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Rehabilitation After Bullying in Sports and the Long-Term Psychological Impact of Sports-Related Traumatic Spinal Cord Injury on Sport Practitioners

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Abstract: *Bullying in sport is different as effects account for the impact on the sports-men. The frequency and type of bullying is different in relation to sport practice. Greater physical impact is correlated to sports like football, handball and basket-ball. Trauma can be produced also in volley-ball but because it is a sport in which all teammates are dependent on each other. Sport practitioners have developed a very high sense of dignity and justice. In many situations sport is practiced from a very young age which means that the collaboration between family, school and sports trainer is very close. The coach has the role to realize educational mentoring. Sometimes the mistake of parents is to drive their children to sports inadequate to their temperament, and here we can find the causes of the amplification of aggressivity of some sports practitioners against their colleagues. In many cases the sport practitioner is not al-ways choosing themselves the sport branch which they practice. Very important are the abilities of the sports instructor, which can practice in the school or outside the school time schedule. Sometimes there are sport instructors which are not prepared efficiently for the sport branches in which they are training and are not always correctly evaluating the physical effort of the sportsmen which they are training. In sport branches where sports men are evolving, it is important to put emphasis not only on performing good results, but also it is important to give attention to group cohesion and the maintaining of the interest in sport for a healthy life. It is also important to psychologically evaluate the sport practitioners if needed. Bullying is a wide-spread situation and so it is found also in the sports practice and the sports mentors must take in account the prevention and the fight against these facts.*

Keywords: *trauma bullying; sport; trainer; sports-counseillor; sports traumatic spinal cord injury.*

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1. Introduction

The practice of a sport can lead in many situations to sports injuries and removal of the athlete from the competitive circuit. The return to the sports field might be burdened by a series of inconveniences such as a more reluctant attitude from teammates toward the injured athlete, the athlete's concerns toward their own performance and the insecurities generated by the fear of not being able to cope with the competitional group, as well as issues related to self-representation within their own community and beyond. This pressure experienced by athletes is perceived in the terms of their own civic and psychological education gained before starting performance sport. Civic education helps the athletes grow up with a broader vision about life and life expectancies. The athletes experience pressure from their own families, coaches, schoolmates, teammates and the general public (McCrory, 2000).

How do verbal arguments escalate into physical outbursts on the sports field? It is important to investigate further the signs which indicate the escalation of emotions and physical aggression.

Bullying is found in different forms in 35% of adolescents in the general population. However, in sport, noble values such as loyalty, fairness, fair play, respect, awareness of personal limits are promoted (Fazel et al., 2022).

In this context, understanding and analysing the factors that contribute to the occurrence of sports injuries becomes essential, which has led to the development and use of advanced prediction methods, such as artificial intelligence. Artificial intelligence (AI) methods have already been successfully applied in sports science, especially in game analysis, tactics, performance and prediction of competition outcomes, and are now on the verge of revolutionizing clinical medicine. However, for clinicians, both the use and understanding of AI concepts can often be difficult.

Although the term artificial intelligence is a very broad one, in practice it is often associated mainly with machine learning (ML) methods, which has only one part of this complex field that aims to imitate human intelligence.

2. Materials and Methods

We investigated existing research in the field and we highlighted the attitudes most strongly associated with bullying and we also investigated the factors associated with bullying in sports. The search strategy included pointing out the vulnerability of athletes following bullying and gaining a better understanding on how to ameliorate the effects of bullying in sports, as well as identifying measures to be taken for recovery after vertebra-medullary trauma under such conditions. We also examined situations of rehabilitation, and we also highlighted the risks associated with addictive behaviours. The inclusion criteria included articles in which bullying in sport was highlighted as well as those involving bullying and substance abuse. The exclusion criteria included articles on spinal cord injuries in sports where bullying was not present. Articles which highlighted muscular pain due to other pathologies and chronic back pain not related to spinal cord trauma were also excluded.

3. Results

3.1. Bullying with Major Traumatic Impact

3.1.1. The Importance of Signs for the Trainer

Bullying with major traumatic impact is preceded by signs in the dynamics of the team training and the trainer must recognise these signs: sarcastic remarks and the fears related to the evolution together with a teammate, the very frequent mentioning of the name of a member of the opposing team and the mental or verbal planning of actions: „If I see him/her, I will tell them this". The coach must quickly give advice about sport and discuss fair play with the sports student.

- Bullying with great physical impact can be produced by direct hitting with one's own body, food, head, elbows, or with objects like a ball or a baseball bat. Another way of bullying is by teasing with heavy objects like books, heavy balls, baseball bats. Direct aggression can have the purpose to physically eliminate the opponent from the sports field or it can be due to spontaneous thoughtless outbursts of anger. A particularly dangerous situation is when an athlete is hit with punches and feet after falling down on the sports field or "accidental" falling with the whole body over the victim on the sports field. Bullying can be intra-competitional on the sports field as well as extra-competitional in the sport setting or even in a private setting or on the street.

- More severe impacts occur in sports such as football, handball, boxing, rugby, baseball. Distinguished from all types of trauma spinal cord injuries (TSCI), those produced by different sports occur with a frequency of 14.2% (Toma, 2016).
- Trauma spinal cord injuries (TSCI) are also caused by water sports, accounting for 2-5% of all sports-related trauma (Gaspar & e Silva, 1980).
- On the sports field teammates can make jokes and can trip over someone or they can call a teammate causing them to take a wrong step and then fall, the falls onto the back are particularly dangerous. Other types of trauma can take place in the changing rooms or by removing a chair from under the teammate, leading to very dangerous falls.
- Another factor that leads directly or indirectly to bullying inside the same team is the fact that parents put pressure on the coach leading to a special relation between the coach and one member of the team as well as between the coach and one specific parent thus leading to imbalances between the athletes of a team, leading then to bullying. Acid remarks can come from those who have never practiced a sport, but are very competent in sports commentary, such as an important family member of the athlete like the father or another important figure for the athlete and this criticism is perceived as bullying by the athlete.

Special emphasis must be placed on identifying specific bullying situations within sporting contexts:

1. Fashion-related bullying is also present in sports and may be related to the clothes' appearance, to the quality of the equipment and to the existing competitional fashion models as well as beyond competition through personal hairstyles or accessories.
2. Gymnastics and ballet represent sports where social standards regarding body weight can lead to the development of anorexia nervosa, which in this case is due to a posttraumatic stress disorder caused by the persistent bullying of the athlete's body weight (such bullying can take place over a long period of time and can be practiced by a group of athletes against one member of the team, or in some cases, anorexia can be a consequence of cyberbullying, previous bullying at school or it can be a consequence of bullying performed by an adult with great authority who is always criticising the activity and the body weight of the athlete). Some preexisting personality traits such as: impulsivity, anxious thoughts, dependent personality features, borderline personality features as well as preexisting low self-esteem and perfectionism can increase anorexic behaviour (Coelho, 2021).
3. In sports like gymnastics, after facing different types of bullying, athletes can perform unauthorized exercises outside training hours with the aim to demonstrate to themselves that they can face a greater challenge. This type of exercise can lead to severe Traumatic Spinal Cord Injuries (TSCI), which may not be apparent at the moment of physical effort.
4. This overtraining effect is very harmful and the Traumatic Spinal Cord Injuries (TSCI) are more likely to appear, as the athlete seeks to remain in the sports group. Their belief is that overtraining will help them achieve improved performance in order to avoid future bullying from colleagues. At this moment, there is an effect of plateau in physical activity, accompanied by weight loss as well as reduced strength and bone density, all of this leading to pathological fractures.

The curvatures of the spine represent regions where traumatic impact is preferentially absorbed. There are 2 primary curvatures present at birth: the thoracic and the sacral curvatures. The cervical and lumbar curvatures develop later, after gaining vertical posture (Dalgleish & Frankham, 2001).

In sport, there are positive emotions related to competitiveness, such as joy and pride as well as negative emotions, such as feeling like a burden to teammates, feeling less valuable after a bad performance, financial struggles or law problems (sport-related or family-related), which add more pressure on athletes. Bullying is a reflection of non-performing social matrices and unhealthy beliefs of the micro-groups in which it is taking place. Gossip spreading is also a form of bullying. Bullying generates the disappointment and demotivation of the athletes.

As a result, athletes can experience somatisation, and in the case of Traumatic Spinal Cord Injuries, the pain can be perceived more intensely, which causes the rehabilitation period to take longer (Veinhardt & Fominienė, 2020).

The withdrawal from sports due to bullying is common among teenagers and can be linked to school quitting, rates of school quitting being high in this age group. One reason for quitting sports is competing away from home, where bullying can become more intense, as well as the occurrence of physical accidents that interrupt participation. The average age of quitting sport is 15 years old for about 75% of young athletes. At this age, parents play an important role in influencing the school preferences of their children as they prepare for university. As a result, they may encourage their children to quit sports and choose a stable career in fields such as engineering, medicine, physics or history. Girls quit sports in greater numbers than boys. This may be because girls have more social obligations and they are more likely to be influenced by other people's opinions. Additionally, the use of attributable nicknames represents a form of bullying that can become particularly severe. Studies show that 39.8% of athletes have reported bullying in their own team. Trainers must promote ethical methods of competition as well as ethical methods of performance evaluation and athletes must be educated to understand and respect the ethics of performance. Children and teenagers who previously experienced bullying at school are more susceptible to bullying. This type of experience can cause them to feel helpless and the persistence of it can determine the athlete to become more sensitive and lead to a transfer of the „parental" figure onto their coach. The coach must be very attentive to the phenomenon of counter transfer and must be well trained not only in physiology but also in psychology (Veinhardt & Fominienė, 2020).

Bullying in sports can have dramatic consequences, leading to forensic issues which could involve their family and social services, compensation in money and rights of the disability after the Traumatic Spinal Cord Injury (TSCI) and the social rehabilitation of a person with a permanent disability after sports bullying, such as Traumatic Spinal Cord Injury (TSCI).

For some athletes, bullying leads to major life changes, such as divorce or separation, losing friends and a persistent feeling of inequity.

3.1.2. Observations During Practice Regarding Patients after Bullying in Sports

- The bully tries to test the limits of the person with whom they interact.
- In many situations, the bully is aware that the person they attack exceeds them in abilities and performance.
- Individuals should be aware of their own competencies.
- Bullying is often overlooked by trainers.
- Within communities, we must be aware of bullying as it has been and continues to be a widespread phenomenon. Different perspectives exist and science has not yet provided all the solutions.
- Bullying prior to competition negatively influences the success in sport performance.

3.2. Traumatic Spinal Cord Injury and its Impact

Athletes can develop a stroke as a result of a vertebral trauma, which can lead to dissection of the vertebral arteries (McCrory, 2000).

Acute traumatic myelopathy may occur in athletes without radiographic findings. This condition is known as Spinal Cord Injury Without Radiographic Abnormality (SCIWORA) and is present in 13-19% of patients who have experienced Traumatic Spinal Cord Injury (TSCI). The traumatic impact involves high energy forces that lead to hyperextension or hyperflexion of the spine, often combined with elongation. These lesions generate free radicals, lipid peroxidation, lesions of cellular membranes which further lead to ischaemia accompanied by oedema of the spinal cord. Unfortunately, the result of these physiopathological processes can lead to tetraparesis (Basile et al., 2023).

In table 1, meta-analyses highlight mechanisms involved in Traumatic Spinal Cord Injury (TSCI):

Table 1. Mechanisms of vertebro-medullary trauma:

Author	Year	Mechanism of lesion	Physiopathology	Radiology	Effect
Basile Giuseppe	Acta Biomed, 2023	High energy force Hyperextension of the head, Flexion of the head, Traction	Free radicals, Lipid peroxidation, Ischaemia oedema	Injury of the medulla without radiological findings of the spine	Tetraparesis
Maugeri Grazia	Antioxidants, 2023	Trauma with tissue-related injury and bone injury	Blood vessel involvement, Blood outside the vessel change the permeability of the blood-brain barrier	Vertebral fractures, Different types of vertebral disc herniations	The impact on the nervous function under the level of medullary lesion resulting in paralysis, bladder dysfunction, sexual function dysfunction, sensory deficits, oedema of the legs or arms
Porcelli Daniel	International Journal of Medical Science and Clinical Research Studies, 2023	Direct trauma caused by impact	Subluxation of atlas bone, Fracture of the posterior arch at C1 level	Involvement of ligaments can make a difference between a stable and an unstable fracture	Stable fractures can heal completely by “restitutio ad integrum” but their occurrence can limit future sport performance
Mark Patek Mark Stewart	Trauma, 2023	Secondary mechanisms	Oedema, Inflammation, Hypotension, together with hypoxemia	Trauma above the T6 level - lesions of the sympathetic nervous system lead to hypotension and vasodilation	Vasovagal reflexes, causing bradycardia and respiratory issues
Jason L. Zaremski, Matthew C. Diamond,	PM&R, 2017	Neuropraxia	Nervous blockade	Cervical lesion by traumatic injury	Nervous involvement under the lesional level, football players especially
Iida Kyyrönen	Master of Science Thesis University of Tampere August, 2019	Persistent pain	Has the role to distract the attention of the patient from the feeling of guilt	Present or not radiological signs	Acute pain until first 6 weeks of duration, subacute pain lasting from 6 weeks to 3 months, chronic pain is the pain longer than 3 months

The destruction resulted from trauma can be followed by multiple deficits such as motor deficits, muscular spasms, and, over time, medullary spasticity may develop, as well as bladder dysfunction with urinary incontinence leading to the use of a urinary catheter through the urethra or suprapubic aspiration of urine and sexual function involvement. Over time, after Traumatic Spinal Cord Injury (TSCI), oxidative stress and nerve cell death is present in the medulla. After the impact, the correction objectives also include treatment of the endocrine system, the immune system, and the resolution of the cardiovascular effects. Blood may arise through the blood-brain barrier into the brain and medulla, together with the migration and herniation of the intervertebral discs (Maugeri et al., 2023).

After contusion in the cervical region, a subluxation of the atlas can be induced, and it may be accompanied by a fracture of the posterior arch of C1 vertebra. However, if the integrity of the ligaments in this region is preserved, the fracture remains stable. If the ligaments at the C1 level have suffered ruptures, then C1 and C2 are fixed and cervical mobility is lost (Porcelli et al., 2023).

A phenomenon which can appear in spinal trauma is neuropraxia, especially when the trauma is in the cervical region. This type of trauma is frequently present in football players. At the thoracic level, compression fractures are more frequent and can be accompanied by rib fractures and sometimes fractures of the clavicle. At the lumbar spine level, vertebral fractures may occur with associated radiculopathies, which can be present together with previously unknown vertebral malformations (Zaremski et al., 2017).

The medulla realises the connection between the central nervous system and the peripheral nervous system and plays the role of modulating the impulses from the brain to the periphery. The traumatic impact acts through a direct mechanism on the medulla, the bones, ligaments and the blood vessels at this level. The traumatic impact also determines secondary mechanisms in the form of bleeding, oedema, and the development of inflammation together with hypotension and hypoxemia, leading to the amplification and complication of these phenomena. The ASIA system allows the clinician to standardise the care for these patients. In the case of spinal trauma above the T6 level, vasodilation and hypotension occur due to important lesions of the sympathetic system. Together with these events, bradycardia may also appear, and overlapping vasovagal reflexes can occur through laryngoscopy, which may be fatal, even triggering cardiorespiratory arrest (Patek & Stewart, 2023).

Vertebro-medullary trauma in athletes can also be produced through defenestration when the athlete is outside the competitive area or outside the training programme, for example at a party, or when they are involved in activities at home, such as cleaning windows that could lead to accidental or sometimes voluntary defenestration.

The traumatic impact is higher in athletes who are consuming benzodiazepines. Therefore, they must avoid sports training if they are under such treatment, and the coach must know every substance that the athletes take before training. In sport, benzodiazepines are forbidden because they modify reactions and distort perception, and may cause anxiety and insomnia. Diazepam has a relatively long half-life of approximately 33 hours, whereas midazolam has a much shorter half-life of approximately 2-3 hours (Greenblatt et al., 1989). Phenobarbital exhibits an even longer half-life, often approaching 80-120 hours (Fulga et al., 2019), which may prolong psychomotor impairment and recovery time.

If the trauma is very severe, intubation is required, and there are some particularities in the prehospital setting. Substances used could include fentanyl, ketamine and rocuronium, which relax the muscles, and transport from the trauma scene to a hospital setting must be taken into account. A very effective method to avoid intracranial hypertension is the use of opioids in the hospital settings. Intracranial hypertension after sports trauma may also appear as a reaction to the intubation manoeuvre, especially when the patient has associated cranial trauma. Ketamine is useful when arterial hypertension is present in these patients, although arterial hypertension may aggravate cerebral oedema in head trauma cases. The AVPU protocol (Alert, Voice, Pain, Unresponsive) is used, and another widely used scale is the Glasgow Coma Scale (GCS), in which a very important emphasis is placed on pupil dimensions and reactivity. A very good platform is ATMIST, where a report is completed including the patient's age, the moment of impact, the exact mechanism of the trauma, and other signs that can help the clinician manage the case (Scallan et al., 2023).

4. Discussion

4.1. Effects of trauma after bullying

The effects of bullying in sport and the effects of physical aggression can have an impact for a long period of time. Victims tend to internalise the trauma coming from the environment, even if it is less intensive than in other forms of abuse (such as sexual and psychological abuse), and the discomfort remains high after the traumatic event (Fulga et al., 2008).

Physical violence can induce long-term physical suffering, as well as psychological and psychiatric impact, and even death. Following the traumatic impact, the athlete may experience educational delays because they cannot keep up with their colleagues. In this context, there is also a complex identification process: the athlete seems not to belong anymore to the former educational group or to the group of athletes. After a severe traumatic impact, they may experience the feeling of diving into a "no man's land". All plans and purposes are redefined (McCrory, 2000).

Following vertebro-medullary trauma, the sportsman may experience severe chronic back pain, known as Tension myoneural syndrome, described as early as the 1970s by the psychiatrist John Sarno. The theory suggests that physical symptoms often serve to protect the patient's brain from feelings of guilt, anger and shame. Thus, the brain establishes the center of the pain in a specific body part, allowing the patient to better integrate the traumatic impact into their experience. In many situations, minor herniated discs, degeneration of intervertebral discs, or minimal scoliosis do not explain the intensity of the pain. Researchers conclude that additional factors contribute to the perceived intensity of pain following the traumatic impact, including emotional processing, life perceptions, and the microenvironment in which the individual lives. Acute pain lasts up to 6 weeks after the traumatic impact, subacute pain lasts from 6 weeks to 3 months, and pain persisting beyond 3 months is considered chronic following a fracture or muscle tension. The temporal distribution of pain after trauma is illustrated in Figure 1 (Kyyrönen, 2019).

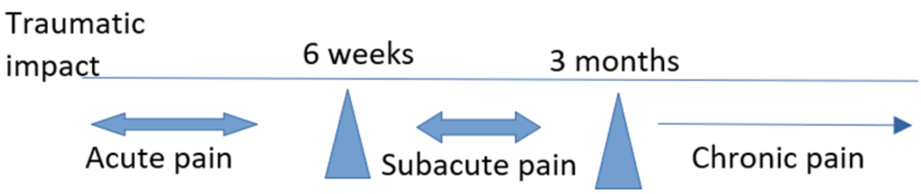

Figure 1. The Temporal Distribution of Pain after Trauma (Kyyrönen, 2019)

Pain following Traumatic Spinal Cord Injury (TSCI) can be difficult to attribute to a single factor. Peripheral nerve involvement could represent a cause of tension myoneural syndrome, and subjective perception of pain is highly significant (Toth, 2006). Imbalance in rehabilitation mechanisms may result in functional limitations, and the purpose of evaluating athletes is to compare the natural course of trauma with the interventions needed for treatment and rehabilitation. Muscle tenderness is important to analyse, as well as the risk of developing muscle atrophy (Irnich, 2013). Hydration of the sportsman is also important. Due to constant bullying, the athlete may conceal physical trauma and may become dehydrated, restoration of hydro-electrolytic balance is necessary following trauma. Through perspiration, liquids are lost depending on humidity, temperature and exercise intensity. If the body loses more than 2% of its liquids, dehydration occurs. Hyponatremia can appear after the traumatic event, and the athlete can develop hyponatremic encephalopathy which manifests with vomiting, confusion, and headache. All together these symptoms will retraumatise the victim, if they become the target of jokes when confused, and the seriousness of the emergency is not recognised by their teammates. The persistence of jokes can exacerbate hyponatremia, as the victim will attempt the same exercises as their colleagues to demonstrate to them that they can face the situation, despite feeling unwell. Biochemically, IL-6 is released from muscle and stimulates the release of arginine-vasopressin which impacts sodium balance (Ecelbarger et al., 2016).

The calculation of long-term impact of the sports practitioners who have suffered bullying-related trauma may be enhanced through the integration of artificial intelligence into medical practice. This enables the development of algorithms to predict outcomes following a traumatic post-bullying event, thereby assisting experts in establishing improved protocols of standard care. Artificial Intelligence also supports the analysis of images from competitions in which trauma occurs (Piraianu et al., 2023). In cases such as spondylolysis and spondylolisthesis, accurate analysis using AI of CT and MRI images can prevent further damage and facilitate improved rehabilitation after repetitive trauma, which is sometimes under-recognised or unreported by athletes, reflecting the concept of the spine as the "tree of life" (Ekhator et al., 2024).

In the case of athletes who are at the beginning of their careers, they might be vulnerable. Although they possess talent and the sports club invests for them, even minor subjective or objective mistakes may lead to marginalisation and mockery by their team. Encouragement may diminish, creating a maladaptive cycle in which performance declines and bullying becomes intensified. If the athlete has a very good mood he will overcome these unpleasant moments, but some athletes might not overcome this experience and they might internalise this trauma. Examples include football and other team sports such as rugby and handball, but may also occur in gymnastics and figure skating.

When the athlete transitions from one sport category to another, new groups may form, and the phenomenon of bullying may develop with other characteristics. Bullying can intensify or the onset of bullying can be the moment after transitioning to the new sports category. In this situation, the sports performance is affected.

After bullying, the sports practitioner may engage in substance abuse, which in turn may influence the response of the patient to new trauma. Others may react with violence following persistent bullying (Parent et al., 2020).

Molecular imaging combined with artificial intelligence models, where spatial and temporal evolution is evaluated, aims to improve the diagnosis of vertebro-medullary trauma and is useful in sport, allowing lesions to be better evaluated. AI systems contain a large memory of images analysed by humans. When a new image is introduced, the results are interpreted by AI and reinterpreted by a specialist. The help of AI models is now more comprehensive for specialists and in some situations crucial for better solutions and less recovery time (Klontzas et al., 2020). Cross-referencing of signs, symptoms, and therapeutic solutions in sports-induced traumatic spinal cord injury are enhanced by AI-based machine learning models, which integrate larger expertise within the field (Klontzas et al., 2020).

4.2. From Injury Prediction to Rehabilitation: Machine Learning Applications in Understanding Long-Term Impacts in Sport

Machine learning refers to the study of algorithms capable of automatically learning from data in order to generate new decisions or predictions. Modern ML techniques include neural networks, support vector machines and random forests, all of which are components of a "machine learning workflow".

For an ML model to work properly, it is essential that the data used is of high quality and relevant to the intended objective, such as predicting the risk of injury. This data is divided into two categories: the training set and the test set. In the first stage, the algorithm learns from the training set the relationship between the desired outcome (for example, the occurrence or absence of an injury) and the factors that can influence it (also called predictors, variables, covariates or explanatory variables). Subsequently, the model's performance is evaluated using the test set, to check how well it can predict on new, previously unseen data. This evaluation must be carried out exclusively on data different from the training set, which is why separating the data is essential from the initial phase.

The quality and volume of the datasets play a decisive role in the accuracy of the results obtained. To optimise these large and complex datasets and ensure the most efficient operation of machine learning (ML) algorithms, various preprocessing techniques can be used, such as missing value imputation, data standardisation or discretisation, along with dimensionality reduction and selection of relevant variables.

In addition, many ML methods require tuning of the operating parameters, i.e., optimising settings that cannot be directly inferred from the data (e.g., the number of trees in a Random Forest model). After the entire workflow is fully trained on the training dataset, the model is used to make predictions on the test dataset.

Given that the actual results of the test dataset are known, the performance of the model can be accurately evaluated. Ultimately, models that achieve good results can help identify the most important risk factors, highlighting those variables that have the strongest influence on the analysed results (Van Eetvelde et al., 2021).

4.2.1. A multi-season machine learning framework for analysing the relationship between training load and injury in professional soccer

The following paper represents the first research of its kind and proposes an innovative method that can fill the gaps in previous studies, while providing an applicable solution for injury prediction in football. Through an extensive analysis of a unique dataset, collected over several seasons and originating from elite Premier League players, the aim was to develop a complex machine learning model capable of assessing the injury risk of players over a seven-day period.

The study included 35 professional male footballers from an English Premier League club. Their mean age was 25.79 ± 3.75 years, with values ranging from 18 to 37 years. Data were collected over several seasons, starting with 2014–2015 and up to and including the 2018–2019 season. Overall, the number of injuries has varied from season to season. In the 2014–15 season, 11 cases were reported, followed by 6 in the 2015–16 season, which was the club's first participation in the English Premier League. Subsequently, a significant increase was observed, with 28 injuries in 2016–17, 41 in 2017–18 and 47 in the 2018–19 season. The “load” data included information obtained through the global positioning system (GPS), physical data such as skinfold measurements and body fat percentage, psychological data such as subjective perception of exertion (RPE), and various demographic information.

A complex model, based on multiple dimensions of loading, was developed to predict whether a player will suffer an injury within the next seven days. To build the injury prediction model, a main dataset was initially constructed that included 106 variables related to training load. This included 40 variables from GPS data, 6 personal information variables, 14 physical variables, 4 psychological variables, 14 variables each for Acute Chronic Workload Ratio (ACWR), Mean Short-term Workload Ratio (MSWR) and Exponentially Weighted Moving Average (EWMA). The dataset also contained an injury label variable, which had a value of 1 if the player was injured and 0 otherwise, along with 10,653 individual observations, each representing a row of training data and personal information for a player.

Of the total, 10,520 observations were associated with the absence of injuries, while only 133 indicated the occurrence of an injury, which highlights a major imbalance in the data (ratio of 0.013). To obtain this final perspective, all previous observations were labeled (i.e., each row or data point that preceded an initial injury event) in the seven-day interval before each injury point with the value 1 and completely removed the original injury records.

The rationale for this removal is the assumption that an injury occurring on a given day does not occur in isolation, but is the consequence of the training loads accumulated on the previous days. Following these modifications, the injury prediction model over a seven-day window is based on a restructured dataset that includes 10,520 observations, of which 10,142 are labeled as non-injury and 378 as injury, resulting in an imbalance ratio of 0.037.

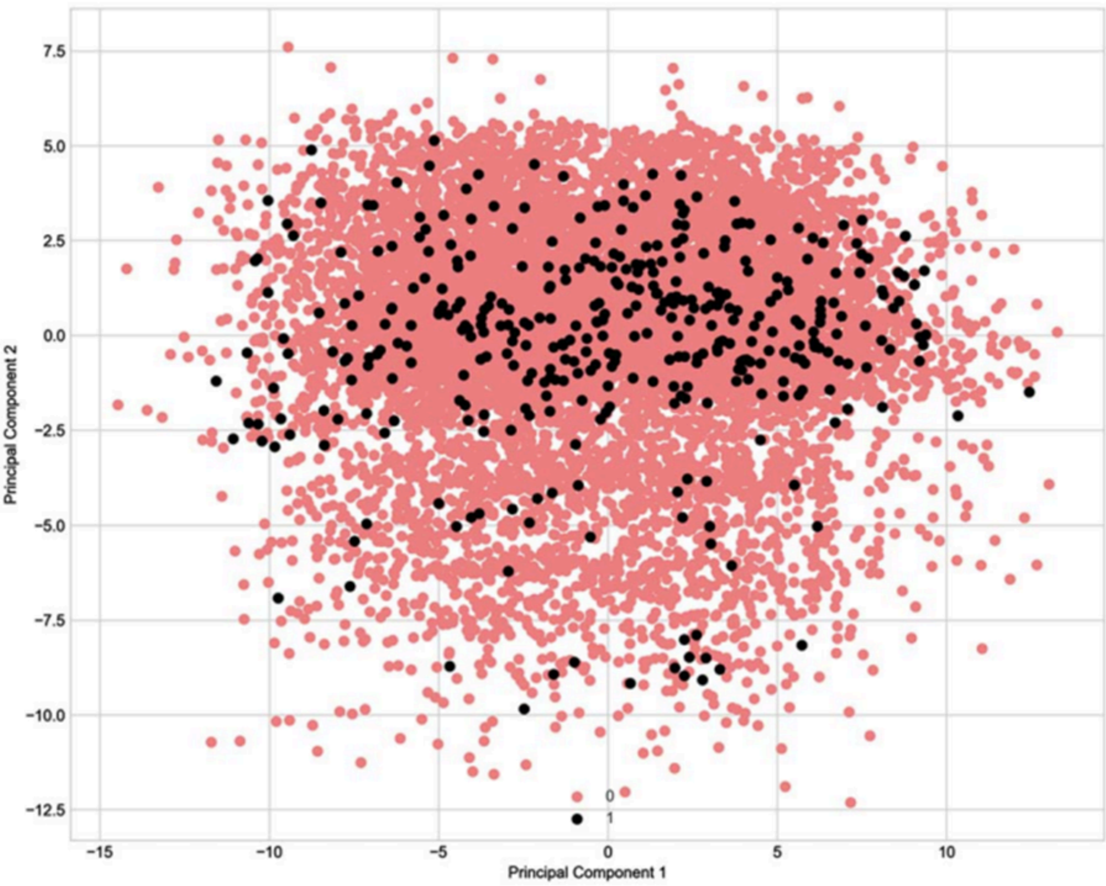

Figure 2. Principal component analysis performed on the dataset used for accident prediction over a seven-day window.Note: A principal component analysis was performed on dataset D (corresponding to the seven-day accident prediction), which contains 106 variables. Red dots indicate data without accidents, while black dots mark accident cases. Adapted from Majumdar et al. (2024)

The Python programming language was used to develop, validate, and test the model. Several machine learning algorithms were tried, such as logistic regression, k-nearest neighbors, decision tree, and random forest, but they had poor performance, failing to correctly identify most of the real injury cases.

In contrast, the XGBoost and artificial neural network (ANN) methods provided superior results. For this reason, the following analysis focuses exclusively on these two approaches and the results obtained with them.

In addition, several data preprocessing techniques were applied, including oversampling of minority classes (i.e., injury cases), variable normalisation (e.g., scaling each training load), and optimisation of various hyperparameters.

First, we separated the entire dataset into two components: the training set (DTrain), which includes information from the first four and a half seasons, and the test set (DTest), which covers the remaining half of the season. The training set DTrain consisted of 9,548 non-injury observations and 341 injury-related observations. In contrast, the test set DTest contained 493 non-injury cases and 37 injury cases. For a more detailed analysis, the test set was divided into three distinct months. Month 1 included 161 non-injury and 14 injury-related observations; Month 2 included 162 non-injury and 14 injury-related observations; and Month 3 had 170 non-injury and 9 injury-related observations. In months 4 and 5, no injury cases were recorded at all.

The XGBoost-based model was able to correctly identify 13 of the 14 injuries in Month 1, as well as 8 of the 9 injuries in Month 3, but in Month 2 it detected only 5 of the 14 real injury cases. In contrast, the artificial neural network (ANN)-based model correctly identified 11 of the 14 injuries in Month 1, 9 of the 14 in Month 2, and 8 of the 9 in Month 3.The ANN model also achieved better results in terms of precision and sensitivity (recall) for both injury and non-injury cases in cross-validation when performance was aggregated across Months 1, 2, and 3.

To understand and visually represent how each model produces predictions, as well as the contribution of each variable (i.e., each training load) to the result, the SHAP (Shapley Additive Explanations) method was used. In this approach, higher SHAP values indicate a stronger influence of that variable on the model's prediction. The five most relevant variables for estimating injury risk in the training and validation data are: location of the last injury, exponentially weighted moving average of meta-energy, weight, meta-energy, and age.

The aim of this research was to apply machine learning methods to investigate the relationship between training load and injury occurrence in football. The results indicated that two algorithms, XGBoost and an artificial neural network, provided the best performance. The XGBoost model was able to correctly identify 26 out of 37 injuries, with a precision of 10% and a recall of 73%. In contrast, the ANN model correctly detected 28 out of 37 injuries, with a precision of 13% and a recall of 77%. For the ANN model, which performed slightly better, the most relevant variables in determining injury risk were "area of last injury" and "weight".

Therefore, even though the precision (i.e. the proportion of injuries predicted correctly out of the total number of positive, correct, and incorrect predictions) was quite low—indicating that a significant portion of the injuries predicted by the model did not correspond to real cases—the recall values (i.e. the proportion of injuries correctly identified out of the total number of real injuries) were high. This shows that the model favored identifying as many real injury cases as possible, even if this resulted in a decrease in precision.

The use of artificial neural networks (ANNs), in combination with explainable artificial intelligence methods, highlighted the potential of these approaches to provide relevant information on the relationship between training load and injury occurrence.

Various data preprocessing techniques were applied, including specific methods for imputation of missing values, generation of new variables, handling of significant imbalance between the "injury" and "no injury" classes, as well as a rigorous training and validation process. The models were tested on real data, and performance optimisation in terms of recall and precision contributed to obtaining relevant results. All of these aspects have the potential to form a solid foundation for future research that uses machine learning in a more applied way in accident prediction (Majumdar et al., 2024).

4.2.2. A machine learning approach for predicting sports injuries and enhancing athletic performance

In the past five years, sports injury prediction has seen significant development in the field of machine learning (ML), driven by the increasing availability of wearable sensors and the availability of more complex and richer longitudinal datasets. Various supervised classification methods, especially those based on decision trees such as Random Forest and XGBoost, along with other similar algorithms, have consistently proven to be effective as benchmarks in injury prediction tasks. Several narrative analyses and systematic reviews have highlighted that these methods typically work on small samples and assume a competitive data context, while deep learning techniques show their potential especially in situations where large and well-organized time series are available.

The widespread adoption of wearable technologies such as GPS, heart rate monitors, and inertial measurement units (accelerometers) has become standard in field-based performance sports. These devices provide high-frequency, multimodal data streams that are essential for machine learning (ML) applications. Studies examining their use highlight the importance of assessing both external and internal load: external load includes measures such as distance traveled and speed (obtained via GPS), while internal load refers to physiological parameters such as heart rate and heart rate variability (HRV). Combined, this information allows the construction of complex indicators of effort and recovery, which are frequently used in ML models for direct predictions.

The following study used a public dataset of university athletes, which includes structured information on demographic characteristics, symptoms, training load, recovery behaviors, performance indicators, and injury recovery. The sample analysed consisted of 200 athletes who play on various competitive university teams. The data were obtained from institutional sources, athlete monitoring diaries, and systems dedicated to tracking team performance.

The dataset brings together a range of variables commonly used to assess sports performance and estimate injury risk. It includes demographic information such as age, gender, height and weight, along with training volume data such as session intensity, number of hours of weekly training and frequency of matches. In addition, aspects related to recovery, such as the number of recovery days and rest intervals between competitions, are also integrated. The final dataset includes a total of 17 variables, with no missing values. The variable indicating the occurrence of injuries (“Injury_Indicator”) is represented as a binary classification label, where the value 0 signifies the absence of an injury and the value 1 indicates its presence.

The data processing process was carried out in Python, using the Pandas, NumPy and Scikit-learn libraries. Outliers were identified using the z-score method, using a threshold of $|z| > 3$, and then analysed and corrected based on previously established statistical rules, without the involvement of technical staff, given that the dataset comes from a public source (Kaggle) and is of a secondary nature.

Since the dataset contains both continuous and categorical variables, preprocessing methods appropriate for each type were applied. Continuous variables were normalised by min-max scaling to ensure comparability of values, and categorical variables, such as gender or playing position, were transformed by one-hot encoding before being used in the model.

Principal Component Analysis (PCA) was optionally used to highlight any overlaps or redundancies between variables. However, since the dataset only included 17 easily interpretable variables, it was decided to keep all of them to avoid losing their significance in explaining the model.

In the final stage, the data were divided by stratified sampling into two subsets: 80% for training and 20% for testing, thus maintaining balanced proportions between injured and non-injured athletes in both groups.

The workflow was structured in five essential steps: data input, data preprocessing, model selection via AutoML, cross-validation, and generation of interpretable results. A low-complexity AutoML framework based on PyCaret library 3.0 was used for implementation, which allowed for the automation of the model training process, the selection of relevant variables, and the optimization of hyperparameters, with a focus on reproducibility and scalability.

Several types of algorithms were evaluated, including Random Forest (RF), Extreme Gradient Boosting (XGBoost), LightGBM, and artificial neural networks (ANN), to which a stacked ensemble model combining RF and ANN was added. Ensemble-based models were chosen due to their high performance on structured, tabular data, as well as their better resistance to overfitting compared to individual neural network models. Neural networks were included for their ability to capture complex nonlinear relationships in sets of multiple variables, including in contexts that do not involve time series. To increase the interpretability of the results, explainable artificial intelligence (XAI) techniques were integrated, in particular SHAP (Shapley Additive Explanations), used to assess the contribution of each variable and to provide transparent explanations of the accident risk predictions. These tools improve the usability of the model, providing coaches, sports scientists, and decision-makers with clear and easy-to-interpret information.

To reduce estimation errors and increase the robustness of the results, 5-fold stratified cross-validation was used, which is particularly suitable for a moderately sized dataset (n = 200 athletes). The performance of the models was evaluated by several indicators: accuracy, precision, recall, F1 score, and area under the ROC curve (ROC–AUC). Since the output variable is binary and the analysis did not involve regression models, the RMSE (root mean square error) metric is not relevant and, consequently, was not used.

Random Forest turned out to be the best performing model, achieving an accuracy of 98% and a ROC–AUC score of 0.97. The high performance, together with a well-balanced F1 score, indicates a strong generalisation capacity and the ability to model nonlinear relationships between variables related to loading, exposure, and recovery. XGBoost also achieved good results, but with slightly lower values for precision and F1-score. In contrast, the artificial neural network performed worse in classification, especially in recall, a behavior often seen in neural networks trained on small tabular datasets without extensive optimisations.

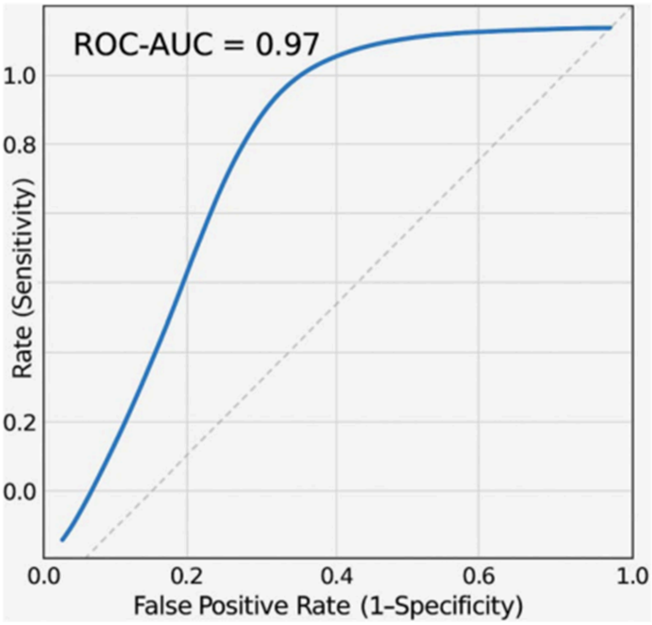

Figure 3. The curve indicates that the model is able to effectively differentiate between injured and non-injured athletes using variables associated with workload, recovery, and performance. The Random Forest classifier achieved an AUC score of 0.97, reflecting a very high ability to separate the two classes. Adapted from Raju et al. (2026)

The results of this study indicate that a machine learning model trained on a public dataset of university athletes can provide effective predictions of injury risk in multi-sport students. The use of structured tabular data based on variables such as training load, recovery, and demographic factors, rather than complex time-series measurements from wearable devices, gives the model better generalization ability, especially in resource-limited settings.

Also, the high values obtained for performance indicators (approximately 98% accuracy and ROC–AUC of approximately 0.97) suggest that variables associated with training volume and intensity, work time, and rest and balance factors have significant predictive power in estimating and preventing injuries in this context.

Future studies should extend the analysis by integrating additional data sources, such as data from wearable sensors, psychological state indicators, nutrition and environmental factors, as well as by using longitudinal research designs. At the same time, exploring transfer learning models in sports contexts with low data volumes may open new promising research directions.

Overall, this research proposes an efficient and interpretable machine learning architecture for classifying injury risk in university athletes, based on available variables related to loading and recovery. Even if it cannot replace expertise in the field, the model supports the decision-making process in sports monitoring and provides a basis for the development of more scalable and data-dependent injury prevention strategies, in the context of emerging performance sports (Raju et al., 2026).

4.3. Rehabilitation after Bullying in Vertebro-medullary Trauma for Sport Practitioners

Physical rehabilitation goes hand in hand with psychological rehabilitation. The sport practitioner is more willing to engage in physical exercises if they are supported psychologically. Some sport practitioners may not hasten their rehabilitation because they fear that, if they are in good parameters again they will be forced to come back to the same place where they experienced bullying. An important aspect is to place emphasis on the education of the sport practitioner, encouraging them to graduate high school, license degree, master's degree and PhD degree. However, the most important factor in the rehabilitation process remains the cooperation of the patient (Toma, 2016).

Antioxidant substances and vitamins, which help the restoration of muscular tissue, can be used. Glutathione is a strong antioxidant that combats oxidative stress in the patients with Traumatic Spinal Cord Injury (TSCI). GlyNac is a combination of Glycine and N-acetylcysteine that stimulates the synthesis of glutathione synthetase. Together with exercises such as body weight-supported treadmill training (BWSTT), these methods showed good results in the rehabilitation after Traumatic Spinal Cord Injury (TSCI) in experiments performed on rats. Glutathione results from substances such as glutamate, glycine, and cysteine, which may present altered concentrations in the cerebrospinal fluid after the traumatic impact (Xu et al., 2023).

Artificial intelligence can support the design of recovery programmes for sport practitioners by processing large datasets and providing evidence of progress throughout rehabilitation. These data may be compared with similar cases from other centres, enabling broader monitoring and benchmarking. Profiling of the sport practitioner following trauma can thus be performed, including predictive estimations regarding rehabilitation duration, required resources, and risks of decompensation (Poalelungi et al, 2023).

Bullying prevention should address both physical and psychiatric effects of bullying:

1. If the bullying is addressed to one person from another person

Intervention: Discussion with both victim and aggressor, involving the trainer and psychologist, and counselling for both parties.

2. If the bullying took place for a long or short period of time

Intervention: to discuss the disclosure moment and how to manage the impact of bullying and therapies needed.

3. If the parents and family of the sports practitioner and trainers know about the bullying and they try to combat it

Intervention: It is good to make supplementary investigation if needed but it is good to convince the family to avoid overinvestigation of the traumatised sportsmen because of supplementary psychological trauma because of overinvestigation. The motivation of the family members could be to have more testimonials to can revenge. The therapeutic role is to concentrate family efforts on rehabilitation

4. If the bullying was reported to police or social services

Intervention: Assessment of legal measures taken to combat bullying and to prevent it.

5. If the bullying led to physical effects or psychiatric effects

Intervention: Identification of the most appropriate medication and rehabilitation process.

6. If the sport practitioner quit the team

Intervention: Encouragement of the sport practitioner to come back to sport practice and take part again in competitional activity

7. If the sport practitioner has a permanent disability

Intervention: Identification of opportunities for beginning a new life and for social reintegration, and breaking the connection with harmful environments.

8. Self-esteem and self-image

Intervention: Sportsmen must focus on personal success and daily life.

Prevention programmes for violence in sport may include educational sessions about bullying within sports clubs, as well as activities such as volunteering, twinning of one sport club with another sport club, allowing sport practitioners to learn about different organizational cultures, and broaden their perspectives (Fazel et al., 2022).

Athletes who have survived bullying, have developed programmes for the prevention of abuse in sport, especially through popularisation of their stories (McMahon et al., 2023).

Another prevention method is the constant monitoring of biological parameters. Similar to the general pediatric population, the sport practice in children must be searched rigorously constantly for the neurological status and functioning of the cognitive functions as well as other systems and organs, such as the investigation for nonalcoholic fatty liver disease which can be enhanced by stress factors when preexisting epigenetic factors exist and a dysmetabolic state. We must measure the weight of the sports practitioner and calculate their BMI, because in some sports they can be overweight (throwing, judo, and other sports). The known incidence of nonalcoholic fatty liver disease (NAFLD) in children is about 17%. Children who experienced bullying can develop eating disorders like bulimia and anorexia, that are very difficult to combat and sometimes the criticism received from their coaches about weight can lead to eating disorders and overtraining. Children with NAFLD may develop insulin resistance which can be calculated with the HOMA-IR formula (glucose mg/dlx insulinemia/405) (Pelin et al., 2022).

The sports trainer must be prepared to recognise and anticipate the danger for the sport practitioners to become physically hurt, his intervention being to prevent such situations and when trauma is produced to take action as rapidly as possible after the international protocols of Basic Life Support and with the aim to reduce the traumatic impact on long term on the sport practitioner (Sports Medicine Australia, 2006).

Sport should represent a lifestyle rather than an imposition, contributing to the holistic development of the sport practitioner. Its benefits begin in early life, including improved bone mass development, physiological regulation of blood pressure, healthy weight management, prevention of bone demineralisation, increased life expectancy, improved organisation of daily life, enhanced self-esteem, and overall well-being (Coulson, 2013).

In the diet of a sports practitioner, honey is a complex nutritional substance. One of its most important properties is antioxidation, as well as antiviral and anti-inflammatory properties. These protect the sports practitioners from cancer through their rich flavonoid content. The flavonoids and the phenolic acids heal microlesions, due to their influence on the activity of B-type lymphocytes. An improved immunity may help the sports practitioner face high stress levels induced by competition and group interactions (Jicman et al., 2022).

The internalisation of models of victimisation tends to adopt behaviours of sedentarism and the role of the trainer is to prevent the victimisation model (Pacífico et al., 2024).

Worldwide, it is important to seek teachers' perspectives on bullying. Coaches must take into consideration collaborating with the professors and the teachers of their sports practitioners, to prevent further bullying. Education is also needed for students who are bystanders in bullying in sports environments (Martínez-Carrera et al., 2024).

In performance sport, it is important to exclude the existence of BK infection, which may mimic chronic adenoiditis and can be deceptive, presenting with symptoms such as nasal obstruction and rhinorrhoea. BK glossitis might be misdiagnosed as a neoplasm. The teammates of the sport practitioner may joke about the physical state of the ill sports practitioner. The trainer must seek the intervention of the general practitioner, the sports' team doctor, the infectionist and epidemiologist and stop the marginalisation of the ill sport practitioner or the bullying caused by the arising anxiety. The sport practitioner may have a decline in their competitional performance when coming back on the sports field. The trainer and the teammates must be very kind and diplomatic to them. In such moments, the sport practitioner tends to conceal their symptoms because of the pressure to perform. If teammates observe symptoms they must give a report to the trainer but without bullying their teammate. The sport practitioner must understand the importance of reporting symptoms and that it is not a shame to have a disease and that if it is reported on time, he will have a good time and can come back to the competitional activity. Many times, the complaint of the sport practitioner is the lack of support from the team and sometimes from their own family (Tatu et al., 2022).

The trainer can prevent bullying by grouping athletes based on age, competence and hobbies. The trainer will work on communication between the sports practitioners, and the sports trainer will engage the sports team in cultural activities and in extracurricular activities (Vveinhardt & Fominienė, 2020).

Bullying is influenced by cultural factors and may not always be recognised by the aggressor. Family members often play a crucial role, both as support systems and as individuals affected by the situation. The way parents perceive and process bullying experiences is highly relevant. Transitions between teams and differences in organisational culture also represent critical factors in the experience of the sport practitioner (Nichifor et al., 2023).

5. Conclusions

A profound understanding of bullying mechanisms allows for a more effective approach to this phenomenon among sport practitioners, whether at the beginning of their careers or at elite levels. Important aspects include transitions between age categories, transfers between teams within the same sport, migration to different sports, or relocation to new geographical areas. Equally important are education, family support, and the support of coaching and technical staff during key life events, such as forming a family, the birth of a child, or the loss of a family member. During such moments, the team and staff should provide emotional support to the affected sport practitioner. Isolation is particularly difficult to endure and may itself represent a form of bullying, manifesting through ignoring, lack of feedback, or absence of meaningful communication during training. Sports teams, through their activity, reflect broader societal dynamics and values, acting as a mirror of the communities from which they originate.

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Abbreviations

The following abbreviations are used in this manuscript:

TSCI = Traumatic Spinal Cord Injury
SCIWORA = Spinal Cord Injury Without Radiographic Abnormality
GCS = Glasgow Comma Scale
NAFLD = Nonfatty alcohol liver disease
BMI = Body Mass Index

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