging modality for TMJ disease, but it is an excellent first-line tool for quickly excluding macroscopic pathology such as large odontogenic infections, sizable bone cysts, tumors, and mandibular fractures before advanced 3D imaging is performed [11, 12].

3.4. CBCT: Bony Imaging

CBCT is the latest technology in maxillofacial imaging. It has largely replaced the use of conventional multi-slice medical CT scans for evaluating the bony orofacial region. CBCT uses a divergent cone-shaped X-ray beam and a flat-panel detector to capture a volume of data representing the entire maxillofacial region in a single rotation. This yields a significant reduction in radiation when compared to medical CT, with an excellent sub-millimeter spatial resolution.

In the sports diagnostic algorithm, CBCT is the preferred imaging modality for evaluating the bone. It offers highly accurate, multiplanar (axial, coronal, and sagittal) cross-sectional images that are free of structural overlap [14]. In patients with clinical evidence of bone-to-bone contact such as coarse crepitus, a “grating” or scraping sound upon mandibular translation, or a history of a direct blow, CBCT is the imaging modality of choice. It is an excellent tool for the early detection of subtle bony changes associated with TMJ-OA such as cortical erosions, subchondral cysts, osteophytes, condylar flattening, and generalized sclerosis. In addition, it is very sensitive for detecting nondisplaced or micro-fractures of the condylar neck or head that are not evident on a conventional panoramic radiograph in contact sports [15, 16].

3.5. MRI: The Soft Tissue Imaging Gold Standard

While CBCT imaging offers an excellent view of the hard tissues, it fails to provide information on the complex soft tissue anatomy of the TMJ. MRI, therefore, remains the gold standard imaging modality for the soft tissues. Magnetic fields and radiofrequency pulses are used to generate an image. MRI offers superior contrast resolution, which allows for direct visualization of the articular disc, joint capsule, synovial fluid, bilaminar zone (retrodiscal tissues), and masticatory musculature.

In elite sports medicine, high field strength MRI scanners (≥3.0 Tesla) are recommended. A comprehensive TMJ MRI protocol should consist of the following sequences:

- **T1-weighted and Proton Density (PD) sequences:** High in anatomical detail and are necessary to ascertain the morphological shape and position of the articular disc in relation to the condyle and articular eminence.
- **T2-weighted and STIR (Short Tau Inversion Recovery) sequences:** Highly sensitive to fluid and are indicated in acutely injured patients for the presence of joint effusion (acute synovitis) and BME. BME is an essential early metabolic indicator of joint distress and signifies subchondral micro-traumatic stress and inflammation before irreversible structural erosion is evident on CBCT [17, 18].

In addition, dynamic (kinematic) MRI protocols imaging the TMJ during various degrees of mouth opening are necessary for the diagnosis of dynamic functional disorders such as Disc Displacement with Reduction (DDwR) and Disc Displacement without Reduction (DDwoR) [19, 20].

3.6. High-Frequency US: Point-of-Care Diagnostics

High-frequency (≥15 MHz) linear probe US has been increasingly used in sports medicine as a point-of-care (POCUS) diagnostic tool. The advantages of diagnostic US are its non-invasive nature, absence of ionizing radiation, cost-effectiveness, and dynamic functional analysis capability.

Although US waves are unable to penetrate cortical bone and thus cannot be used to examine the deep intra-articular space or the medial portion of the articular disc, they can be used to sensitively examine superficial soft tissue. In the clinical setting of athletes, US can be used to examine the presence of lateral joint capsule distension and the amount of inflammatory joint effusion, as well as the cross-sectional thickness and morphological change of the masseter and temporalis muscles. Muscle hypertrophy and hypoechoic lesions (myofascial trigger points) on US images can be used as indirect signs of chronic exertional bruxism or muscle spasm. Therefore, US can be used as a useful adjunct tool for immediate sideline triage and follow-up assessment [21].

Modality	Primary Indications in Sports	Key Advantages	Key Limitations	Radiation dose
OPG	Initial screening, gross trauma	Low cost, wide availability, rapid	Geometric distortion, structural overlap	Low
CBCT	Condylar fractures, Osteoarthritis	Sub-millimeter bony resolution, 3D	Poor soft tissue contrast	Low/medium
MRI	Disc displacement, Joint effusion	Gold standard for soft tissues	Expensive, long scan time, claustrophobia	None
US	Sideline triage, muscle hypertrophy	Real-time, point-of-care, dynamic	Operator dependent, limited acoustic window	None

Table 1: Summary of Imaging Modalities for TMJ in Sports Medicine.

3.7. AI and Deep Learning for TMD

Over the past few years, AI, especially deep Convolutional Neural Networks (CNNs), has made tremendous progress in the field of radiologic diagnostics [22], which can compensate for the diagnostic limitations in sports medicine facilities and developing countries where it is difficult to access high-field MRI in a timely and cost-effective manner.

3.7.1. TMJ-PanoNet Recently, a novel AI model, called the TMJ-PanoNet model, was proposed for the extraction of relevant diagnostic information from conventional 2D panoramic radiographs. The TMJ-PanoNet model uses a two-stage, hierarchical deep learning framework:

- **Stage 1: Region of Interest (ROI) Detection.** The TMJ-PanoNet model utilizes the YOLOv5s object detection architecture. YOLOv5s can scan a whole panoramic radiograph to detect and crop the ROIs, such as left and right TMJs, and eliminate the surrounding unnecessary dental and cranial structures.

- **Stage 2: Feature Extraction and Classification.** The detected condylar images are input into a modified ResNet-18 architecture equipped with Dual Attention Networks (DANet). Finally, the network classifies the TMJ into Normal (NR), Disc Displacement with Reduction (DDR), or Disc Displacement without Reduction (DDNR).

3.7.2. Clinical Triage and Performance Metrics of AI In validation studies, models such as TMJ-PanoNet have demonstrated binary classification accuracies ranging from 80.8% to 85% when predicting soft-tissue disc displacements using only 2D panoramic radiographs. Based on osseous changes, the TMJ-PanoNet model can statistically predict the position and configuration of the articular disc. For sports medicine physicians, routine dental OPGs taken before the season can be used as a screening tool to identify asymptomatic athletes at risk for TMD [23, 24, 25].

4. Discussion

4.1. Symptom Based Diagnostic Algorithm for Sports Medicine

The key outcome of this review is the suggested symptomatically oriented decision tree for the demand of sports medicine, shifting from a general imaging referral to specific imaging based on the clinical presentation.

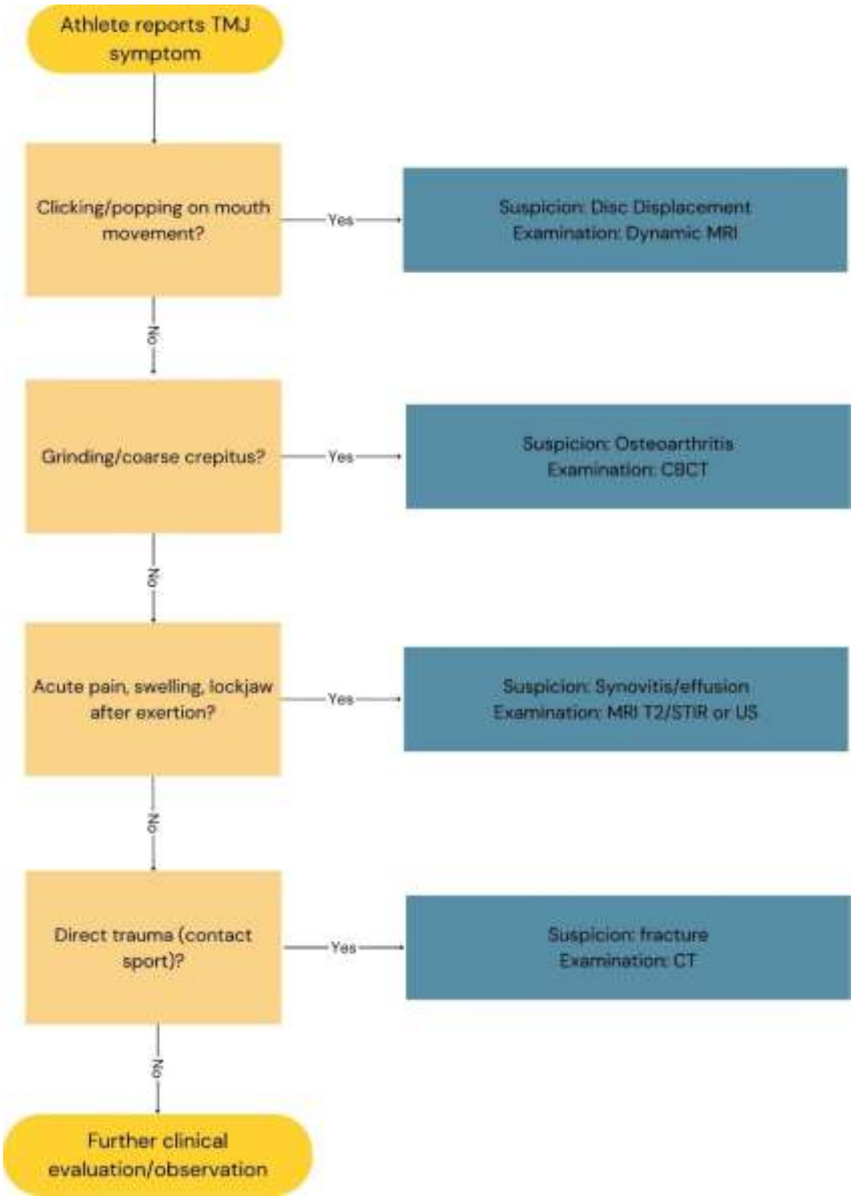

Figure 2. Diagnostic Decision Tree in TMJ symptoms.

4.1.1. Case 1: Patient Reporting a Click or a Pop

- **Complaint:** The patient reports a click or a pop during mouth opening and mouth closure, indicative of Disc Displacement with Reduction (DDwR).
- **Proposed Modality:** Dynamic MRI. CBCT lacks the diagnostic ability to image the soft tissue, and thus dynamic MRI is indicated for direct visualization of the disc-condyle relationship [17, 19].

4.1.2. Case 2: Patient Reporting Grinding or Coarse Crepitus

- **Complaint:** Sensation of grinding or coarse crepitus within the joint, accompanied by a dull ache, indicative of advanced osteoarthritis and possible disc perforation [26].

- **Proposed Modality:** CBCT. For high resolution of structural integrity to assess the morphology of the condyle, joint space, and osteophytes to accurately stage the degenerative joint disease [27, 28].

4.1.3. Case 3: Patient Reporting Acute Pain, Swelling, and Trismus

- **Complaint:** Following strenuous activity the patient reports sharp acute pain, swelling and trismus indicative of acute synovitis, capsulitis, or retrodiscitis.
- **Proposed Modality:** T2 and STIR MRI Sequences. To visualize joint effusion and bone marrow edema that are not visible on radiographic imaging [10, 18].

4.1.4. Case 4: Patient Reporting Acute Direct Trauma

- **Complaint:** Acute direct trauma to the mandible resulting in an acute malocclusion, pain and bleeding from the auditory meatus.
- **Proposed Modality:** CBCT (or Medical CT). Acute three-dimensional imaging of the bone is warranted. CBCT is highly sensitive in detecting non-displaced condylar neck fractures [3, 8].

4.2. Incorporation into the "Return to Play" Process

The timeframe for the diagnosis of elite athletes should be more aggressive than for non-athletes. A "wait and see" approach or a period of rest is not plausible in elite sports as this results in rapid deconditioning and substantial financial losses. It is highly recommended to use ultrasonography (US) for serial follow-up. Although MRI is the gold standard for the initial diagnosis, serial MRI scans for follow-up is not feasible due to cost and logistics. In contrast, during the treatment phase, POCUS can be used by physiotherapists for monitoring the reduction of joint effusion to assist the return to play (RTP) decision [21].

4.3. Modality Comparison: Clinical Efficacy vs. Diagnostic Utility

While MRI is the gold standard for imaging of the soft tissues, the clinical utility of this modality is frequently compromised by: long image acquisition time (30 to 45 min); mandatory absolute patient cooperation; significant operational expenses; and the need for highly calibrated expert evaluation [29]. Conversely, CBCT image acquisition is completed within 10 to 20 s, but the technique lacks sufficient contrast resolution to identify early soft tissue pathological changes.

One of the most contemporary trends in sports dentistry diagnostics is the use of MRI-CBCT Fusion Imaging. Using advanced registration algorithms, the high-resolution 3D osseous image data from CBCT can be fused with the soft tissue image data from MRI. This results in the creation of a high-definition “digital twin” of the athlete’s TMJ [5, 30].

4.4. Limitations and Cost Barriers in Sports Dentistry

Currently, there are several limitations to consider. Firstly, the majority of deep learning models, including TMJ-PanoNet, have been trained on relatively homogenous data samples from single centers. Extensive multi-center testing is required to validate the clinical efficacy of this technology on various ethnic backgrounds and different radiographic imaging device manufacturers to account for sensor noise and contrast differences [31].

Secondly, cost remains a significant barrier. The excessive costs of 3.0T MRI, maxillofacial radiology and fusion software programs, restrict the utilization of these diagnostics to professional level sports teams. This creates a pressing need for the widespread deployment of AI-assisted OPG screening, which has the potential to level the playing field by providing predictive screening data at a fraction of the cost [23, 25].

5. Conclusions

The early detection of TMD in sports athletes requires a paradigm shift from general requisitioning of imaging studies to a symptoms driven approach to imaging requests based on biomechanical considerations. While MRI is the imaging modality of choice for the analysis of soft tissue derangements, disc morphology and early inflammatory changes, CBCT is required for definitive osseous staging and trauma evaluation.

Artificial intelligence and deep learning networks have emerged as a major breakthrough in maxillofacial radiology. AI can be used to provide accurate automated triage via the screening of standard OPGs. AI is a cost-effective screening tool for the early detection of TMD. The application of this technology within a structured symptom driven clinical algorithm allows the sports medicine community to ensure timely and targeted treatment. This comprehensive diagnostic strategy maintains biomechanical health, prevents the progression of chronic joint disease and supports long-term athletic function and performance.

Declarations

Disclosure: The author reports no financial or commercial disclosures relevant to the content of this manuscript.

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Funding: The study did not receive external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement:Not applicable.

Acknowledgements: Not applicable.

Conflicts of Interest:The authors declare no conflicts of interest. All authors have read and agreed with the published version of the manuscript.

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