Injuries in Skating and Sledding Winter Sports: Patterns and Imaging Findings

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Abstract

While skiing and snowboarding are amongst the most common winter sports, skating and sledding activities are also popular for competition or recreation. Related injuries following an acute trauma mainly involve head, spine, upper and lower limbs. For elite athletes, overuse injuries represent a significant burden. In skating, lesions can be related to boot structure and design. This article reviews epidemiology, patterns, and imaging findings of common injuries in ice skating, short track speed skating, curling, luge, bobsleigh, and skeleton.

Keywords
- ► sledding
- ► skating
- ► winter sports
- ► imaging
- ► injuries

Winter sports performed on snow or ice are popular among millions of people worldwide, practicing different activities. They are mostly recreational for tourists or locals in areas with snow and mountains during winter or in artificial snow or ice-covered areas all year-round.

Winter Olympic Games have been held since 1924 and global cumulative audience for the 2018 PyeongChang (South Korea) Games was 1.92 billion, attracting new generations of children, teenagers, and adults to these sports regularly. However, competitive and recreational winter sports can lead to serious injuries. In 2018, almost 200,000 patients were treated in the United States for injuries related to winter sports alone.[1] Injury rate is higher in beginners with risk factors arising from the athlete (lack of physical fitness, inadequate skills), the equipment, or the physical environment (impact).[2] Beginners are more at risk of acute trauma, hitting their head when falling backward or injuring their wrist when falling forward on their outstretched hand. For elite athletes, training or competition can be responsible for acute or overuse injuries. While ski and snowboard are the most popular winter sports, skating or sledding activities are also practiced by occasional or elite athletes.

This article reviews the injuries described in ice skating, short track speed skating, curling, luge, bobsleigh and skeleton, illustrated with selected related imaging findings.

Ice Skating

Ice skating is performed on frozen lakes that are ice tested and prepared for public use by local authorities, on skating rinks (►**Fig. 1**) or on temporary skating rinks, increasingly popular in urban outdoors around Christmas.

Beginners are prone to fall on the ice and suffer from acute injuries, such as sprains, abrasions or fractures.[3] Upper limb trauma secondary to a fall on an outstretched hand is the most frequent trauma: radial, humeral, carpal, metacarpal or phalangeal fractures can occur. When skaters try to avoid a fall, a twisting mechanism of the lower limb can lead to knee, leg, or ankle injuries, such as sprain, torn menisci, ligamentous tear, and fractures. Contusions, direct blow to muscle (►**Fig. 2**), lacerations, or concussions are common. Traumatic lumbar compression fractures are described.

Elite figure skaters train for physical strength (focusing on speed, power, balance, endurance, agility, and flexibility) and decision-making skills before stepping onto the ice. They need to execute accurately successive technical free skating skills and mandatory elements of a program, such as axels, toe loops, lutzes, and salchows, back to back, while keeping the music flow to express the aesthetics associated with the sport.

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Fig. 1 Female ice skater.

Fig. 2 Female ice skater sustaining a fall with a direct blow. Magnetic resonance (**a**) axial and (**b**) coronal T2-weighted fat saturation sequence of the pelvis demonstrates a right-sided gluteus maximus muscle tear with adjacent soft tissue contusion (arrows).

Figure skating has been an Olympic sport since the 1908 Games. The scoring system of a program includes both component scores for presentation and artistry (interpretation of the music, composition, performance, transition, and skating skills) and technical scores for jumps, spins, steps, and loops.

Power-to-weight ratio, aerobic capacity, and vertical height jumping training fuel the ability to execute accurately the required multiple rapid and complex aerial moves and to deliver a fast, fluid, and precise performance. Muscle strength balance, spins and jumps, and efficient conversion of the explosive power of the lower limbs into the perfect take-off can be trained with a harness system and ropes to target specific rotation patterns and body tilting, focusing on gaining agility. A rotational speed of up to 300 revolutions per minute is achieved by female figure skaters during their training, aiming at scoring high in jumping performances.

The rapid decelerations, changes in direction, and the force of landing after multiple aerial movements make figure skaters especially vulnerable to knee injuries. Stability and control of the knee joint under load is vital to keep athletes at the top of their sport.

Because professional athletes can spend up to 6 hours per day, 6 days per week,[4] practicing, they are at risk of chronic and overuse injuries, mostly of the lower limbs. High loads of training combined with insufficient rest can lead to medial tibial stress syndrome, jumper's knee, and stress fracture, the most frequent overuse injury in female junior skaters[4] (►**Fig. 3**).

Fig. 3 Young ice skater training 14 hours a week had a heel trauma during training after a jump performed bare foot. Mixed pattern of traumatic and overuse injury demonstrated on magnetic resonance (**a**) sagittal and (**b**) coronal T2-weighted fat saturation images of the ankle. Calcaneal trabecular fracture (short arrows), surrounding bone marrow edema, and reactive quadratus plantae muscle edema (long arrow) are illustrated.

Fig. 4 Boot-related injuries.

Fig. 5 Summary of injuries in ice skaters.

Pairs skaters are more susceptible to upper limb lesions in lifting (trapezius strain, biceps tendinosis, rotator cuff injuries).[5] Jump take-off and landing mechanics are risk factors for navicular stress fractures, articular cartilage damage in the ankle or foot, and chronic peroneal tendon subluxation. Muscles strains around the hip (adductor complex, hip flexor, groin, internal or external oblique) can occur in athletes performing triple jumps.[6]

Off-ice flexibility training helps prevent injuries related to muscle inflexibility, in particular for thigh iliotibial bands, hamstrings, or quadriceps.[7] Worsening of a preexisting injury can significantly burden the physical fitness of athletes.

The structure of skate boots, composed of hard rigid layers of leather combined with excessive stiffness or inadequate boot fit, can contribute to injuries, summarized in ►**Fig. 4**. Affecting one or two feet in as many as 34% of skaters, retrocalcaneal bursitis can be caused by repetitive deep ankle dorsiflexion movements.[8] Risks factors include higher body weight and greater in-skate ankle flexibility. Boot heel cup design can play a role in posterior skin calluses and the occurrence of superficial calcaneal bursitis. Boot collar and tongue, as well as lateral ankle regions, can cause skin calluses, abrasion, or tenosynovitis of the toe extensors and tibialis anterior.

Osgood-Schlatter's disease, Sever's disease, patellar tendinopathy, Achilles paratendinopathy, and posterior tibial tendinopathy can result from repetitive jump-related stress to tendons and entheses.[8] Patellofemoral pain syndrome or sacroiliac joint dysfunction can follow repetitive movement patterns, stressing or shearing articular cartilage in solicited weight-bearing limbs. Landing from a spinning jump impacts facet joints and increases the risk of spondylosis. ►**Fig. 5** summarizes injuries in ice skaters.

Prevention of injuries can focus on wearing an adequate boot size and on rest, in agreement with the physical maturity of athletes. Finally, winter sport athletes who train in cold outdoor environments experience higher rates of exercise-induced asthma than most elite athletes.

The incidence of injuries in figure skating on epidemiological studies is usually low.[9] Proportions of athletes in figure skating with an injury during the 2018 Olympics was $< 10\%$ with no severe lesions.[10] Incidence of injury was 13.4% in figure skaters during the Sotchi 2014 Games, mostly training related.[11]

Short Track Speed Skating

Short track speed skating is a highly unpredictable physical and tactical winter sport of precision, speed, strategy, power, decision making, and overtaking. Skaters race up to speeds of 50 kph in a 60×30-m ice rink in which the track is laid out in an oval of 111.12 m. Four to six athletes participate in a frenetic speed race, 500, 1,000, 1,500 or 3,000 m length, or in a relay of four of 3,000 or 5,000 m, racing against each other counterclockwise.

Equipment includes ice skating boots with sharp blades 46 cm long and 1 mm wide, allowing them to carve into the ice, cut-proof gloves with gliding tips, helmet, aerodynamic suit, safety glasses, and shin and neck guards. Detailed and precise training and physical preparation are focused on very sport-specific exercises targeting muscle memory of the movement patterns needed for efficient skating on ice. To achieve long stride patterns, athletic training focuses on simulating body angles, strengthening core resistance, and balance.

From the starting point and after they hear the starting gun shot, athletes perform 6 to 8 steps to the first corner where they have less than 1 second to transition to their leaning phase (►**Fig. 6**). Race position needs a 20- to 30-degree body angle and a low center of gravity to create aerodynamics and a stable base to improve balance. When the finish line comes into sight, athletes execute a clever overtaking, requiring precise timing and decision-making

Fig. 6 Short track speed skater leaning.

skills at high speed to try to win the race, sometimes by the tip of their blades. It has been an Olympic sport since 1992.

There are inherent dangers involving skating at high speed with sharp blades and close proximity to the barriers and other athletes. One wrong step, and skaters can go down at a very high speed. Physical contact between contestants is not allowed, but it is not always avoidable. Athletes are at risk of sustaining on-ice or off-ice training injuries, as well as competition-related injuries.

A total of 95 athletes responded to a study by Quinn et al[12] on injuries in short track speed skating during one season. Numbers of injuries were higher in the lower limb (knee, ankle, leg essentially) than in the upper limb and spine. Groin injuries and a few head injuries were also described. Acute-onset injury during training accounted for nearly 60% of all injuries, mostly groin and muscle strains (►Fig. 7), knee contusions, or undifferentiated pain, ankle sprains, and hand or wrist fractures. Competition-related injuries included shoulder dislocation, groin strains, concussions, and knee contusions. Skaters are susceptible to direct blows to a muscle after a fall or collision.

Incidence of lower leg lacerations experienced by short track speed skaters was 15 in 36,562 user-days in a study by Snouse et al.[13] Lacerations can also occur to the arms and hands.

More frequent in the knee (patellofemoral pain syndrome) and spine, overuse injuries can also result in medial tibial stress syndrome, Achilles tendinopathy, or groin strains.

Palmer-Green et al[14] did an epidemiological study of injury and illness in a Great Britain short track speed skating squad and found rates of 2.7 injuries per 1,000 athlete training hours and 13 injuries per 100 competition starts. Thigh, lumbar spine, and knee injuries were the most frequent. Overuse and contact against a static object (more severe), as well as noncontact trauma, were the most common causes of injury. ►Fig. 8 summarizes the injuries reported in short track speed skating.

Curling

Curling originated in Scotland in the 16th century and has been an Olympic sport since 1998. Curlers play on ice, divided in two teams of four players. One player delivers an 18.6-kg polished granite stone on a 44.5 × 4.75-m curling rink towards a target. Another player, called the skip, is responsible for the strategy while two players sweep the ice with brooms (►Fig. 9) around the moving stone to influence its trajectory. Modifying the coefficient of friction between ice and stone to regulate its direction and travel distance is performed by increasing the ice temperature and smoothing the ice by removing debris and frost. Stone delivery can be achieved by lifting the stone up and back before swinging it forward or sliding back the stone before propelling it forward (no-backswing delivery). The curler delivering the stone then slides along the ice in a position of extreme knee and hip flexion on the nondominant lower

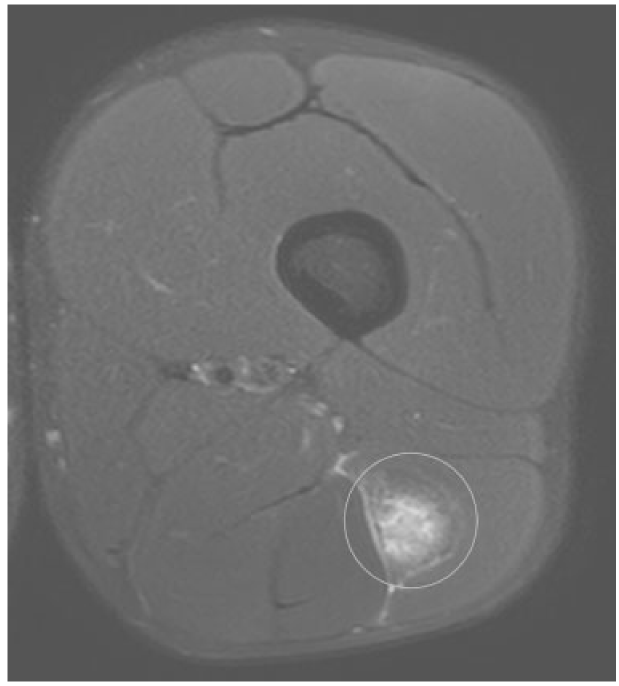

Fig. 7 Short track speed skater with an on-ice training muscle strain. Magnetic resonance axial T2-weighted fat saturation sequence of the left thigh shows a myotendinous injury (circle) and edema surrounding connective tissue within the long head of the biceps femoris muscle.

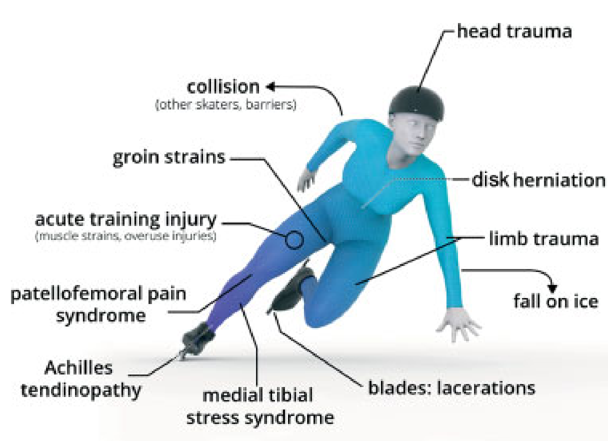

Fig. 8 Summary of injuries in short track speed skating.

Fig. 9 Curlers sweeping the ice.

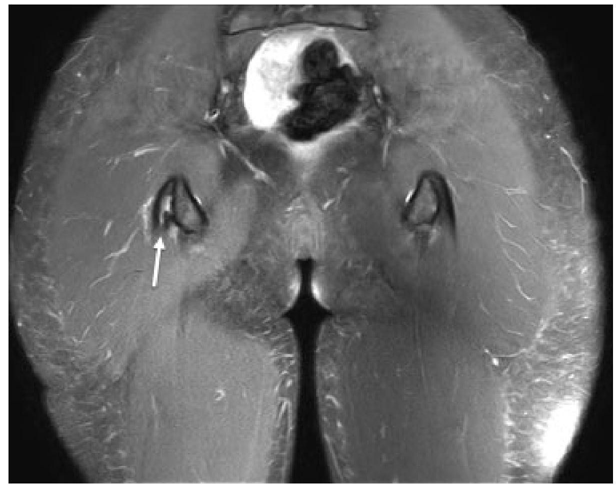

Fig. 10 Magnetic resonance coronal T2-weighted fat saturation image of the pelvis shows right chronic tendinopathy of the hamstrings with partial tear (arrow) of common proximal origin of the biceps femoris long head/semitendinous muscles at the posteromedial aspect of the ischial tuberosity in a curler.

limb. Curlers sweeping the ice must move quickly, smoothly, and efficiently across the ice, maintaining their balance while using their upper limb vigorously to sweep with spinal flexion.

Equipment includes appropriate footwear: curling sliders with a Teflon bottom sole, allowing curlers to glide while delivering the stone, and curling grippers with a rubber bottom sole to have traction on the ice.

The combination of downward force and brush head speed necessary for effective sweeping is the most physical aspect of curling.[15] Each team plays typically > 1 hour.

Recreational curlers are more at risk of falling due to the slipperiness of the ice with > 90% of acute injuries resulting from a fall,[16] often attributed to a lack of proper footwear. Ting and Brison[16] found a rate of 0.17 acute injuries per 1,000 athlete exposures that requires an emergency department presentation in recreational curlers. Athletes either slip backward, resulting in an occipital closed head injury and concussion, or slip forward, resulting in a fall on an outstretched hand injury that can lead to a fracture of the distal radius or soft tissue injury in the hand, elbow, shoulder, or wrist. Dislocations or fractures of the shoulder or elbow are less frequent, as well as lower limb soft tissue injuries or fractures of the hip, knee, or ankle.

Although acute injuries are rare among professional curlers (mostly sprains to the knee, back, shoulder, hamstring, or ankle), overuse injuries (►**Fig. 10**) are more frequent. Reeser and Berg[17] investigated injury patterns in competitive curlers, and exposure to acute injuries occurred at a self-reported rate of 2 to 2.3 per 1,000 games. A total of 79% of curlers participating in their study reported musculoskeletal pain, mostly involving the knee (54%), back (33%), shoulder (20%), hip (11%), and neck (7%). Competitive curlers can experience shoulder injuries, such as a torn rotator cuff due to repetitive sweeping or stone delivery. The lunge position used to throw the stone requires a combination of core strength and hip range of motion with the knee flexed well beyond 90 degrees. Repetitive bending at the waist increases stress and strain through the lumbar spine and knee and can generate herniated lumbar disks and nerve root compression. Patellofemoral pain syndrome or a torn meniscus can follow the frequent flexed knee position performed to deliver the stone. Snapping in the forearm tendon is also described. Injury incidence in the PyeongChang 2018 Olympic Winter Games was 8% in curling.[10]

Luge

Luge is a racing sledding sport where the rider is positioned lying face up, feet first, on a flat sled without brakes (►**Fig. 11**). Speed can exceed 140 kph, riding down an ice track. Initiation of movement is performed in a sitting position through grab handles on either side of the track to propel the rider forward. Once launched, athletes use their hands in spike gloves to paddle and gain speed. Steering is performed by applying force with the calf of each leg or by exerting opposite shoulder pressure to shift their weight.

Luge races involving Vikings might have occurred as long ago as A.D. 800 in Scandinavia. Competitive luge racing started in Switzerland in the late 1800s, and it became an

Fig. 11 Luger.

Olympic sport in 1964. It can be performed with a single rider, in doubles, or in team relay.

Apart from the luge sled, made of fiberglass and steel, riders' equipment includes a skin-tight rubberized racing suit, spiked gloves providing traction when the slider is paddling over the ice at the start, boots, and a helmet with a visor.

In a retrospective study[18] analyzing injuries in luge covering 7 years, crashes were responsible for 64% of injuries. The risk of sustaining an injury was 0.39 per person per year. Contusions were the most common injury (51%), followed by strains (27%). Although concussions (2%) or fractures (3%) were the most serious injuries, soft tissue lesions, such as bruises, abrasions, or lacerations, were more common after a fall from the sled or a crash. Neck muscles are highly solicited during sledding to keep the luge balanced and counteract the forces exerted on the head. Neck muscles strains are therefore not uncommon. Hand injuries are also a characteristic of this sport because it is one of the first body parts of the athletes to come in contact with the ice track during a fall or a crash.

Another study on the epidemiology of luge injuries[19] depicted 54% of lower limb injuries (knee injuries, foot, ankle, tibial or femoral fractures), 35% of upper limb injuries (shoulder dislocation or fracture, clavicular, humeral, radial or ulnar fractures, acromioclavicular dislocation), and other lesions (11%) including spine fracture and abdominal or head injuries. Upper limbs are used repetitively to initiate the start, so rotator cuff tears can occur in elite athletes.

International luge athletes are also vulnerable to overuse injuries. Up to half of riders can experience a chronic mild to moderate musculoskeletal spinal injury during their career.[20] The most common are sprains and intervertebral disk injuries, mostly due to repetitive forward bending at the start and repetitive load during training. Morison et al[20] found an annual rate of musculoskeletal injuries of the spine of 0.13 injuries per athlete per year, predominantly in the cervical and lumbar segments. The same author[21] studied the kinematics of the lumbar spine during the pull phase of the luge start, analyzing the explosive flexion and extension of hip and spine used to achieve maximal power. Different techniques among athletes were found in the so-called compression phase of the start, with various body positioning modifying the risks of spinal injuries.

One athlete from Georgia, Nodar Kumaritashvili, died during training at the Vancouver Olympics following ejection from the track at 145 kpm, but that outcome is extremely rare.

Bobsled (or Bobsleigh)

Bobsledding (or bobsleighing) is performed sliding down an ice-covered natural or artificial curving incline on a four-runner racing sled that carries either two or four persons (►**Fig. 12**) with a steering mechanism of two metal rings actuating a pulley system. Originating from St. Moritz, Switzerland, in the late 1860s and invented at first to entertain wealthy tourists, it became an Olympic sport in 1924.

Fig. 12 Bobsleighers.

Athletes need a race suit made from Lycra to provide aerodynamics, a helmet to prevent head injuries, gloves, and footwear with ice spikes under the front part of the foot to offer grip while sprinting to move the sled from the standing start. Sleds are light and aerodynamic with a body made from fiberglass, carbon fiber, or a mixture of both.

First, athletes push the sled, grabbing handles on the side and back of the sled to gain maximal speed over a 65-m distance, then load into it in quick succession. Tracks vary from 1,200 to 1,900 m in length and 12 to 21 turns. Competitive athletes can reach speeds up to 155 kph and experience 5 to 6 G (gravitational forces). Explosive leg strength and power, agility, and flexibility are needed to gain maximal speed at the start and move the sled as fast as possible. Athletes' muscles are then solicited to maintain stability in the lumbar spine and control their trunk subject to strong pressures while sledding down the ice track in a sharply forward stooped position.

The vast majority of injuries occur during common athletic training.[22] The most frequent are hamstring strains and calf muscle injuries.

During a run, injuries are more frequent at the start, with athletes at risk of hamstring strains due to the requisite combination of speed, power, and strength necessary to push the sled efficiently.[23]

Soft tissue injuries can occur at the initial running phase while getting into the sled or with team member's footwear spikes. Riding down the bobsled, spinal disk herniations and nerve root compression can result from the strong forces applied on the spine.

Crashes or ejection from the sled can lead to cervical spine injury, lumbar compression fractures, abrasions and burns to the skin, and contusions to shoulder, arm, or hand.

Traumatic head and brain injuries and concussions can affect up to 13 to 18% of all sledding athletes.[24] In bobsleigh, crash and concussion rates can be counted as 1.5% and 0.2% of all runs, respectively. When a crash occurs, 17% of athletes suffer from concussion. Injury can also result from repetitive subconcussion or due to neck strain, likely originating from years of repetitive crashes, headbanging,

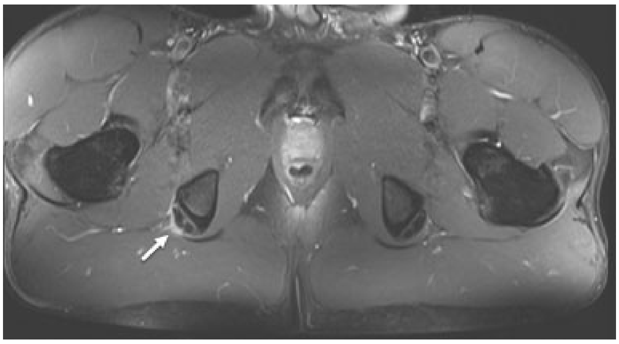

Fig. 13 Magnetic resonance gadolinium-enhanced fat-saturated axial T1-weighted image of the pelvis demonstrates right chronic hamstrings tendinopathy (arrow) in an elite bobsleigher.

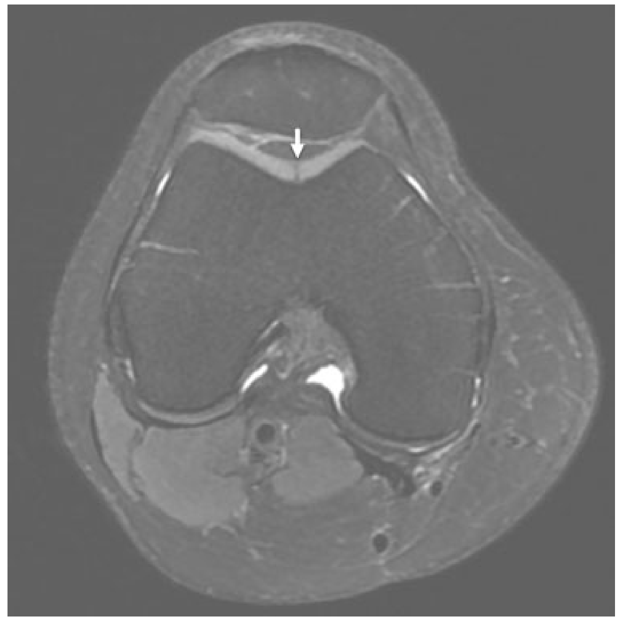

Fig. 14 Magnetic resonance axial T2-weighted fat saturation image of the knee shows a trochlear cleft: cartilage black line sign indicating incomplete closed cartilage fissure (arrow) in a female bobsleigher.

brain-rattling vibrations, and strong gravitational acceleration forces.

Symptoms include chronic headaches, a heightened sensitivity to bright lights and loud noises, difficulties maintaining focus, as well as problems with balance, coordination, or memory. They can significantly impact life and lead to psychological distress, gradual brain deterioration, and suicidal behaviors. The term *sled head* was coined to refer to these symptoms in athletes practicing sliding sports. Conventional neuroimaging examinations are typically normal in concussed athletes.[25,26] Research is focusing on advanced neuroimaging techniques with the aim of identifying diagnostic and prognostic biomarkers of concussion that could provide useful information in terms of return-to-play interval as well as risks of future cognitive impairment. Diffusion tensor imaging, task-based and resting-state functional magnetic resonance imaging, positron emission tomography, ^{1}H magnetic resonance spectroscopy, and perfusion imaging could play a role in the medical follow-up of sledding athletes in the near future to depict structural or metabolic alterations in the brain more accurately.

Overuse injuries can affect elite athletes, targeting tendons like hamstrings (►**Fig. 13**), Achilles tendon (a Great Britain Olympic bobsleigh pilot ruptured his Achilles tendon in training), cartilage (►**Fig. 14**), or bone. A stress fracture of the ulna was reported[27] in the brakeman (final athlete), responsible for decelerating the bobsled with two hand brake levers after crossing the finish line. Deadly injuries are extremely rare.

Skeleton

Similar to bobsled, skeleton was born in St. Moritz, Switzerland, and consists of a single athlete running fast from the start over 65 m (►**Fig. 15**), and then getting into a moving sled that needs to be driven and steered down a frozen track lying face down and headfirst. Sleds are made of carbon fiber with a steel frame and saddle to keep the rider in place. Steering is accomplished by athletes using either lateral air drag forces (tilting head, shifting shoulders, spine, and body weight more on one side than the other) or dragging a toe to try to modify ice friction. Suit, helmet, gloves, and footwear are similar to bobsled. It has been an Olympic sport since 1928. Elite riders can experience accelerations up to 5 G and reach speeds > 130 kph. Authorities (International or National Bobsled and Skeleton Federation) or events (Skeleton and Bobsleigh World Cup) are usually paired with bobsleigh.

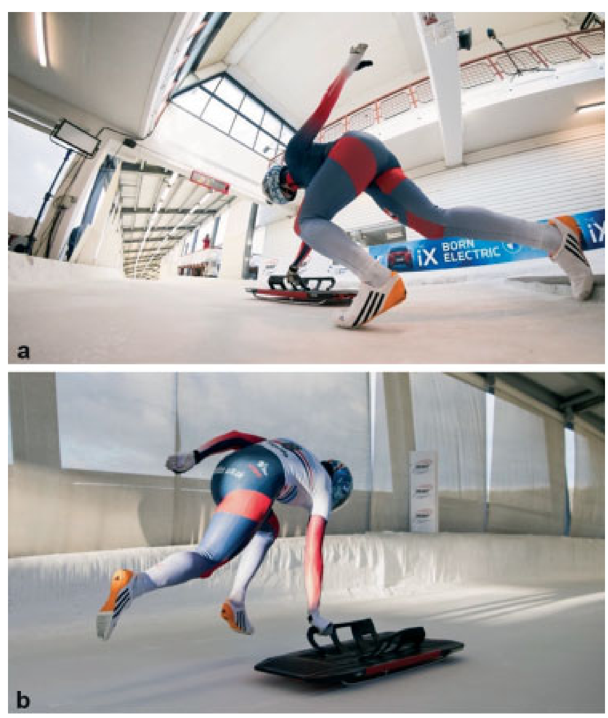

Fig. 15 (**a, b**) Olympic skeleton rider at the start. (Reproduced with permission from James Harper, Sports Sphere, Olympic Talent Management, London, UK, per e-mail on November 27, 2020.)

Fig. 16 Skeleton racer with an off-ice training muscle strain. Magnetic resonance (**a**) axial and (**b**) coronal T2-weighted fat saturation sequence of the thigh demonstrates a tear (arrows) of the tendinous direct head of the left rectus femoris muscle.

To our knowledge, no specific literature is available related to skeleton injuries. However, according to articles on the epidemiology of injuries during the Olympic Winter Games, they are similar to those of bobsleigh, coming either from muscular strains while athletic training (►**Fig. 16**) or similar overuse injuries. Overloads of tendon insertions or stress to knee cartilage are possible. Muscular injuries from direct blows can occur in falls or crashes. Contusions to shoulders, arms, and legs happen when the sledder hits a wall. There is also increasing concern about concussion and long-lasting effects like mental illness due to repetitive crashes.

However, very few injuries occurred during recent international events, with two and five injuries in 159 and 47 skeleton athletes during the 2010[28] and 2014[11] Olympic Games, respectively.

Conflict of Interest

None declared.

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