QUALITY IN SPORT

eISSN 2450-3118 · Open Access · Peer-reviewed

apcz.umk.pl/QS Nicolaus Copernicus University in Toruń

Cite as: CIESIELSKI, Maciej, KUŚ, Justyna, STADNICKA, Olga, PYSIEWICZ, Mateusz, BIAŁOWĄS, Patrycja, CZAPIŃSKI, Olgierd, ZIĘBA, Natalia, KNAPIK, Anna, BRODOWSKA, Anna and TOMICKA, Ewa. Sport-Specific Loading in Femoroacetabular Impingement (FAI): Development, Treatment, and Return to Sport. Quality in Sport. 2026;57:72597. https://doi.org/10.12775/QS.2026.57.72597

ARTICLE TIMELINE

Received: 25.05.2026. Revised: 30.05.2026. Accepted: 31.05.2026. Published: 10.06.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines: Medical Sciences; Health 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: Nauki medyczne; Nauki o zdrowiu.

Sport-Specific Loading in Femoroacetabular Impingement (FAI): Development, Treatment, and Return to Sport

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1. Abstract

Femoroacetabular impingement (FAI), particularly cam-type morphology, is increasingly recognized as a major cause of hip pain and functional limitation in young athletes. Growing evidence suggests that repetitive sport-specific mechanical loading during skeletal maturation contributes to the development of cam deformity and may influence postoperative outcomes after hip arthroscopy. High-impact sports involving repetitive hip flexion, internal rotation, axial loading, and rapid directional changes-especially ice hockey, soccer, and basketball-demonstrate a significantly increased prevalence of cam morphology compared with non-athletic populations. Current findings support a mechanobiological model in which repetitive loading during adolescence induces adaptive remodeling of the proximal femur, potentially progressing from physiological adaptation to pathological impingement. Although both physiotherapy and arthroscopic treatment improve symptoms and hip function, hip arthroscopy generally provides superior short-term improvements in patient-reported outcomes. Return-to-sport rates following arthroscopy are consistently high, commonly ranging from 80% to 90%; however, successful return to competition does not necessarily correspond to restoration of pre-injury performance levels. Postoperative recovery appears to vary according to biomechanical demands, age, revision surgery, duration of symptoms, and the severity of intra-articular damage. Arthroscopic treatment provides superior short-term improvements in patient-reported outcomes compared with conservative management. Nevertheless, physiotherapy remains a reasonable first-line approach, particularly in less severe cases, and does not appear to adversely influence the outcomes of subsequent surgical intervention.

Aim: The aim of this narrative review is to evaluate the influence of sport on the development and clinical course of femoroacetabular impingement, with particular emphasis on treatment outcomes, including return to sport following hip arthroscopy and conservative management.

Methods: A narrative review of the literature was conducted using the PubMed database. Studies were selected based on relevance to femoroacetabular impingement, cam morphology, athletic populations, hip arthroscopy, and return-to-sport outcomes.

Keywords

"femoroacetabular impingement", "FAI", "cam morphology", "cam deformity", "osteogenic adaptation", "athletic performance after hip arthroscopy", "return to sport after hip arthroscopy", “cam deformity in adolescent athletes”, “athletic hip injuries”, “sport type”

2. Introduction

The Problem

Femoroacetabular Impingement (FAI) is a condition where the hip joint experiences abnormal friction due to structural irregularities. This mechanical conflict occurs when the proximal femur and acetabulum do not fit together perfectly, typically manifesting as pincer lesions (socket overcoverage), cam deformities (an aspherical femoral head-neck junction), or a combination of both. These structural issues, often quantified by the alpha angle, frequently lead to damage at the chondrolabral junction. (1,2)

The Shift in Perspective

In young and physically active populations, femoroacetabular impingement (FAI) syndrome frequently leads to significant hip pain and functional limitations. While both arthroscopic surgery and structured physical therapy protocols effectively alleviate discomfort and improve mobility, surgical intervention appears to provide more substantial improvements in the short term compared to non-operative treatment alone.(3) A systematic review of randomized controlled trials comparing hip arthroscopy with physiotherapy in patients with femoroacetabular impingement demonstrated that both treatment modalities lead to clinically meaningful improvements in patient-reported outcomes over short-term follow-up. However, pooled analyses indicated that arthroscopic intervention provides statistically greater improvements in hip-specific outcome scores compared with physiotherapy alone, particularly in as-treated analyses. Importantly, physiotherapy did not compromise subsequent surgical outcomes in patients who ultimately required operative treatment after failed conservative management. (4)

Controversy: congenital vs acquired origin

Cam morphology of the proximal femur is characterized by an abnormal contour at the femoral head–neck junction, which can be detected in a substantial proportion of the asymptomatic population and is most commonly quantified using parameters such as the alpha angle or femoral head–neck offset ratio. (2,5)

Environmental influences related to participation in high-intensity sports appear to represent one of the primary risk factors for the development of idiopathic cam morphology, particularly during late adolescence, when the proximal femoral physis remains open and is approaching closure.(2,5) Current evidence suggests that repetitive mechanical loading of the hip joint, including microtrauma and shear stresses across the growth plate, may induce adaptive changes in the capital femoral epiphysis that gradually result in cam formation by skeletal maturity.(2,5) Importantly, this process seems to occur within a critical developmental window, as cam deformities are rarely observed before approximately 13 years of age or after skeletal maturity, highlighting adolescence as a period of increased susceptibility to mechanical influences.(2) Male athletes participating in high-impact sports such as hockey, basketball, and soccer appear to be at particularly increased risk, with studies demonstrating a higher likelihood of epiphyseal alterations at the anterosuperior femoral head–neck junction associated with intensive sporting activity.(2) Although the precise thresholds of mechanical loading and the full spectrum of contributing factors remain unclear, participation in sports during adolescence is consistently associated with the development of cam morphology, supporting a strong environmental component in its pathogenesis.(2,5) At the same time, some studies reporting associations with subtle slipped capital femoral epiphysis–like changes suggest that cam morphology may be multifactorial in origin, rather than purely mechanically acquired.(2) From an etiological standpoint, cam deformity is typically divided into primary (idiopathic) and secondary forms, which arise through distinct mechanisms.(2,5) Secondary cam morphology is explained by established pathological conditions such as slipped capital femoral epiphysis, Legg–Calvé–Perthes disease, or post-traumatic deformities of the proximal femur, and may also include subtle or subclinical epiphyseal slips that were previously misclassified as idiopathic cases.(2)

In contrast, the origin of primary cam morphology remains controversial.(2,5) Increasing evidence supports the hypothesis that it develops during adolescence as an adaptive response of the proximal femoral epiphysis to repetitive mechanical loading, potentially representing a short-term structural adaptation to maintain physeal stability under high stress, albeit with long-term consequences in the form of altered femoral head–neck morphology.(2,5) However, despite this prevailing mechanobiological explanation, the exact classification, terminology, and conceptual definition of primary cam morphology remain inconsistent across studies.(5) Recent work has emphasized that cam morphology should be understood as a spectrum of morphological variation rather than a strictly pathological entity, and that its presence in many asymptomatic individuals-particularly athletic males-further complicates its interpretation as a disease state.(5) Overall, current evidence suggests that while secondary cam deformities have clearly defined pathological origins, primary cam morphology is most likely multifactorial, with a strong predominance of acquired, sport-related environmental influences during skeletal maturation, whereas a purely congenital origin appears less supported but cannot be completely excluded. (2,5)

Objective: The objective of this study is **t**o evaluate the impact of different sports participation on the development and treatment outcomes of femoroacetabular impingement.

3. Materials and methods

The search for relevant literature was conducted using the PubMed database. The search strategy included combinations of keywords related to femoroacetabular impingement, cam morphology, athletes, hip arthroscopy, and return to sport.

4. Pathogenesis of FAI in Sports Context

4.1 Growth-related development of CAM

A growing body of longitudinal and cross-sectional evidence supports the concept that cam morphology develops during skeletal maturation as a growth-related adaptation influenced by mechanical loading.(6–8)

Studies in adolescent athletic populations consistently demonstrate that the most pronounced changes in femoral head–neck morphology occur during early to mid-adolescence, particularly between the ages of approximately 11 and 14 years, which appears to represent a critical developmental window. (7,8) During this period, rapid increases in alpha angle and femoral head asphericity have been observed, especially in individuals engaged in regular or high-level sporting activity, with a clear dose–response relationship between activity intensity and morphological change.(8) Importantly, these alterations are preceded by soft tissue hypertrophy at the femoral head–neck junction, followed by progressive osseous remodeling, suggesting a stepwise developmental process.(6) Central to this mechanism is the role of the open proximal femoral physis, which appears to be particularly vulnerable to mechanical stress.(2,7) Longitudinal imaging studies have demonstrated that cam morphology develops predominantly in hips with open growth plates, with a significantly higher likelihood of morphological progression observed prior to physeal closure and minimal changes thereafter.(7) Furthermore, structural changes within the capital femoral epiphysis-specifically epiphyseal hypertrophy and extension along the femoral neck-have been shown to correlate strongly with increasing alpha angles and the emergence of cam-type morphology. (2) These epiphyseal adaptations occur in close temporal proximity to physeal closure and are thought to reflect a biological response to increased shear forces across the growth plate. (2,7) It has been proposed that such changes may initially serve a stabilizing function, potentially reducing the risk of overt epiphyseal slippage, but ultimately result in altered femoral head–neck geometry. (2) Collectively, these findings support a growth-related, mechanobiological model of cam development, in which repetitive loading during a vulnerable phase of skeletal maturation leads to adaptive-but potentially pathological-remodeling of the proximal femur.(2,6–8)

4.2 Mechanical loading theory

The mechanical loading theory provides a widely accepted explanation for the development of cam morphology in athletes. Repetitive hip flexion combined with internal rotation, particularly under high-load conditions, generates substantial shear forces across the proximal femoral physis. These forces are especially pronounced in sports that involve deep flexion, pivoting, and rapid directional changes, such as football, ice hockey, and basketball.(7–9) Over time, this repetitive mechanical stress is thought to induce adaptive changes within the capital femoral epiphysis, including hypertrophy and extension along the femoral neck.(2,9) Importantly, imaging and longitudinal studies suggest that these alterations are not random but occur in predictable anatomical regions subjected to peak mechanical loading, particularly the anterosuperior aspect of the femoral head–neck junction.(2,7) The accumulation of microtrauma and physeal shear stress may disrupt normal growth patterns, ultimately leading to decreased head–neck offset and the formation of cam morphology.(2,9) This mechanistic model is further supported by the observation that higher levels of physical activity are associated with greater morphological changes, reinforcing the role of repetitive loading as a key driver of pathological adaptation in the developing hip.(8,9)

4.3 Sports-specific osteogenic adaptation

The development of cam morphology in athletes can also be interpreted through the framework of adaptive bone remodeling, consistent with Wolff's law, which states that bone structure adapts to the mechanical loads placed upon it. In this context, repeated exposure to high-intensity, sport-specific loading patterns during adolescence may stimulate osteogenic responses in the proximal femur, leading to structural changes at the femoral head–neck junction. Rather than representing a purely pathological process, cam morphology may initially reflect a physiological adaptation to increased mechanical demand.(6,9,10) Evidence demonstrating a dose–response relationship between activity level and the degree of cam morphology further supports this concept, indicating that greater training intensity and frequency are associated with more pronounced structural changes.(8,9) However, while such adaptations may enhance joint stability or load distribution in the short term, they may also result in loss of sphericity of the femoral head and predispose individuals to femoroacetabular impingement over time.(9,11) This suggests that cam morphology represents a continuum between physiological adaptation and pathological remodeling, influenced by the magnitude, frequency, and timing of mechanical loading during skeletal development.(8–11)

Current evidence supports a unified mechanobiological model of femoroacetabular impingement development in athletes, in which cam morphology arises as a consequence of repetitive mechanical loading applied to a biologically vulnerable, skeletally immature hip.(7–9) The available literature consistently indicates that this process is temporally restricted to adolescence, particularly during the period when the proximal femoral physis remains open and responsive to external forces.(7,8) Importantly, the presence of a dose–response relationship between physical activity and cam morphology, as well as the limited progression of deformity after physeal closure, strongly supports an acquired rather than congenital origin.(7–9,12) Therefore, cam morphology should be understood as the result of an interaction between mechanical loading and developmental biology, in which high-intensity sporting activity during a critical phase of growth leads to structural adaptation that may transition from physiological to pathological. This concept has important clinical implications, suggesting that modification of training load and timing during adolescence may represent a potential strategy for reducing the risk of FAI and its long-term consequences, including early hip osteoarthritis. (7–9,12)

5. Sport-Specific Risk Profiles

5.1 High-risk sports

Sports associated with a high risk of developing femoroacetabular impingement (FAI), particularly cam-type deformity, include ice hockey, soccer, and basketball.(13,14) Evidence from meta-analyses indicates that athletes participating in high-impact sports are significantly more likely to develop cam morphology compared to non-athletic controls, with reported risk increases ranging from approximately 1.9 to 8.0 times. The pooled prevalence of cam deformity in athletes reaches approximately 41%, compared to 17% in control populations.(13) Among these disciplines, ice hockey demonstrates one of the highest prevalences of cam-type deformity.(14) Studies conducted on elite players report radiographic cam morphology in nearly 70% of hips, with bilateral involvement observed in over 60% of athletes.(15) Notably, the highest prevalence has been identified in goalkeepers, exceeding 90%, likely reflecting the extreme hip positions and repetitive loading patterns required in this position.(15) Soccer is also strongly associated with an increased prevalence of cam deformity. Cross-sectional studies have demonstrated a high frequency of FAI-related radiographic findings in both adolescent and adult elite players, with no significant differences between these groups, suggesting that morphological changes develop during skeletal maturation.(16) Furthermore, players who engaged in high-frequency training (≥4 sessions per week) before the age of 12 exhibited a significantly higher prevalence of cam deformity (64% vs. 40%) and pathological cam morphology (30% vs. 12%) compared to those who began intensive training later.(17) Basketball is likewise considered a high-risk sport, although the available evidence is less extensive. Existing studies indicate an increased prevalence of cam morphology among young basketball players compared to non-athletic controls.(13) In summary, current evidence consistently identifies ice hockey, soccer, and basketball as high-risk sports for the development of cam-type FAI, particularly when high training intensity and early sport specialization occur during skeletal growth.(13,14)

5.2 Mechanisms per sport

The mechanisms underlying the development of femoroacetabular impingement vary between sports but share a common feature: repetitive mechanical loading of the hip joint at extreme ranges of motion during skeletal maturation(13,17,18). In ice hockey, the primary contributing factor is the skating posture, which involves sustained deep hip flexion combined with internal rotation. This biomechanical pattern promotes repetitive contact between the femoral head–neck junction and the acetabular rim, potentially leading to adaptive osseous changes. The strong association between cam deformity and the degree of sport specialization-where moderate and high specialization levels are linked to markedly increased odds of cam morphology-further supports the role of cumulative mechanical exposure.(18) In soccer, the dominant mechanisms include repetitive kicking and rapid directional changes (cutting maneuvers). These actions generate substantial shear and rotational forces across the hip joint. In basketball, the primary contributing factors are frequent jumping and abrupt changes in direction. These movements subject the hip joint to repetitive axial and rotational loads. Although the evidence is less robust compared to hockey and soccer, the available data indicate a higher prevalence of cam morphology in basketball players, suggesting a similar overload-related mechanism.(13) Overall, despite sport-specific differences, these activities share a common biomechanical pathway involving repetitive loading of the hip in positions of flexion and rotation. When occurring during periods of skeletal immaturity, such loading may disrupt normal development of the femoral head–neck junction, ultimately leading to cam-type deformity and subsequent FAI (13,17,18)

5.4 Comparative synthesis

This table provides a comparative synthesis of selected sports in relation to their biomechanical demands and the associated risk of developing CAM-type femoroacetabular impingement. It summarizes the dominant movement patterns, key loading characteristics, and underlying mechanisms of hip joint stress specific to each sport, highlighting how repetitive and sport-specific forces during skeletal growth may contribute to osseous remodeling at the femoral head–neck junction. Additionally, it presents the relative level of CAM risk and references supporting evidence from the literature.

Sport	Dominant biomechanical pattern	Key loading characteristics	Mechanism of hip stress	Relative CAM risk	Supporting evidence
Ice hockey	Deep hip flexion + internal rotation (skating posture)	Repetitive sustained end-range hip flexion under load; high cumulative exposure during growth	Repetitive femoral head–neck contact in flexion/internal rotation leading to osseous remodeling	Very high	(13–15,18)
Soccer	Repetitive kicking + cutting maneuvers	High-velocity rotational movements, shear forces, asymmetric loading	Repeated torsional and shear stress at femoral head–neck junction during growth	High	(13,14,16,17)
Basketball	Jumping, + landing + rapid directional changes	Repetitive axial loading with deceleration and rotation	Combined compressive and rotational hip loading	Moderate –high	(13,14)

9. Return to Sport (RTS) After Arthroscopy

9.1 RTS rates

Return-to-sport (RTS) rates following hip arthroscopy for femoroacetabular impingement are consistently high across both recreational and professional athletic populations, with most studies reporting that approximately 80–90% of athletes are able to resume sporting activity after surgery.(19–21) In cohorts of professional athletes, RTS rates of around 85% have been observed across multiple disciplines, including baseball, basketball, football, and ice hockey, with no significant differences between sports despite variation in performance outcomes.(21,22) Similarly, sport-specific analyses in basketball players demonstrate RTS rates exceeding 80%, with a substantial proportion of athletes returning to their pre-injury performance.(23)

On the other hand according to other sources, returning to sport does not necessarily equate to full restoration of pre-injury performance, as a proportion of athletes experience measurable declines in competitive output or sport-specific performance metrics after their return.(20–22) Outcomes also appear to be influenced by multiple factors, including age and surgical history. Increasing age has been identified as a negative predictor of RTS, while athletes undergoing revision procedures demonstrate substantially lower return rates compared to those treated with primary arthroscopy.(21) In addition, the level of competition may influence recovery trajectories and long-term participation, with elite and professional athletes demonstrating different patterns of return compared to recreational populations.(24) Rehabilitation strategies and adherence to structured return-to-sport protocols are also considered critical determinants of successful outcomes, with staged progression and objective functional criteria increasingly emphasized in the literature.(25) Furthermore, long-term considerations such as the potential need for conversion to total hip arthroplasty, particularly in older individuals, highlight the importance of appropriate patient selection and preoperative counseling. (23)

9.2 Sport type

Outcomes after hip arthroscopy also vary depending on the type of sport, reflecting differences in biomechanical demands and performance requirements. While overall RTS rates remain high across disciplines, sport-specific analyses indicate variability in postoperative performance and career longevity. Movement patterns characteristic of each discipline play a key role in determining long-term outcomes after hip arthroscopy. (21,22)

9.3 Performance outcomes

Although return-to-sport rates after hip arthroscopy for femoroacetabular impingement are generally high, successful RTS does not necessarily indicate complete restoration of pre-injury athletic performance. Several studies have demonstrated that athletes may return to competition while still experiencing reductions in sport-specific performance metrics, playing time, or career longevity.(20–22) Postoperative performance outcomes also appear to vary between sports, suggesting that the biomechanical demands of different athletic disciplines influence recovery after surgery. Athletes participating in sports requiring repetitive hip flexion, rotational loading, and explosive directional changes may experience greater difficulty returning to their previous competitive level despite successful RTS.(22,26) In professional cohorts, certain sports have demonstrated modest declines in postoperative performance, whereas others showed minimal differences compared to preoperative levels or matched controls.(21,22)

10. Discussion

The findings of this review support a coherent mechanobiological framework linking sport participation, femoroacetabular impingement (FAI) development, and postoperative functional outcomes after hip arthroscopy. Across the available literature, a consistent pattern emerges in which high-intensity, repetitive hip loading during skeletal maturation is strongly associated with the development of cam morphology. This relationship appears particularly evident in sports characterized by deep hip flexion, rotational loading, and frequent change-of-direction movements. Importantly, cam morphology should not be interpreted as a strictly pathological entity in all cases. Instead, current evidence supports the interpretation of cam formation as a continuum between physiological adaptation and structural overgrowth. In many athletes, particularly males engaged in high-load sports, morphological changes may initially represent an adaptive response to repetitive stress. However, with continued exposure or unfavorable loading patterns, these adaptations may progress toward clinically relevant impingement and symptom development. From a clinical standpoint, both arthroscopic surgery and conservative treatment strategies improve symptoms and hip function in patients with FAI. Nevertheless, pooled evidence suggests that surgical management provides superior short-term improvements in patient-reported outcomes, although non-operative treatment remains a valid initial approach and does not appear to compromise later surgical results. This supports a staged treatment strategy in which physiotherapy may serve as first-line management, particularly in less severe cases. Return-to-sport (RTS) outcomes following hip arthroscopy are generally favorable, with most athletes resuming sporting activity. However, RTS alone does not fully capture postoperative recovery. A recurrent finding across studies is that returning to sport does not guarantee restoration of pre-injury performance levels. Subtle but meaningful reductions in performance metrics, competitive output, or career longevity may persist despite successful surgical intervention.

Sport-specific variability appears to play a significant role in postoperative outcomes. Athletes participating in sports with high rotational demands or repetitive extreme hip positions may experience more pronounced limitations after surgery compared with those in less mechanically demanding disciplines. Taken together, these findings highlight that FAI is best understood as a condition at the intersection of developmental biology and sport-specific biomechanics. Its manifestation and clinical consequences depend not only on anatomical morphology but also on the cumulative mechanical environment experienced during growth and athletic participation. This has direct implications for both prevention and management strategies, particularly regarding training load modulation during adolescence and individualized postoperative rehabilitation protocols. Additionally, factors such as increasing age, revision surgery, duration of symptoms before surgery, and the severity of chondrolabral damage may negatively affect postoperative performance and long-term athletic durability. Overall, current evidence suggests that evaluation of surgical success in athletes should extend beyond RTS alone and include assessment of performance quality, competitive level, and long-term participation in sport.

11. Conclusion

Cam-type femoroacetabular impingement appears to develop primarily as a result of repetitive mechanical loading during skeletal maturation, particularly in athletes exposed to high-intensity sport-specific hip demands. The condition reflects a spectrum ranging from adaptive bone remodeling to clinically relevant pathological impingement. Although hip arthroscopy provides high rates of return to sport and significant symptom improvement, recovery is not uniform across all athletes or sports. Return to sport does not necessarily equate to full recovery of pre-injury performance, and outcomes are influenced by sport-specific biomechanics as well as patient-related and surgical factors. Overall, current evidence supports a model in which FAI represents an interaction between growth-related susceptibility and mechanical stress exposure. Recognition of this relationship is essential for optimizing both preventive strategies in young athletes and realistic postoperative expectations in those undergoing hip arthroscopy.

Current evidence indicates that surgical treatment yields greater short-term improvements in patient-reported outcomes compared with conservative management; however, non-operative therapy remains an appropriate first-line option and does not appear to negatively affect subsequent surgical results. These findings support a staged treatment approach, with physiotherapy considered particularly in less advanced cases. Return-to-sport outcomes after hip arthroscopy show considerable variability depending on sport-specific demands, with athletes engaged in activities requiring high rotational loads or extreme hip positions potentially experiencing more functional limitations postoperatively than those in less demanding disciplines. In addition, postoperative recovery and return to sport are influenced by several prognostic factors, including older age, prior surgical intervention, longer preoperative symptom duration, and greater intra-articular pathology severity. Athletes involved in sports characterized by repetitive hip flexion, rotational stress, and rapid changes of direction may face more challenges in returning to their pre-injury competitive level, even after achieving successful return to sport.

Disclosure

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Writing – Review & Editing: Natalia Zięba, Ewa Tomicka
Final Approval of the Manuscript: all authors.

Financing statement
This research received no external funding.

Institutional Review Board Statement
Not applicable

Informed Consent Statement
Not applicable

Data Availability Statement
Not applicable.

Conflict of interests
The authors deny any conflict of interest.

Declaration of the use of generative AI and AI-assisted technologies in the writing process
In preparing this work, the author(s) used Chat GPTfor the purpose of verifying bibliographic style, creating visual aspect of the table inserted as well as checking the grammatic and spelling mistakes in the text. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

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