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Inversion Injury of Ankle Joint and Foot in Children: Association With Sports Participation and Comorbidities (Analysis Based on Medical Information System Data)

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ABSTRACT

BACKGROUND: Ankle joint and foot injuries are the most common type of musculoskeletal trauma in children. Their mechanism of injury mainly determines the pattern of damage.

AIM: To optimize the diagnosis and treatment of inversion injuries of the ankle joint and foot in children and assess their association with sports participation and comorbidities.

METHODS: Outpatient medical records of patients treated at the consultative and diagnostic department between 2014 and 2023 were analyzed. Overall, 1518 cases involving ankle joint and foot injuries were determined, including 111 patients referred with a preliminary diagnosis of sprain and an inversion injury mechanism.

RESULTS: The study included boys and girls aged 10–16 years, one-third of them participated in sports, primarily team and gymnastic disciplines. Recurrent inversion injuries occurred more often in children who participated in sports, which should be considered when planning training programs and return to sport. Analysis of the incidence of injuries associated with inversion trauma showed that ligament sprains were most common in nonathlete children (39%), whereas bone fractures predominated in children who participated in sports (38%).

CONCLUSION: This study revealed a high incidence of bone and ligament injuries associated with inversion trauma in children and elucidated the contribution of sports participation to these injuries. The broader use of magnetic resonance imaging and ultrasound, along with the refinement and standardization of their protocols, improves the understanding of inversion injuries of the foot and facilitates development of more effective diagnostic and treatment algorithms.

Keywords: inversion foot injury; ankle ligament sprain; foot bone fracture.

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ОРИГИНАЛЬНОЕ ИССЛЕДОВАНИЕ
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Инверсионная травма голеностопного сустава и стопы у детей: связь с занятиями спортом и сопутствующей патологией (результаты анализа данных медицинской информационной системы учреждения)

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АННОТАЦИЯ

Обоснование. Травма голеностопного сустава и стопы — наиболее распространенный вариант повреждений опорно-двигательного аппарата у детей. Механизм травмы в значительной степени определяет характер повреждений.

Цель — определение путей оптимизации диагностики и лечения инверсионной травмы голеностопного сустава и стопы у детей, ее связи с занятиями спортом и сопутствующей патологией.

Материалы и методы. Были проанализированы записи в амбулаторных картах пациентов, обращавшихся в консультативно-диагностическое отделение за 2014–2023 гг. Отобрано 1518 случаев, содержащих данные, относящиеся к травмам голеностопного сустава и стопы, из которых 111 пациентов были направлены с предварительным диагнозом «растяжение» и указанием на инверсионный механизм повреждения.

Результаты. Среди пациентов были как мальчики, так и девочки в возрастном диапазоне 10–16 лет, 1/3 из которых занимались спортом (преимущественно — игровыми и гимнастическими видами). У детей, занимавшихся спортом, повторные инверсионные травмы происходили значительно чаще, что необходимо учитывать при планировании тренировочного процесса и возвращения к занятиям спортом после травмы. Анализ частоты заболеваний и повреждений, ассоциированных с инверсионной травмой, показал, что у детей, не занимавшихся спортом, наиболее часто можно было наблюдать растяжения связок (39%), тогда как у детей, занимавшихся спортом, — переломы костей (38%).

Заключение. В данном исследовании выявлена высокая частота повреждений костей и связок при инверсионной травме у детей, а также уточнена роль занятий спортом при данной травме. Более широкое применение магнитно-резонансной томографии и ультразвукового исследования, а также совершенствование и стандартизация методик их проведения позволят расширить представления об инверсионной травме стопы и разработать более совершенные алгоритмы диагностики и лечения.

Ключевые слова: инверзионная травма стопы; растяжение связок голеностопного сустава; переломы костей стопы.

Как цитировать

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BACKGROUND

Ankle joint and foot injuries constitute the most prevalent manifestations of musculoskeletal trauma in children [1]. They account for up to 30% of all sports-related injuries [2]. The prevalent notion that bone injuries (such as fractures and epiphysiolyses) are more common than soft tissue injuries in ankle joint and foot trauma has been influenced by the anatomical and physiological features of pediatric patients [3].

The primary objective of the classification and systematization of musculoskeletal injuries and other diseases is to enhance diagnostic and therapeutic effectiveness. The identification of specific injury types facilitates the development of algorithms for medical decision-making. A prominent example is the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification, which is based on clinical and radiological data and is essential to modern traumatology [4]. However, when trying to directly assess the nature of injuries, it can occasionally be difficult to make a clinical and radiological diagnosis. This phenomenon is especially evident in pediatric practice, where the clinical profile becomes more complex due to unossified cartilages, growth plates, the dissociation of the mechanical strength of bones and ligaments, and the inherent challenges in collecting a detailed history and analyzing complaints. In clinical practice, similar complicated diagnostic challenges frequently occur in sports and school injuries.

Diagnosing and classifying soft tissue injuries is a major challenge for medical professionals. Sprains constitute the most prevalent type of ligament injury (including foot and ankle ligaments). It accounts for over 80% of all ankle and foot injuries, with a recurrence rate as high as 80% [5].

Although the diagnosis may seem straightforward and obvious, it is important to note that the diagnostic challenges associated with this type of injury have become more apparent in recent decades. This is largely due to the expanding range of the available imaging modalities. Clinical diagnosis is the primary basis for the traditional three-grade classification system of ligament sprains [6]. Radiological examination is primarily employed to exclude potential bone lesions [7]. The true incidence of ligament injuries in children and adolescents remains unclear because of the restricted use of imaging techniques, such as magnetic resonance imaging (MRI) and ultrasound (US), following foot and ankle injuries in pediatric patients. Additionally, the interpretation of the imaging data can be challenging. The role of MRI and the interpretation of its findings remain controversial. Numerous studies have demonstrated that US-based ligament injury diagnosis is accurate; however, operator competence greatly affects its efficacy [8]. Finally, when it comes to pediatric foot injuries, MRI and US are not currently the preferred first-line imaging modalities.

The International Classification of Diseases (ICD) was initially developed to address the challenges presented by medical statistics. In the context of the healthcare system, numerous regulations, including clinical guidelines, federal laws, and departmental orders, that govern the delivery of primary specialized medical care have incorporated the code of disease or injury in accordance with the ICD-10 classification system. In ICD-10, officially adopted in the Russian Federation, the diagnosis of sprain and strain of the ankle is classified as S93.4. This category includes a variety of specific diagnoses, accompanied by detailed descriptions of the anatomical variants of ligament injuries.

The injury mechanism largely determines the nature of the damage. When deciding on the optimal assessment and treatment strategies, determining the biomechanics of complex ankle and foot injuries is more important than identifying the mechanism of long tubular bone injury [9]. Most foot movements, whether occurring during routine daily activities (e.g., walking, running, climbing, or descending) or demanding external loads (e.g., sports, dancing, or hiking), are multiplanar. The analysis of the resultant motions can distinguish two rather typical patterns that are determined by the bone and joint geometry as well as the ligament and muscle functions. One of these patterns (inversion) provides propulsion, while the other (eversion) provides support for adaptation and clearance. The complex anatomy of the human foot, its diverse functions, and evolution-based biomechanical patterns of movement facilitate the identification of injuries produced by forceful movements in a particular direction. Among the various etiologies, inversion injury has been identified as a key contributor. This form of injury was identified from the study of patients exhibiting typical injury patterns [7]. Currently, the inversion mechanism is the most common cause of ankle and foot injuries in children [10]. However, most researchers have not provided a clear description of the term "inversion injury."

The nomenclature employed to describe foot movements exhibits historical diversity. The study "The Jargon of Pedal Movements" [11] summarizes a survey of specialists in biomechanics, clinical anatomy, and orthopedics. The authors of the study examined 72 responses and discovered that the terms "varus" and "valgus" are frequently regarded as synonyms for "supination" and "pronation," "inversion" and "eversion," and "adduction" and "abduction." The authors largely attribute this variability to the wide range of viable foot biomechanics theories and concepts. They emphasize the confusion between inversion/eversion and pronation/supination. Japanese academics have attempted to unify the terminology for describing foot motion, especially the concepts of "inversion" and "eversion" [12]. The researchers compared the definitions of foot motion used by the Japanese Association of Rehabilitation Medicine and the Japanese

Orthopedic Association to those used by the American College of Foot and Ankle Surgeons and the International Society of Biomechanics. This comparison was made to discover potential overlaps and variations between the respective definitions. Inversion and eversion are defined as frontal plane motions by the International Society of Biomechanics and the American College of Foot and Ankle Surgeons. Conversely, in Japan, these terms refer to three-plane motions. Of the 141 articles reviewed by the authors, 92 (66%) regarded inversion and eversion as frontal plane motions, while four articles (3%) considered them to be three-plane motions. The remaining 43 articles (31%) did not offer any precise definition. To avoid confusion in the terminology, the authors suggest that the meanings of inversion and eversion be made clear [13].

In a study conducted by an international team comprising prominent pediatric orthopedists [14], inversion was defined as a combination of internal rotation, plantar flexion, and supination, while eversion described a combination of external rotation, dorsiflexion, and pronation. The authors of this article deemed this definition to be the most practical and employed it to classify injury mechanisms in their clinical practice.

The purpose of highlighting inversion foot injuries in children in the authors' practice was to acquire additional information to optimize diagnostic and treatment strategies. The medical information system (MIS) serves as a comprehensive database that records the injury mechanism, patient's medical history details, assessment results, and follow-up information. This multimodel approach enables a comprehensive evaluation of the consistency between the referral and initial examination nomenclature and the patient's medical history, the circumstances and injury mechanisms, and the findings of subsequent assessments.

This **study aimed** to determine how to optimize the diagnosis and treatment of inversion foot injury in children and to evaluate its link to sports activities and concomitant disorders.

METHODS

A comprehensive review of the Federal Center's MIS database was conducted to determine the study objectives. The information collection process involved identifying unique patient records relevant to inversion foot injury, which were subsequently compiled into a database and subjected to meticulous analysis. The primary selection criteria, or keywords used to identify unique records, were the terms describing the injury mechanism, which helped identify inversion foot injuries.

The medical records of patients who presented to the Consultative and Diagnostic Department between 2014 and 2023 were extensively reviewed. A keyword-based search in the MIS identified 1,518 foot injury cases. The acquired observations were then filtered to include records containing the keywords "inversion" and "sprain" while allowing for variations in speech patterns (i.e., declension and number categories). This resulted in 111 unique records of patients who were referred with a preliminary diagnosis of "sprain" or seeking a second opinion with a documented diagnosis from their medical history. The observations deemed suitable for further analysis were then collated into a database. The database records were then compared in two categories, i.e., "medical history," which included the reason for referral, the number of injury episodes, treatment details, sports, etc., and "diagnosis." In cases where the injury was sports-related, the sports activity was analyzed. However, the outcome was categorized and examined as unrelated to sports when young athletes suffered injuries while participating in non-sporting activities.

The following parameters were assessed in the analysis:

- the patient's age
- sports activities
- Conditions associated with ankle ligament sprain (diseases and pathologic processes diagnosed after inversion foot injury in patients initially diagnosed with ligament sprain)
- history and duration of postinjury immobilization
- number of repeated inversion foot injuries in the follow-up period
- pain syndrome at the presentation
- ICD-10 code.

In addition to descriptive statistics, the collected data was analyzed using nonparametric statistical techniques. The Brunner–Munzel test was employed to determine differences between unrelated groups, whereas Pearson's χ^2-test was used to compare categorical variables. The probability of error was set at 5%. The logistic regression model was used to estimate the event's probability.

RESULTS

Most study participants (77 patients, or 69%) did not engage in sports. Participants with inversion injuries were noted to be engaged in diverse sporting activities, including soccer (n = 5), basketball, handball, and physical education in school teams (n = 3 each), and volleyball and hockey (n = 2 each). Additionally, the sample comprised those participating in gymnastics, such as artistic and rhythmic gymnastics (n = 6), acrobatics (n = 3), cheerleading and ballet (n = 1 each), karate (n = 2), and track-and-field, skateboarding, and swimming (n = 1 each).

The mean age at presentation was 13.5 (11; 16) years for athletes and 13 (10; 15) years for non-athletes. The age differences between the athletes and non-athletes were not statistically significant (Fig. 1).

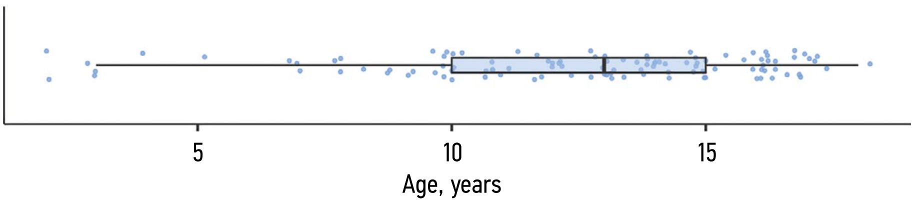

Fig. 1. Age-wise distribution of patients with inversion injuries.

Table 1. Distribution of diagnoses according to the International Classification of Diseases 10th revision (ICD-10).

The ICD category	Description	Proportion of patients, %
M	Diseases of the musculoskeletal system and connective tissue	60
S	Injury, poisoning and certain other consequences of external causes	23
T		11
Q	Congenital malformations, deformations, and chromosomal abnormalities	5
Z	Factors affecting health status and contact with health services	1

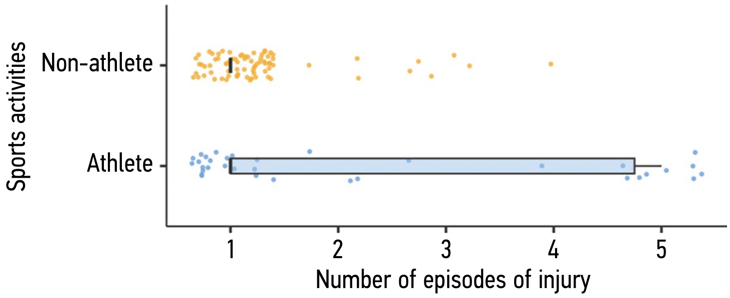

Fig. 2. Number of inversion foot injuries in athletes and non-athletes.

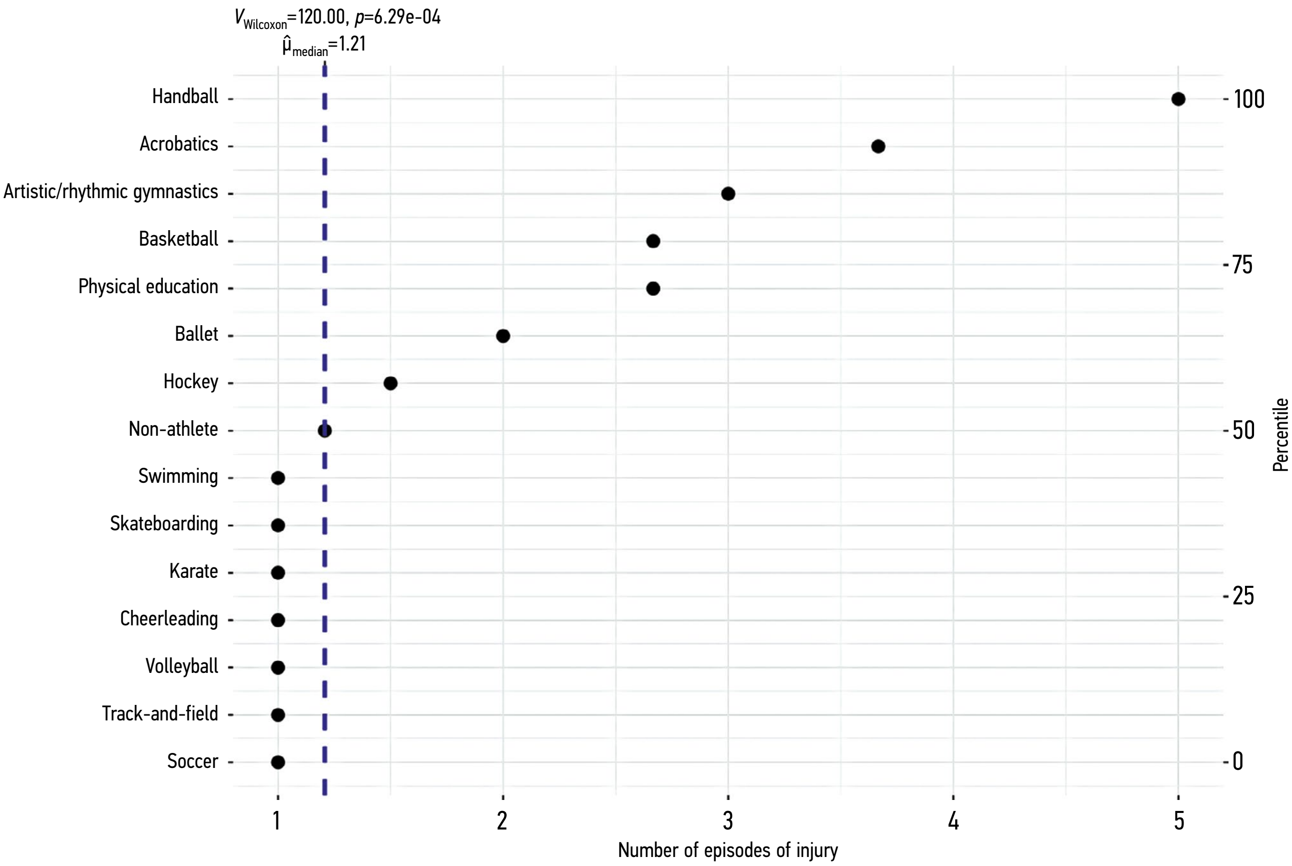

Fig. 3. Number of inversion injuries in patients by sports discipline.

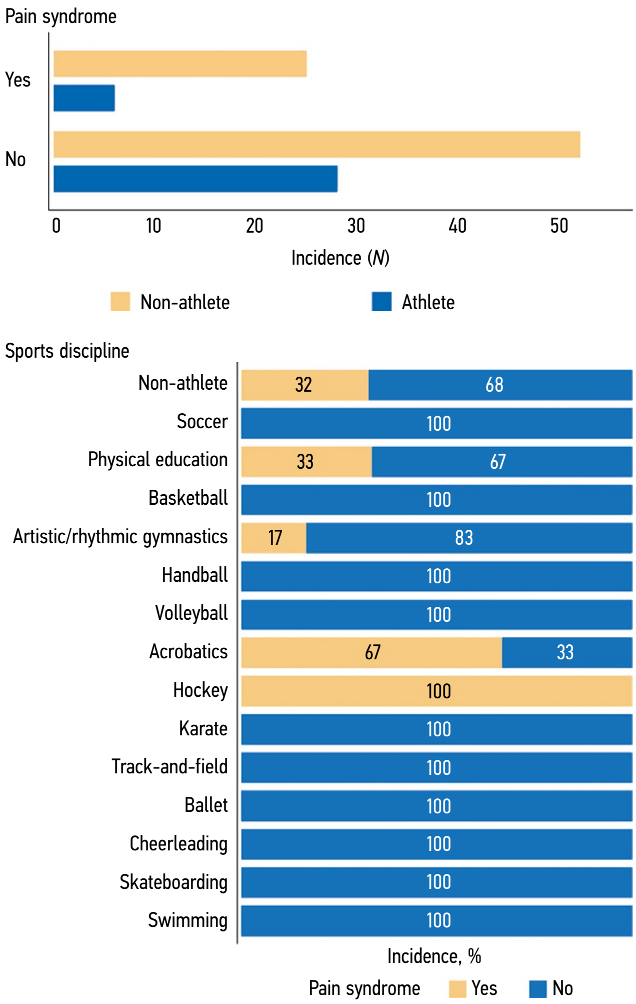

Fig. 4. Patient distribution based on the presence of pain syndrome.

As shown in Table 1, ICD-10 codes relating to acute injury (S and T, classified as “Injury...”) were observed for a relatively small proportion of patients (34%). The remaining 66% of the patients were diagnosed with various conditions and diseases (classified as M, T, Q, or Z of ICD-10). This dissociation will be discussed in the relevant section of this study.

An analysis of the connection between participation in sports and the frequency of recurring foot injuries (Fig. 2) indicates that most patients, both athletes and non-athletes, experienced only one episode of inversion foot injury. Additionally, children who engaged in sports reported an average of one additional case of inversion injury (Brunner–Munzel test; 3.36; $p = 0.002$), which evidently correlated with the nature and intensity of exercise in athletes.

The authors examined the incidence of recurrent episodes of inversion injuries in patients participating in various sports (Fig. 3).

The most common repeated inversion injuries of the feet occurred in children who participated in sports such as handball, acrobatics, track-and-field, and artistic/rhythmic gymnastics. Children who participated in these activities exhibited a history of three or more inversion foot injuries.

Figure 4 illustrates the patient distribution based on whether pain syndrome was present at the time of presentation.

Although a higher incidence of pain was documented among the non-athletes, these differences were not statistically significant ($\chi^2 = 2.61$; $p = 0.11$). Notably, the sports discipline did not have a significant influence on the incidence of pain syndrome in the study groups of children ($\chi^2 = 2.02$; $p = 0.15$).

Significant variations in the length of immobilization between athletes and non-athletes were found in an examination of the treatment that patients were administered before visiting the clinic (Fig. 5).

Most patients received no immobilization for ankle sprains (45% of non-athletes and 62% of athletes). For pediatric patients engaged in sports, rigid foot fixation was employed in most cases. Conversely, for children who did not participate in any sports activity, the frequency of immobilization with rigid braces and soft retainers was comparable, with approximately 30% and 25% of such participants receiving these treatments, respectively.

Significant findings emerged from the analysis of the follow-up data pertaining to the incidence of ligament injuries, fractures, osteochondropathies, tarsal coalitions, compression neuropathies, and developmental anomalies. Figure 6 depicts the primary diseases and injuries identified following an ankle sprain. Those diseases that were not classified within the selected groups were categorized as “other conditions” and included cuboid syndrome, posterior ankle impingement, and ganglion cyst.

As observed in Fig. 6, athletes experienced twice as many fractures as non-athletes, while inversion injuries

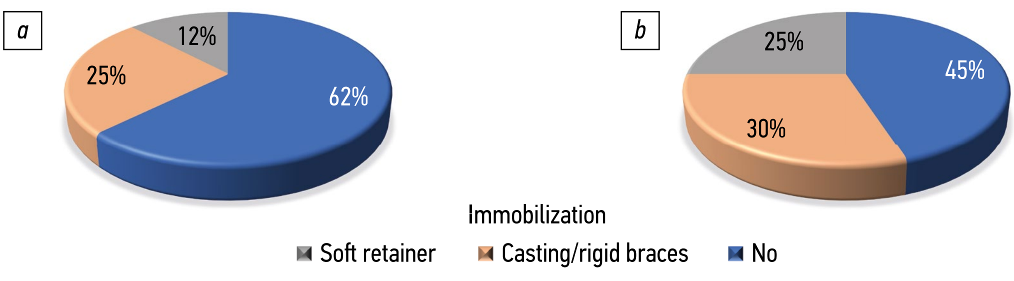

Fig. 5. The type of immobilization for ankle sprain in *a*, athletes and *b*, non-athletes.

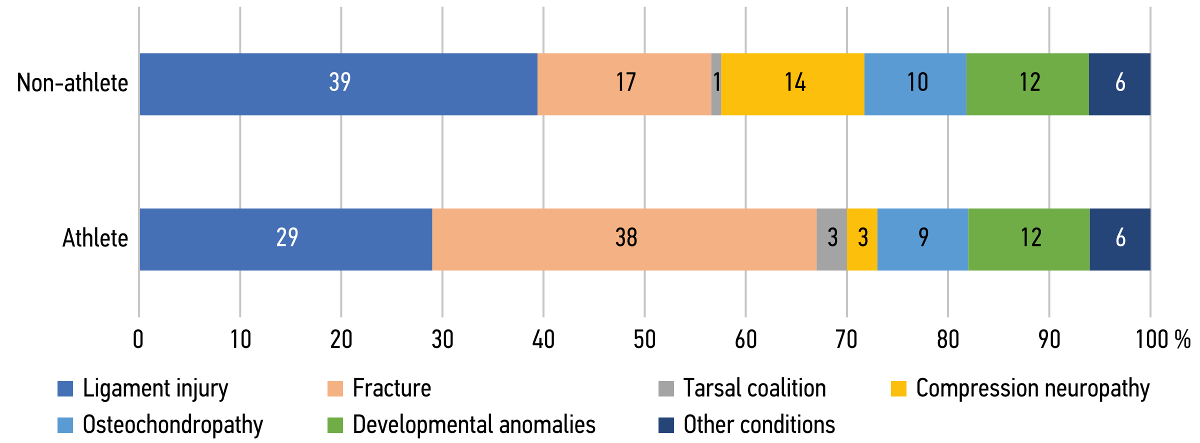

Fig. 6. Incidence of diseases and injuries linked to inversion foot injury.

Table 2. Weighted limiting mean probabilities of diseases and injuries related to inversion foot injury in athletes and non-athletes.

Sports discipline	Type of injury	No. of patients	Probability	SE (standard error)
Non-athlete	Ligament injury	30	0.3896	0.0556
	Fracture	13	0.1688	0.0427
	Tarsal coalition	1	0.0130	0.0129
	Compression neuropathy	11	0.1429	0.0399
	Osteochondropathy	8	0.1039	0.0348
	Developmental anomalies	9	0.1169	0.0366
	Other conditions	5	0.0649	0.0281
Athlete	Ligament injury	10	0.2941	0.0781
	Fracture	13	0.3824	0.0833
	Tarsal coalition	1	0.0294	0.0290
	Compression neuropathy	1	0.0294	0.0290
	Osteochondropathy	3	0.0883	0.0486
	Developmental anomalies	4	0.1177	0.0553
	Other conditions	2	0.0588	0.0403

in non-athletes were more likely to be accompanied by ligament injuries and compression neuropathies.

Table 2 displays the exact weighted limiting mean probabilities of diseases and injuries associated with inversion foot injury in both athletes and non-athletes.

In patients with inversion foot injury and ankle sprains, a 38% and 17% risk of tarsal fractures was noted for athletes and non-athletes, respectively. Following an inversion foot injury, there was a 10%–11% probability of detecting different developmental abnormalities and osteochondropathy. Using the logistic regression model, the probability of diagnosing other diseases was ascertained to be less than 10%.

DISCUSSION

Forced inversion and eversion have been proven to cause tissue injury, including bone fractures, cartilage and ligament injuries, joint subluxations, and dislocations with varying degrees of severity. Injuries resulting from forced foot inversion are typically referred to as inversion injuries. This type of injury has received a lot of attention in the pertinent English-language journals, both in terms of diagnosis and treatment. However, there is a lack of Russian studies that address inversion injuries as an independent variant of foot injury [15–17].

Inversion foot injuries are now recognized as a distinct category among other forms of pediatric trauma at the authors' clinic (the H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery). This has resulted in the development of a standard assessment algorithm that incorporates clinical and imaging evaluations as well as patient medical histories to determine this injury mechanism. The identification of the injury mechanism (particularly inversion foot injury) aids the evaluation of the risk of injury and the planning of the patient's assessment and treatment.

The topic of sprains secondary to inversion injuries experienced by pediatric patients has become a subject of much discussion. It should be noted that a recent study, which was a systematic review of the literature, was published under the title “Is Lateral Ankle Sprain of the Child and Adolescent a Myth or a Reality?” [18]. Despite two decades of research, the general consensus among medical professionals, as per the authors of the review, is that “children do not have sprains.” This assertion indicates that the periosteum and ligaments in children are more resilient to injury than the epiphysis, which should typically result in bone injuries. Children with inversion injuries with a lack of signs of fracture have often been discovered to be previously diagnosed with epiphyseolysis of the distal fibula on standard radiographs (Salter–Harris type I fracture) [19]. Although follow-up radiographs demonstrate clear signs of bone callus in a smaller proportion of patients, the diagnosis of epiphyseolysis remains concealed in the medical record.

As this study illustrates, establishing the inversion mechanism of ankle and foot injuries at the initial stage of pediatric patient assessment helps specialists focus their attention when planning the assessment and treatment. It also creates a typical patient’s profile, which includes both males and females in the age range of 10–16 years, one-third of whom are engaged in sports (primarily team sports and gymnastics).

Most diagnoses in the study patients were related to musculoskeletal diseases (ICD-10 M) and not to injuries (S and T). While discussing the significance and value of population-based research based on ICD-10 search queries, it is important to note that the statistical classification of diseases, i.e., ICD, frequently replaces the role of clinical classifications. Because many regulatory and financial documents (clinical guidelines, tariffs and standards of the mandatory health insurance system, and regulations governing high-tech medical care) are based on ICD-10 codes, physicians are obliged to modify their activities to these regulatory criteria. Furthermore, from a long-term perspective, using ICD-10 codes for retrospective analysis is particularly problematic because of the frequent alterations in financial and regulatory documentation. This information is relevant for the planning of future population and demographic studies: to ascertain the actual incidence of the injuries studied, it is probably insufficient to search for the ICD-10 key codes, but a more thorough examination of databases and MIS is needed to obtain more objective information.

As the study data reveals, repeated inversion injuries are much more prevalent in children who are engaged in sports. This fact must be considered when planning the training regimen and return to sports after an injury, especially if they participate in handball, acrobatics, and artistic/rhythmic gymnastics.

Based on the author’s research, the severity of the pain syndrome is not linked to sports activity. It is also important to note the somewhat unexpected finding that postinjury fixation and immobilization were used much less often in athletes compared to non-athletes. Therefore, it should be emphasized that the correct assessment of the pain syndrome in young athletes (both by physicians and coaches) is an important element of training and competitive processes in children’s sports [20].

The identification of the nature of the injury and the presence of diseases related to ankle sprain can modify the treatment strategy and are significant prognostic factors for potential functional limitations [21, 22]. An analysis of the incidence of diseases and injuries associated with inversion injuries revealed that non-athletes are more likely to experience sprains (39%), whereas athletes are more likely to suffer fractures (38%). These data are particularly significant given the previously reported frequency of immobilization after inversion injury in athletes. Educating coaches and sports physicians regarding the principles of immobilization and communicating the information about the potential consequences of an inversion injury could probably assist in changing this discrepancy and optimizing long-term treatment outcomes.

These statistics are especially significant in light of the previously documented prevalence of athletes becoming immobile following inversion injuries. This pattern may be related to the previously reported changes in the foot biomechanics under these conditions [23]. Meanwhile, despite the association of recurrent foot injuries with tarsal coalition reported in the available research [24], there was no statistically significant dependence in the study group of patients.

When considering the limitations of this study, it should be noted that the overall incidence of fractures and sprains varied significantly in different studies, particularly due to differences in the diagnostic methods. Ultrasonography is used to diagnose ligament injuries and differentiate between osteochondral or periosteal avulsion fracture, joint effusion, injury of the tendon of the peroneus longus muscle, rupture of the interosseous membrane, calcaneofibular ligament tear, and distal fibular metaphyseal fracture [25]. Radiography and ultrasonography are informative when a fracture is suspected; however, these findings may be insufficient [26, 27], and MRI remains the most accurate diagnostic technique.

In this study, the authors did not review the primary imaging data, making it impracticable to evaluate their informative value in certain situations. Furthermore, the retrospective design of the study limited the ability to standardize the assessment protocol. Nevertheless, even with the available data, multiple important conclusions can be drawn regarding the clinical course, diagnosis, and treatment of inversion foot injuries in children.

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CONCLUSION

Internal rotation, plantar flexion, and supination are the three components that contribute to foot inversion. Consistent harm to the soft tissues and bones can result from forced inversion of the ankle and foot. This mechanism of injury is common in children who participate in sports and may require further evaluation. The aim of identifying inversion foot injuries in children was to acquire additional information to optimize diagnostic and treatment strategies. The study has demonstrated a high incidence of bone and ligament damage related to pediatric inversion injuries and has also clarified the role of sports in this injury. The increased accessibility of MRI and ultrasonography, along with the improvement and standardization of their procedures, will enhance physicians' understanding of inversion foot injury and promote the development of more advanced diagnostic and treatment algorithms.

ADDITIONAL INFORMATION

Author contributions: *A.V. Sapogovskiy:* methodology, database creation, data curation, formal analysis, writing – original draft; *V.M. Kenis:* formal analysis, writing – review & editing; *O.E. Agranovich, S.I. Trofimova, I.A. Abramov, E.V. Petrova, A.N. Kasev:* data curation and formal analysis, writing – original draft. All authors approved the version of the manuscript to be published and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics approval: The study was approved by the Local Ethics Committee of the H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, Ministry of Health of Russia (Protocol No. 24-4-4, January 23, 2025).

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