5 Gymnastics (Artistic, Rhythmic, Trampoline)

Sports-Specific Injures and Unique Mechanisms in Artistic and Rhythmic Gymnastics and Trampoline

Samantha Tayne, Lorena Bejarano-Pineda, and Mark R. Hutchinson

5.1 Introduction

Gymnastics has a long history as a competitive sport, becoming part of the Olympic Games in 1896, and continuing as a very popular sport internationally into today. The International Gymnastics Federation has 148 affiliated or associated federations, with an estimated 50 million people of all ages and around the world participating in a gymnastics club [1]. In particular, gymnastics is one of the most popular youth sports [2]. The sport includes artistic or rhythmic gymnastics which are composed of different elements. In addition, acrobatic sports such as trampoline fall under the organizational auspices of gymnastic governing bodies. In artistic gymnastics, female athletes compete in four elements—the uneven or asymmetric bars, the balance beam, the vault, and the floor. Male artistic gymnasts compete in six elements including the vault and the floor which mirror their female counterparts but also the parallel bars, the high bar, the rings, and the pommel horse which have very different loads and mechanics than the balance beam and uneven bars. Rhythmic gymnasts compete as individuals or in groups on a padded floor mat using one of four different pieces of equipment rope, hoop, ball, clubs, ribbon, or in the case of group competitions, combinations of apparatus. Rhythmic gymnasts focus on balance, grace, coordination, and flexibility while simultaneously using one of the above apparatus. In trampoline, athletes launch themselves up to 30 ft in the air while performing twists and flips. Miss-landing on the trampoline surface or completely leaving the field of play can lead to significant or catastrophic injury. While many injuries and problems overlap across each category of gymnastics, each also introduces specific injury patterns secondary to their unique demands.

Most forms of gymnastics involve training that begins at a very young age, typically around 5 or 6 years old. The junior elite gymnasts train on average 21–37 h per week, while the senior elite train up to 40 h per week [1, 3]. Skeletally immature patients have an increased risk of injury during times of rapid growth. Gymnastics requires power, coordination, balance, and flexibility in order to excel at the various skills. These athletes often train year-round without any dedicated rest period, advancing through various competition levels as they train. Due to the format of gymnastics competition, many gymnasts may begin

S. Tayne · L. Bejarano-Pineda
Department of Orthopaedics, University of Illinois at Chicago, Chicago, IL, USA

M. R. Hutchinson (✉)
Department of Orthopedic Surgery, University of Illinois at Chicago, Chicago, IL, USA
e-mail: mhutch@uic.edu

S. Rocha Piedade et al. (eds.), *Specific Sports-Related Injuries*,
https://doi.org/10.1007/978-3-030-66321-6_5

training to advance in one set of skills while competing with another set of skills [4]. If they have not mastered the fundamentals of one skill before advancing to the next, then they are at increased risk of falls or injuries. The most common injuries are usually secondary to repetitive overuse which occur when the athlete is not given enough down time to recover from minor strains and sprains. Continuing to compete and train when injured, places the athlete at an increased risk of even more severe injuries and longer time away from sport to recover. When caring for gymnasts, it is important to navigate the balance of their need to intensely train and their risk of injury.

5.2 Unique Injury Risks and Mechanics of Gymnastics

Artistic gymnastics involves a combination of explosive, balance, and artistic skills [1]. Large impact loads and repetitive high velocity muscle contractions are required both to take off and land in a controlled fashion, leading to a high risk of lower extremity injuries [3, 4]. In addition, the compressive, distractive, and rotational forces of various joints may also increase the risk of injury during skills other than landing [3, 4]. For example, giant swings, a complete 360° around the bar, or catch and release skills, require a significant amount of torque and power from the shoulder joint, leading to increased risk of injury to the labrum, rotator cuff, or ligaments of the shoulder [3]. Many skills require extreme range of motion of the spine, shoulders, and hips, which may predispose to pathology in those anatomic areas, as well [3–5]. For artistic gymnasts, a key factor to consider is the height at which they perform. Potential energy and risk of more severe injury is directly related to height and is directly correlated with the amount of kinetic energy leading to injury during a fall. The high bar for male gymnasts is 9 ft above the ground and the athletes fly 2–3 ft above that. The upper of the uneven bars for women is 8 ft off the ground, and the balance beam is 4 ft off the ground.

Injuries vary depending on the sex, age, and competitive level of the athlete. Younger athletes with open growth plates have risk of growth plate injuries due to repetitive trauma, particularly at the wrist. Lower extremity injuries are more common in female athletes and upper extremity injuries are more common in male athletes, likely due to upper body strength and weight-bearing requirements [6–8]. Surface contact, particularly with the floor apparatus, is the most common injury mechanism [6, 8]. The beam is also commonly associated with injury for female athletes, and the high bar for males [6, 8]. Landings have the highest rates of injury (49–76%), followed by falls and collisions (27.8%), which goes along with the risk of surface contact, as well [6]. Athletes suffer from higher risk of injury during competition though the type of injury also varies depending on whether it occurs during training or competition [8]. Training typically involves chronic, overuse type injuries, while acute, instability type injuries occur during competition [3, 8]. This makes intuitive sense given the psychological component of competition.

While lower extremity injuries are the most common, artistic gymnastics involves a significant amount of upper extremity weight-bearing, which is unique to the sport. A large proportion of training time is spent performing maneuvers on the upper limbs whether during static or dynamic movements. Injury rates have been described up to 50%, especially in male gymnasts [9]. The most common location of injuries of the upper extremity in male and female gymnasts is the shoulder and wrist, respectively. Several studies suggest that more than 80% of the athletes will experience some wrist and elbow pain during the season [10, 11]. Additionally, Grapton et al. showed that forearm injuries were independently related to trampoline skills [12].

For rhythmic gymnasts, the mechanics of injury are more commonly related to repetitive overuse and the sport's demand for extremes of flexibility. The athletes will toss, catch, attain a specific posture, and repeat elements hundreds of times to perfect their skills. If not balanced or inadequate recovery time is allowed, then the risk of overuse injuries rises. Rhythmic gymnastics,

and to some degree women's artistic gymnastics are esthetic sport which awards visual presentation and favors thin athletes. This introduces pressures for the athlete to control weight which in turn places them at risk of Relative Energy Deficit Syndrome or the Female Athlete Triad.

For trampoline and acrobatic gymnasts, skill level plays a significant role in injury patterns. Attempting to perform advanced level skills before a proper, sequential skill development increases the risk of catastrophic injury. Injuries are most commonly related to overuse; however, the incidence of catastrophic injuries is likely higher in trampoline and acrobatic sport [12].

5.3 Epidemiology

Gymnastics is a sport with high participation rates leading proportionately to increased incident of injury. More than 86,000 gymnastic injuries require medical treatment every year [7]. Participation at the Olympic Games includes artistic, rhythmic, and trampoline gymnastics, with approximately 320 gymnasts registered to compete at each Olympic Games, constituting about 3% of all registered athletes [1, 13]. Edouard et al. reported the incidence of injuries in 963 registered gymnasts during three consecutive Olympic Games with 81 injuries per 1000 gymnasts at the highest level of competition. Artistic gymnastics accounted for most of the injuries (60.4%), followed by rhythmic gymnastics (29.7%), and lastly trampoline (9.9%) [1]. In the American collegiate sports system, women's artistic gymnastics was reported to have the second highest prevalence of injuries after American football [14]. The majority of provided epidemiological data refers to female artistic gymnasts, much less is known regarding injury incidence in male gymnastics or rhythmic and trampoline gymnastics.

In artistic gymnastics, injury rates range from 1.6 to 4.1 per 1000 h of training with elite-level athletes presenting more severe injuries [15, 16]. The 1-year incidence of injury is higher in females than males with 3.7 vs. 1.0 injuries per 1000 h, respectively [6]. Conversely, the 1-year prevalence reported for female and male gymnasts are equal at 2.0 injuries per 1000 h of exposure [17]. The injury risk for rhythmic gymnasts was noted to be 1.08 per 1000 h of training [18]. Lower extremity injuries are more common in female athletes and upper extremity injuries are more common in male athletes, likely due to upper body strength and weight-bearing requirements [6–8]. The most frequent reported injury location was the ankle followed by the lumbar spine and knee [19]. In a 10-year observational study by Westermann et al. men's gymnasts were at increased risk of hand and wrist injuries followed by ankle and foot, knee, shoulder, back, and elbow respectfully [20] (Fig. 5.1). Head and neck injuries accounted for 10–15% of injuries. For women gymnasts, the most common anatomic site of injury was foot and ankle followed by knee, low back, shoulder, elbow, hip, and groin respectfully (Fig. 5.2). When comparing men's and women's artistic gymnasts, the men tended to have more upper extremity and head and neck injuries. The type of injuries among gymnasts are usually sprains (34%), followed by articular pathology (17%), contusions (9%), and fractures (7%) [1]. Similarly in rhythmic gymnastics, the most common site of injury was ankle or foot (26–39%) followed by low back (22–25%) and knee (15–20%) [18, 21] (Fig. 5.3). Leg pain accounted for an additional 15–20% of complaints and injuries followed by hip/thigh and wrist/hand. Shoulder/elbow and head/neck were relatively rare in rhythmic gymnasts. Compared to other acrobatic sports, the frequency of knee and forearm injuries are significantly higher in trampoline [1, 12].

The risk of injury during competition is about two times higher than during practice sessions causing a higher number of time-loss from sport injuries [22]. Most of these injuries are acute in nature. Campbell et al. reported the incidence of acute injuries ranged from 55% to 83%, whereas overuse injuries varied from 26% to 41%, respectively. The incidence of recurrent injuries were lower but considerable ranging from 8% to 32% [6, 19].

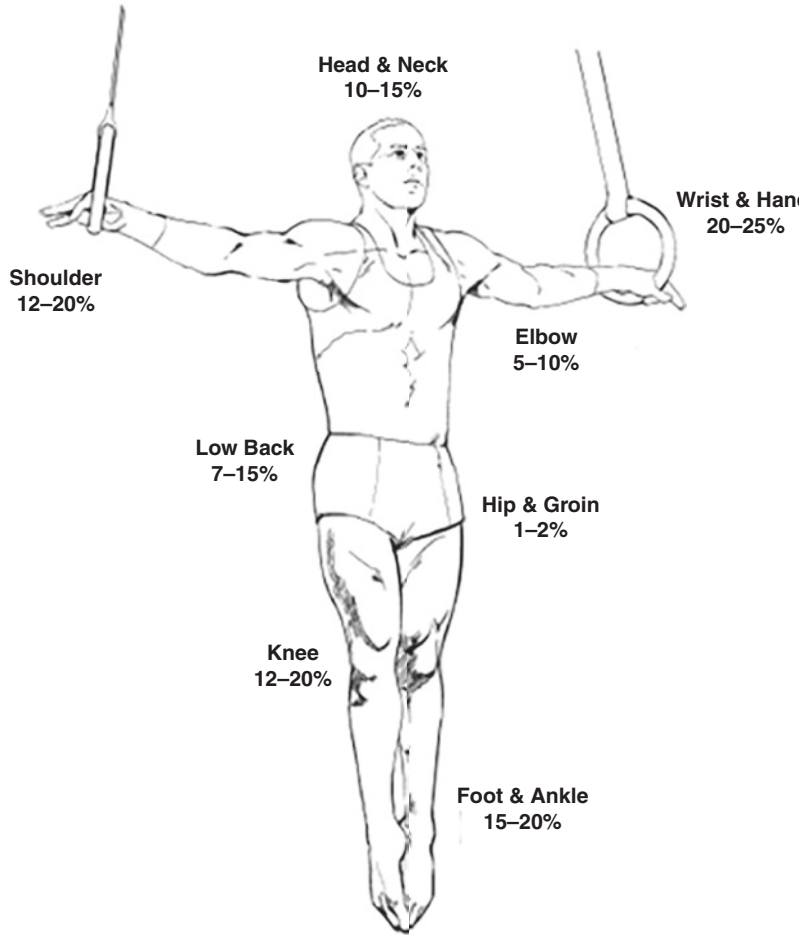

Fig. 5.1 Distribution of injuries by body part in men gymnasts. (© Mark R. Hutchinson, 2021. All Rights Reserved)

5.4 Top Five Injuries Associated with Gymnastics

5.4.1 Ankle Sprains and Strains

The most common reported injury overall in artistic and rhythmic gymnastics is to the lower extremity, specifically sprains of the ankle followed by injuries of the knee [4, 8]. While ankle sprains are the most common injury, injuries to the knee are the most common severe injury requiring surgery [7, 8]. Trampoline skills has been shown to be highly associated with knee injuries, including bony injuries [12]. The mechanism of injury for ankle sprains or knee injuries often stems from incorrect landing, which may occur during a tumbling skill on the floor, skills on the trampoline, a landing from the vault, or from a dismount from the beam or bar [7]. If not stabilized appropriately by the core, or if not absorbing the shock correctly through the knees and hips, injury may occur. Less common injuries of the lower extremity include osteochondral defects of the talus, Osgood Schlatter's, patellofemoral syndrome, or injuries to the hip, such as chondrolabral pathology [5, 8].

The common injuries to the lower extremity, the strains and sprains, particularly of the ankle are treated conservatively with rest, physical therapy, and a guided return to sport. Our recommended treatment and return to sport algorithm is listed in Fig. 5.4. If at any point, the athlete is not progressing as expected, the athlete may need further workup and imaging to rule out fracture, chondral injury, peroneal tendon injury, tarsal coalition, or more severe ligamentous or syndes-

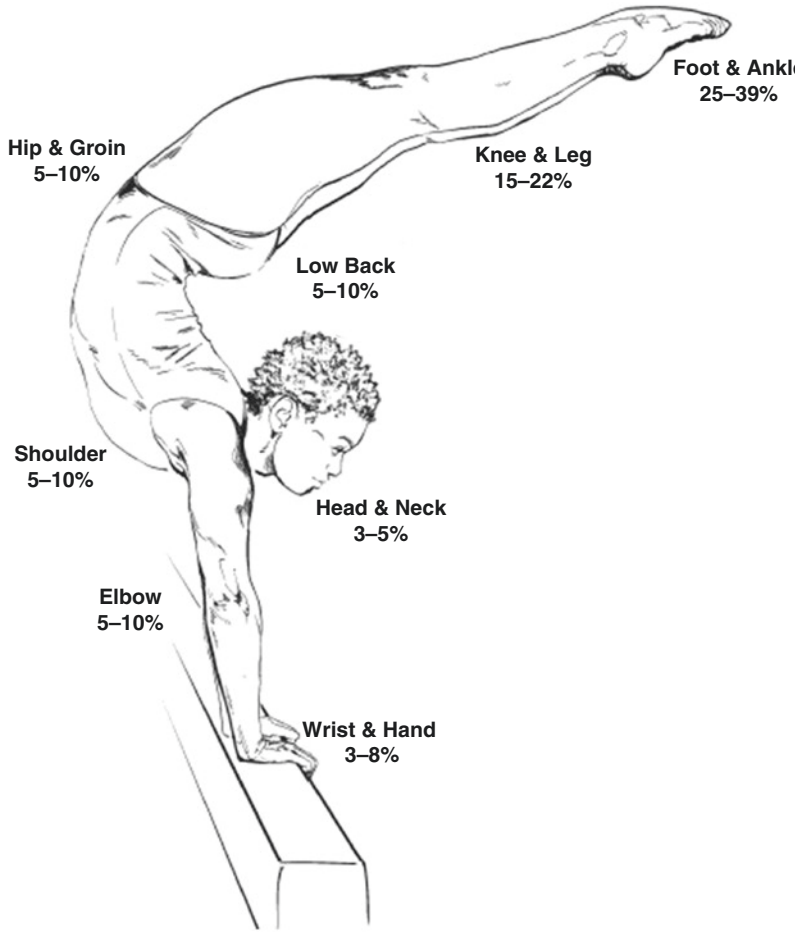

Fig. 5.2 Distribution of injuries by body part in women gymnasts. (© Mark R. Hutchinson, 2021. All Rights Reserved)

motic injury [23–25]. If further workup is negative, the athlete may simply spend more time at the previous step in the algorithm before proceeding. In the acute phase, the athlete will need to rest the extremity and may require limited weight-bearing depending on the severity of the injury. Compressive wraps or stirrup braces may help advance the athlete's progression [23]. The athlete can then progress through physical therapy beginning with range of motion exercises as the swelling decreases, especially since early range of motion has been shown to help with functional outcomes [23]. Therapy should then progress to strengthening and proprioception training, as well as endurance, coordination, and motor control [23, 24]. Ultimately the athlete will begin returning to landing exercises. Once the athlete is prepared to return to gymnastics, he or she should begin with already mastered skills before moving on to more complex movements.

The majority of ankle sprains are treated effectively with conservatively, however up to 20% may develop chronic ankle instability [25]. Surgical treatment is typically not necessary but may be considered in the setting of chronic instability, with a multitude of procedural options depending on the patient and specific injury [23, 25].

5.4.2 Wrist

The wrist is very vulnerable to injuries in male and female gymnasts. Pommel horse and floor exercise are common events causing wrist pain in male gymnasts, whereas floor exercise and vault

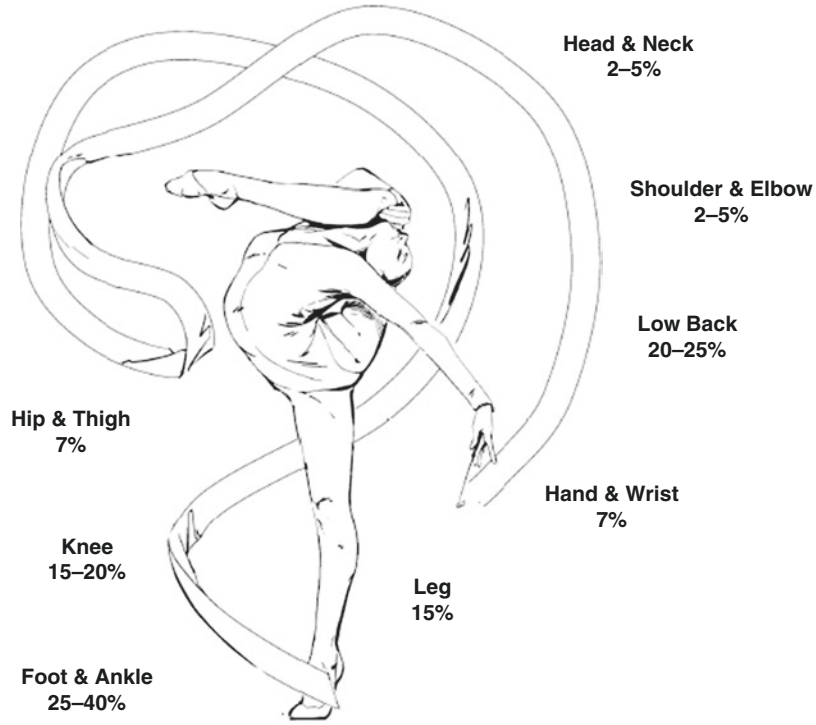

Fig. 5.3 Distribution of injuries by body part in rhythmic gymnastics. (© Mark R. Hutchinson, 2021. All Rights Reserved)

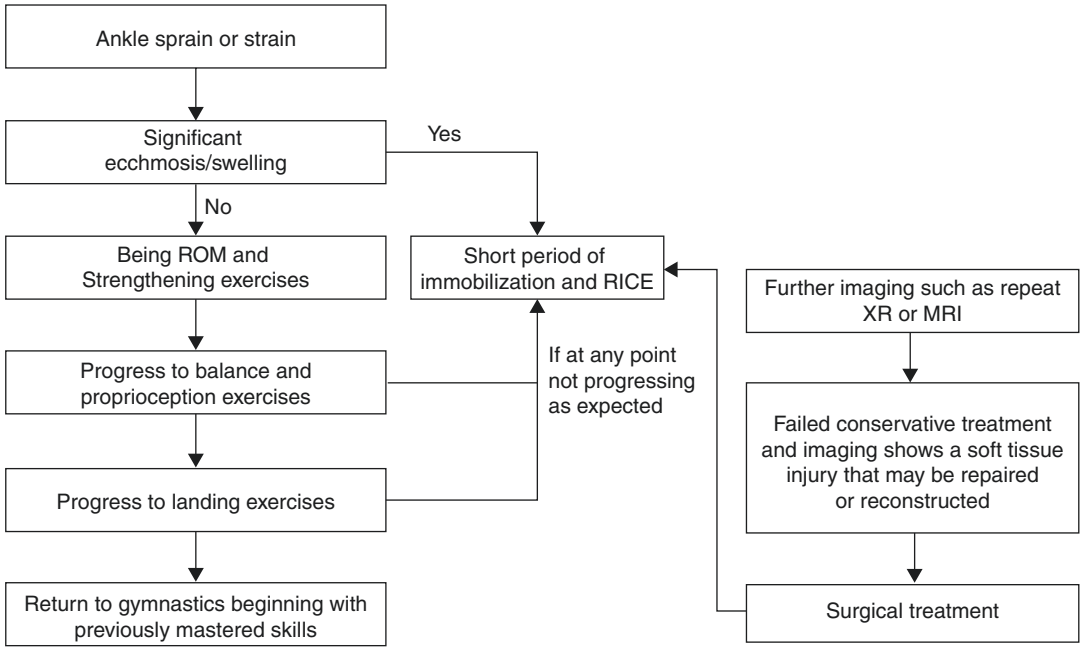

Fig. 5.4 Management of ankle sprain or strain injuries (confirmed no fracture on radiographs). (© Mark R. Hutchinson, 2021. All Rights Reserved)

are the most common in female gymnasts. Rhythmic gymnasts can develop overuse tendinitis secondary to repetitive spirals with the ribbon or when tumbling on the mat. While performing certain skills in gymnastics, the joint experiences forces up to 16 times the body weight making it a common site for injures [11]. The prevalence of wrist pain has been reported as high as 88% in artistic gymnasts [26]. Wrist injuries in gymnasts include distal radial physeal injury, scaphoid stress fracture, triangular fibrocartilage complex (TFCC) tear, grip-lock injuries, ulnar impaction syndrome, and scapholunate dissociation [27].

Distal radial physeal and grip-lock injuries are almost exclusive to artistic gymnastics. Distal radial physis injury occurs in youth athletes with open epiphyseal plates. It results from repetitive compressive loading and shearing forces on the wrist in extension. The distal radius bears about 80% of the axial load during upper extremity weight-bearing activities. In skeletally immature gymnasts, the axial load on the distal radius is higher due to the characteristic negative ulnar variance in this age group [28, 29]. Patients present with chronic dull pain in the dorsal aspect of the wrist. Sport-related activities as floor routines, vaulting or pommel horse precipitates the symptoms. Pain usually is relieved with rest. Chronicity of symptoms should be determined during the assessment, with pain at rest as a sign of severity [27].

Grade of severity is determined by radiographic changes in three stages: stage 1 has an absence of radiographic changes; stage 2 shows cystic changes of the metaphysis and widening of the physis; and in stage 3, there are additional changes in the ulnar variance [7]. Caine et al. described the presence of radiographic abnormalities in 10–85% of gymnastics with distal physeal injury [9]. Magnetic resonance imaging is recommended in the absence of radiographic changes to rule out other causes. The treatment algorithm is shown in Fig. 5.5. For stage 1 and 2 injuries,

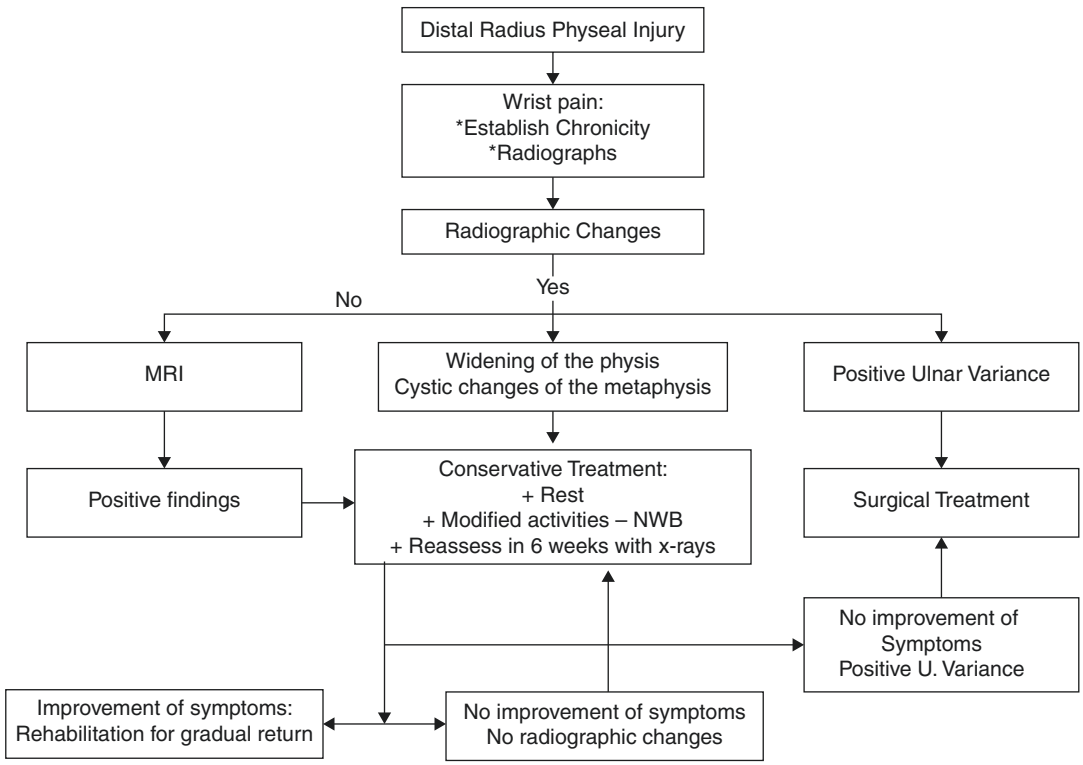

Fig. 5.5 Management of distal radius physeal injury. (© Mark R. Hutchinson, 2021. All Rights Reserved)

treatment is conservative with rest and physical therapy. Rehabilitation should address both upper extremities and focused on strengthening and proprioception. Immobilization using a Gibson brace may help in very symptomatic patients. Reassessment including new radiographs is advised after 6 weeks of treatment to consider progressive increase of training load. Although radiographic changes may take longer to resolve, it is important to monitor patients whose initial radiographs showed significant changes to the physis [2]. Surgery is indicated in advanced cases with stage 3 injuries and positive ulnar variance. Growth arrest is a serious complication in this patient population. Therefore, it is recommended to monitor these patients for at least 1-year post-injury with serial radiographs.

Gymnasts use leather grips or grips with plastic or wooden dowels to protect from friction and increase grip strength. The use of these grips has resulted in a wrist injury called grip-lock injury. This injury occurs when the grip or dowel encircles the bar or a portion of the grip gets caught between the palm and the bar [30]. The gymnast's hand stops rotating, and the body continues moving around the bar, resulting in sprains, tendon injuries, or fractures. Treatment depends on the resulting injury and may require rest and conservative treatment or surgery. Nearly all the patients have reported to return to competition after treatment [27].

Scaphoid stress fractures are commonly reported in elite-level gymnasts, especially in those who rapidly increase of their level of training [31]. Forced hyperextension, radial deviation, and rotation of the wrist generates a significant load over the scaphoid. The majority of these injuries occur at the scaphoid waist, which is the point of greatest bending moment [32]. Scaphoid stress fractures can present in the acute or chronic setting. Patient presents pain over the anatomical snuffbox that is aggravated by extension. The gold standard for diagnosis is MRI. While most injuries can be treated conservatively with good results, with the wrist immobilized in a thumb spica or short arm cast for 8–12 weeks [31], percutaneous fixation may be considered in high-level athletes for earlier rehabilitation and return to sport [33].

5.4.3 Elbow

The high-impact loading of the upper extremity produces high valgus and varus stresses of the elbow during exercises such as bars, tumbling on the floor or trampoline, and landing. Repetitive valgus and varus stress of the elbow results in tension and compression forces over the medial and lateral structures, respectively [7]. The most common elbow injuries are osteochondritis dissecans (OCD) of radiocapitellar joint, ulnar collateral ligament sprains and tears, medial epicondyle apophysitis, or avulsion fractures [34, 35].

Osteochondritis dissecans in the artistic gymnast often involves the capitellum and typically presents between 10 and 14 years of age [36]. Patients present with insidious lateral elbow pain. In more advanced cases, symptoms as catching, locking, or decreased range of motion may be reported. Patients may present with crepitus with range of motion and positive radiocapitellar compression test during the physical exam. Timely diagnosis of capitellar OCD is paramount to avoid premature degenerative changes of the joint [37]. Initial assessment should include three-view plain radiographs including an AP in extension, as well as an AP and lateral in 45° of flexion [38]. Positive findings include lucency of the capitellum, fragmentation and, in advance stages, intra-articular loose bodies. Magnetic resonance imaging is the best modality to evaluate OCD, especially in early-stage lesions with negative radiographs. Treatment is determined by the stability of the lesion, which is shown in the treatment algorithm in Fig. 5.6. Stable lesions have localized flattening, an open physis and adequate range of motion. Conservative treatment is indicated for stable lesions and includes rest and activity modification for 6 months. Outcomes are encouraging with success rates of up to 80% [39]. Unstable lesions consist of intra-articular loose bodies and surgical treatment is indicated in these cases. Athlete may return after achieving full painless range of motion and baseline strength [40].

Ulnar collateral ligament (UCL) injuries are described in artistic gymnasts especially those

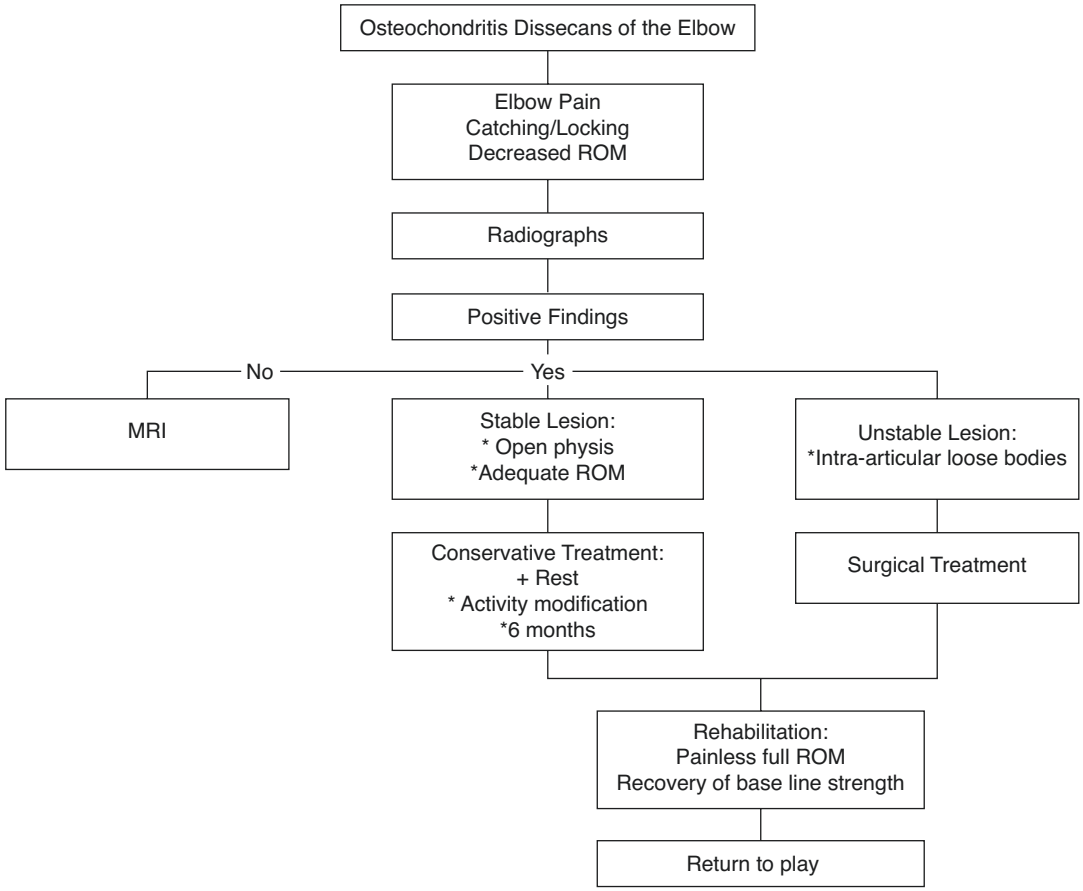

Fig. 5.6 Management of osteochondritis dissecans of the elbow. (© Mark R. Hutchinson, 2021. All Rights Reserved)

with high carrying angles. Repetitive medial tensile stress causes UCL insufficiency or tear. Initial imaging should include AP, lateral, internal/external oblique views, and an oblique axial view with the elbow in 110° of flexion [7]. If medial instability is suspected, MR arthrogram is indicated to evaluate the integrity of the UCL. Partial tears can be treated conservatively with at least 2 months of rest and a progressive strengthening program. Surgical treatment is recommended for complete UCL tear or partial tears that have failed conservative management. The athlete typically cannot return to sport until about 1 year after the procedure, once the athlete has regained full painless range of motion and strength [41].

5.4.4 Shoulder

Shoulder injuries are commonly seen in male's gymnastics and are directly related to the power and repetitive loading demands involved in parallel bars, high bar, pommel horse, and rings. Shoulder injuries include rotator cuff injuries, usually impingement or partial tears, and instability, both chronic and acute [42, 43]. Multidirectional shoulder instability is a unique overuse injury with a high incidence among gymnasts [43]. The hyperlaxity of the athlete and the extreme positions and forces across the shoulder in gymnastics leads to continued microtrauma and plastic deformation of the ligaments. When examining athletes with shoulder pain, signs of

generalized laxity, such as the Beighton score, should be assessed. Other specific shoulder tests include apprehension, relocation, load and shift, and Jerk and Kim tests [42]. Initial treatment for many shoulder symptoms consists of periods of rest and restriction from overhead activities. The athlete should have full painless range of motion and full strength before returning to training or competition [44].

5.4.5 Low Back Injuries

Low back pain has been reported in up to 50% of artistic gymnasts and up to 86% of rhythmic gymnasts [21, 45]. Low back pain is the cited as either the most common or second most common injury in rhythmic gymnastics, with one prospective study showing that elite rhythmic gymnasts have an increased relative risk of low back pain compared to other athletes [46]. Young gymnasts have a high incidence of structural pathology related to low back pain, as rapid growth of bone outpaces the growth of soft tissues, including the musculature and ligaments, which may lead to injury at vulnerable areas of growth cartilage and secondary ossification centers [21]. Both artistic and rhythmic gymnasts are at risk for spondylosis and spondylolisthesis due to the repetitive extreme motion, particularly hyperextension, and due to the stresses placed on the lumbar spine, with the spine seeing 6.5–9.2 times their body weight [7, 21, 47]. Though less common, other causes for back pain in gymnasts may include muscle strain, injury to a vertebral body, injury to an intervertebral disc, injury to articular processes, spinous processes, interspinous ligament, or ring apophysis [47].

Differentiating between spondylosis/spondylolisthesis and the other various causes of low back pain begins with physical exam, including pain with single stance extension and point tenderness, but can be confirmed radiographically. The radiographic incidence of spondylosis has previously been found to be as high as 11–16% [7]. Low back pain, spondylosis, and low grade spondylolisthesis are usually treated conservatively with rest for 3–6 months, bracing, and physical therapy [45, 47, 48]. Therapy should address strengthening lumbar extensors, abdominal muscles, as well as range of motion of the lumbar spine and lower extremities [45, 49]. Young patients may also need to followed radiographically to confirm that there is no progression of the slip [45, 47]. The treatment algorithm for low back pain is presented in Fig. 5.7.

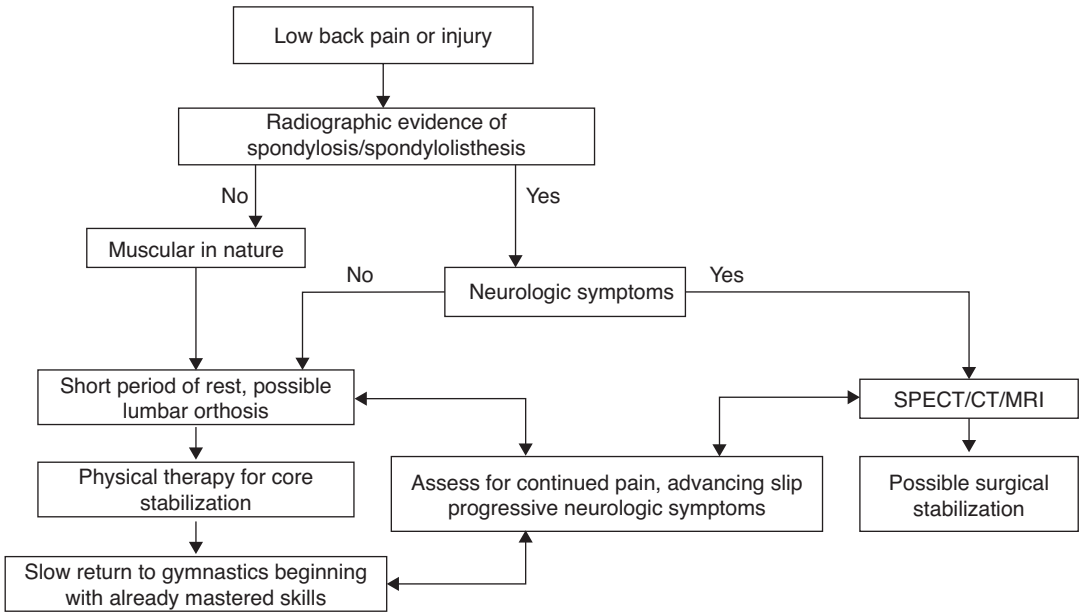

Fig. 5.7 Management of low back pain or injuries. (© Mark R. Hutchinson, 2021. All Rights Reserved)

The algorithm differentiates immediately between low back pain with and without neurologic symptoms. If neurologic symptoms are present, or become present at any time, advanced imaging such as SPECT, CT, or MRI should be obtained. SPECT is best for early diagnosis of spondylosis, while CT is best to assess healing. The athlete should not return to training and competition until completely without symptoms. Additionally, psychosocial factors should be considered in return to play, especially for athletes with back pain and given the high demands placed on young gymnasts [47–49].

Rarely, if pain continues, a slip advances, or neurologic symptoms occur, surgical intervention may be required [7]. Spinal fusion for discogenic back pain is incredibly rare in athletes and is not typically well tolerated; therefore, there is little data on return to play following surgical treatment [45, 47]. Surgical treatment for spondylosis or spondylolisthesis is in situ fusion with autogenous bone graft, and a large majority are able to return to sport with extensive post-operative therapy [48].

More severe or catastrophic injuries of the low back, cervical spine, or head are relatively rare; nonetheless, every safety intervention regarding prevention must be made to avoid them. Collegiate gymnastics and cheerleading account for many of the catastrophic injuries in female sports. The risk is highest when learning a new skill, especially if with inadequate supervision, however is mitigated during training by the use of foam pits, harnesses, and spotters, especially when learning new techniques [8, 47]. If there is concern for an acute head or neck injury, the athlete should immediately be removed from training or competition. Evaluation with imaging or concussion testing should be performed, and further testing determined by those results and the athlete's symptoms. Concussions are the most common injury of the head and neck in gymnastics, which will require removal from training and competition as the athlete completes a concussion-specific return to sport protocol [7]. Athletes must undergo full rehabilitation of balance and any vestibular-ocular deficits before returning training, especially with the twisting and inverting aspects of the sport [7].

5.5 Prevention

Targeting injury prevention in artistic and rhythmic gymnastics as well as trampoline should follow a logical, stepwise approach that is evidenced-based and balances the need for athletes to compete at their highest level with the risk of time-loss from injury. Convincing coaches that injury prevention is important, and often hinges on their understanding of their risk of losing the athlete from performance at the most critical time of competition. In 1992, Willem van Mechelen outlined a logical model that continues to guide prevention strategies nearly 30 years later [50]. First, the extent, incidence, and severity of the injury problem must be established. For gymnastics, this is outlined above in discussing both epidemiology and injury patterns. Next, a fundamental understanding of the etiology and mechanism of injury is essential for creating prevent protocol. For both artistic and rhythmic gymnastics, an important risk factor is the number of repetitions associated with training and competition as well as the timing and intensity of that loading. Another key risk factor is related to acute traumatic events due to falls, landings, and loss of body control while in awkward positions. For trampoline athletes, trained spotters should always be present using a deceleration mat or being able to catch an athlete who leaves the playing field. The third step of van Mechelen's model of injury prevention is the introduction of a targeted intervention that is based on the knowledge gained from steps one and two. The final step is an assessment of the impact of each intervention. Avoiding time-loss from sport and competition, minimizing the expense of injury treatment, and limiting the risk of long-term disability compels the need to invest in preventive measures [50].

Gymnastic equipment has been continuously updated and refined. However, this process has taken place very slowly due to the significant expense and the worldwide nature of the sport. Female gymnasts compete on four apparatuses in artistic gymnastics: floor exercise, vault, balance beam, and uneven bars. The floor exercise is the event where most injuries occur. The floor itself

is made of fiberglass or wooden panels placed over springs. The panels are covered with about 5 cm of foam padding. Thinner mats, gaps between landing mats, and hard tumbling surfaces are predisposing factors to injury. The vault horse has also undergone modifications including more padding and a height raise to provide a more optimum platform for the upper extremities. In the past, the rails of the uneven bars were made of solid wood and would break relatively frequently. The newer rails are composed of a layer of wood laminated on fiberglass tubes, which is sturdier and more elastic [51]. Trampolines need to be routinely evaluated for safety and security. Poorly equipped or designed training facilities have been associated with a higher incidence of injuries [52, 53]. Training aids such as foam pits, trampolines, spotting belts, and bungee devices have been added to reduce the risk of injury and enhance the mastering of new skills.

Elite gymnasts practice from 30 to 40 h per week and up to all 12 months per year. National level gymnasts perform between 700 and 1300 elements per day, corresponding to 220,000 to 400,000 elements per year [51]. Gymnastics training is performed in systematic phases consisting of: general preparatory, specific preparatory, precompetitive, and competitive. Higher incidence of injuries have been reported during the onset of training after an enforced break, during competition, or during the initial preparatory phase [54]. This is likely the result of sudden increase in the training load or intensity that predisposes the athlete to injury. Pettrone et al. reported fatigue as a major contributing factor to injury in clubs with training schedules that exceeded more than 20 h a week [55]. To reduce the risk of injuries related to overuse and loading, gymnasts should be provided with adequate opportunity for cross training and rest. Baseline fitness and training intensity should be carefully monitored on a weekly basis. Rapid increases in training intensity should be avoided.

Another potential injury risk for gymnasts occurs when they attempt new or advanced skills which they might not be fully prepared for. If the athlete has underlying motor imbalances, poor coordination, prior incompletely rehabilitated injuries, or simply inadequate skill levels to attempt a new element, they are at increased risk of injury. To decrease the frequency of injuries, it is recommended that each gymnast is prescreened to identify subtle motor skills or balance dysfunction that is either their baseline, related to training or related to prior injuries. When recognized, the abnormalities should be treated with targeted rehabilitation. Once the imbalance or dysfunction is corrected, then the athlete should be allowed to gradually return to play that implements training strategies and a gradual acquisition of skills that is guided by both the coach in communication with the sports medicine professional.

Landing from dismounts, tumbling runs on the floor or trampoline, and vaults place elevated loads on each segment of the lower extremity kinetic chain. With a perfect, well-aligned landing, sequential load-sharing usually allows a successful landing without injury. However, when the athlete lands awkwardly, severe loads can occur at the ankle, knee, or hip leading to a fall and injury. Injury prevention should not only include a gradual and sequential skill acquisition, but also assure that single limb balance and neuromuscular and proprioception training are optimized [23]. The incidence of the common ankle sprain can be minimized by including proprioceptive training into the warm-up program as well as early recognition and treatment of event mild sprains. Since learning new trampoline skills has a high risk of injury, guidelines for safe practice and injury prevention includes dedicated instruction by a qualified instructor prior to attempt at a new skill, all new skill attempts should be performed under direct supervision of a qualified instructor, and athletes should perform skills one at a time [56, 57]. Good control of the core and lower extremity flexibility play a crucial role in injury prevention of both the lower extremity and lumbar spine [7]. Low back pain can be addressed by not only optimizing core strength and balance but also by working with coaches to reduce the total number lumbar hyperextension elements when possible or gradually introducing hyperextension elements into the

routine while controlling the number of repetitions when necessary.

In addition, the risk of overuse and more significant injuries can also be minimized by optimizing energy balance for gymnasts as well as early identification of relative energy deficits appropriate intervention and treatment. Energy balance should be routinely self-assessed in all gymnasts assuring appropriate energy intake for their caloric demand and preventing the occurrence zzzzz musculoskeletal injuries such as stress fractures which have been correlated with relative energy deficit and the female athlete triad.

A baseline and continued reassessment of fitness is an important tool in injury prevention. Optimizing general fitness in combination with skill training helps to prepare the gymnast for the high-volume training involved in gymnastics. The gymnastics Functional Measurement Tool (GFMT) is a series of ten sport-specific tests that evaluates the physical fitness of female artistic gymnasts. The tests include rope climb, vertical jump, agility sprint time, and handstand hold time, among others [58, 59]. Ling et al. performed a study in NCAA division I women's artistic gymnastics to determine if the total score on the GFMT can identify gymnasts who are at risk of developing injury. A higher score on the vertical jump test was associated with less trunk injuries. A one-unit increase in vertical jump score was associated with a 30% decrease in trunk injuries [58]. Similarly, in rhythmic gymnastics a program used a jump training program in elite rhythmic gymnasts to improve their leaping ability [60]. In this study, those that underwent the training program that included water training and Pilates improved their leaping ability in terms of height, ground reaction time, and explosive force without the occurrence of injury [60].

Further research including gymnastics-specific testing during the preseason and subsequent injury is recommended to identify risk factors and prevention strategies in the sport. Ultimately, performance optimization programs can be created to improve or build upon gymnastics skills that simultaneously address injury prevent injury. Additional programs or training programs should be created and tested for various skills to improve gymnast's abilities while maintaining safety.

Conclusion

Gymnastics is an exciting but incredibly demanding sport with large popularity worldwide. Artistic gymnastics features explosive power, strength, and torque, combined with extremes of flexibility and balance. Rhythmic gymnastics features grace, balance, coordination, and flexibility. Trampoline demonstrates exciting acrobatics and great heights. Each category of gymnastics has its own unique injury patterns with repetitive overuse as a mechanism pervasive across all categories. Both artistic and rhythmic gymnasts have a high degree of lower extremity injuries, such as sprains and low back injuries. Artistic gymnastics, particularly among male gymnasts, has an increased risk of upper extremity injuries compared to other sports. The injury patterns in trampoline mirror those in artistic gymnastics but appear to have an increased risk of forearm injuries or catastrophic injuries due to the potential energy related to the height the athlete achieves. The relative young age of many gymnasts also increases risk of growth plate injuries. Injury prevention programs should be logical, evidenced-based, and effectively target the most common injury patterns or time-loss injuries in a given sport. For all gymnasts, this should include: optimized and complete rehabilitation of prior injuries; a well-maintained, safe environment of training and competition; attention to loading, training intensity, and fatigue to avoid overuse; and targeted programs to common injuries including landing mechanics and proprioceptive training to avoid ankle and lower extremity injuries as well as core strength and flexibility to avoid lumbar spine injuries.

References

1. Edouard P, Steffen K, Junge A, Leglise M, Soligard T, Engebretsen L. Gymnastics injury incidence during the 2008, 2012 and 2016 Olympic Games: analysis of prospectively collected surveillance data from 963 registered gymnasts during Olympic Games. Br J Sports Med. 2018;52(7):475–81.
2. Benjamin HJ, Engel SC, Chudzik D. Wrist pain in gymnasts: a review of common overuse wrist pathology in the gymnastics athlete. Curr Sports Med Rep. 2017;16(5):322–9.
3. Hinds N, Angioi M, Birn-Jeffery A, Twycross-Lewis R. A systematic review of shoulder injury prevalence, proportion, rate, type, onset, severity, mechanism and risk factors in female artistic gymnasts. Phys Ther Sport. 2019;35:106–15.
4. Sweeney EA, Howell DR, James DA, Potter MN, Provance AJ. Returning to sport after gymnastics injuries. Curr Sports Med Rep. 2018;17(11):376–90.
5. Bolia I, Utsunomiya H, Locks R, Briggs K, Philippon MJ. Twenty-year systematic review of the hip pathology, risk factors, treatment, and clinical outcomes in artistic athletes-dancers, figure skaters, and gymnasts. Clin J Sport Med. 2018;28(1):82–90.
6. Campbell RA, Bradshaw EJ, Ball NB, Pease DL, Spratford W. Injury epidemiology and risk factors in competitive artistic gymnasts: a systematic review. Br J Sports Med. 2019;53(17):1056–69.
7. Desai N, Vance DD, Rosenwasser MP, Ahmad CS. Artistic gymnastics injuries; epidemiology, evaluation, and treatment. J Am Acad Orthop Surg. 2019;27(13):459–67.
8. Hart E, Meehan WP, Bae DS, d'Hemecourt P, Stracciolini A. The young injured gymnast: a literature review and discussion. Curr Sports Med Rep. 2018;17(11):366–75.
9. Caine DJ, Nassar L. Gymnastics injuries. Med Sport Sci. 2005;48:18–58.
10. Caine D, Roy S, Singer KM, Broekhoff J. Stress changes of the distal radial growth plate. A radiographic survey and review of the literature. Am J Sports Med. 1992;20(3):290–8.
11. DiFiori JP, Puffer JC, Aish B, Dorey F. Wrist pain, distal radial physeal injury, and ulnar variance in young gymnasts: does a relationship exist? Am J Sports Med. 2002;30(6):879–85.
12. Grapton X, Lion A, Gauchard GC, Barrault D, Perrin PP. Specific injuries induced by the practice of trampoline, tumbling and acrobatic gymnastics. Knee Surg Sports Traumatol Arthrosc. 2013;21(2):494–9.
13. Kolt GS, Caine DJ. Epidemiology of injury in Olympic sports. 1st ed. Wiley-Blackwell: Oxford, UK; 2009. 536 p.
14. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. J Athl Train. 2007;42(2):311–9.
15. Kolt GS, Kirkby RJ. Epidemiology of injury in elite and subelite female gymnasts: a comparison of retrospective and prospective findings. Br J Sports Med. 1999;33(5):312–8.
16. Caine D, Cochrane B, Caine C, Zemper E. An epidemiologic investigation of injuries affecting young competitive female gymnasts. Am J Sports Med. 1989;17(6):811–20.
17. Dixon M, Fricker P. Injuries to elite gymnasts over 10 yr. Med Sci Sports Exerc. 1993;25(12):1322–9.
18. Cupisti A, D'Alessandro C, Evangelisti I, Umbri C, Rossi M, Galetta F, et al. Injury survey in competitive sub-elite rhythmic gymnasts: results from a prospective controlled study. J Sports Med Phys Fitness. 2007;47(2):203–7.
19. Bak K, Kalms SB, Olesen S, Jargensen U. Epidemiology of injuries in gymnastics. Scand J Med Sci Sports. 1994;4(2):148–54.
20. Westermann RW, Giblin M, Vaske A, Grosso K, Wolf BR. Evaluation of men's and women's gymnastics injuries. Sports Health. 2015;7(2):161–5.
21. Purcell L, Micheli L. Low back pain in young athletes. Sports Health Multidiscip Approach. 2009;1(3):212–22.
22. Marshall SW, Covassin T, Dick R, Nassar LG, Agel J. Descriptive epidemiology of collegiate women's gymnastics injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. J Athl Train. 2007;42(2):234–40.
23. Shawen SB, Dworak T, Anderson RB. Return to play following ankle sprain and lateral ligament reconstruction. Clin Sports Med. 2016;35(4):697–709.
24. Vancolen SY, Nadeem I, Horner NS, Johal H, Alolabi B, Khan M. Return to sport after ankle syndesmotic injury: a systematic review. Sports Health Multidiscip Approach. 2019;11(2):116–22.
25. Giannini S, Ruffilli A, Pagliazzi G, Mazzotti A, Evangelisti G, Buda R, et al. Treatment algorithm for chronic lateral ankle instability. Muscles Ligaments Tendons J. 2015;4(4):455–60.
26. Webb BG, Rettig LA. Gymnastic wrist injuries. Curr Sports Med Rep. 2008;7(5):289–95.
27. Wolf MR, Avery D, Wolf JM. Upper extremity injuries in gymnasts. Hand Clin. 2017;33(1):187–97.
28. Hafner R, Poznanski AK, Donovan JM. Ulnar variance in children—standard measurements for evaluation of ulnar shortening in juvenile rheumatoid arthritis, hereditary multiple exostosis and other bone or joint disorders in childhood. Skelet Radiol. 1989;18(7):513–6.
29. Palmer AK, Werner FW. Biomechanics of the distal radioulnar joint. Clin Orthop. 1984;(187):26–35.
30. Samuelson M, Reider B, Weiss D. Grip lock injuries to the forearm in male gymnasts. Am J Sports Med. 1996;24(1):15–8.
31. Matzkin E, Singer DI. Scaphoid stress fracture in a 13-year-old gymnast: a case report. J Hand Surg. 2000;25(4):710–3.

32. Weber ER, Chao EY. An experimental approach to the mechanism of scaphoid waist fractures. J Hand Surg. 1978;3(2):142–8.
33. Nakamoto JC, Saito M, Medina G, Schor B. Scaphoid stress fracture in high-level gymnast: a case report. Case Rep Orthop [Internet]. 2011 [cited 2020 Jan 20];2011. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3504270/.
34. Saluan P, Styron J, Ackley JF, Prinzbach A, Billow D. Injury types and incidence rates in precollegiate female gymnasts: a 21-year experience at a single training facility. Orthop J Sports Med. 2015;3(4):2325967115577596.
35. Overlin AJF, Chima B, Erickson S. Update on artistic gymnastics. Curr Sports Med Rep. 2011;10(5):304–9.
36. Dexel J, Marschner K, Beck H, Platzek I, Wasnik S, Schuler M, et al. Comparative study of elbow disorders in young high-performance gymnasts. Int J Sports Med. 2014;35(11):960–5.
37. Bauer M, Jonsson K, Josefsson PO, Lindén B. Osteochondritis dissecans of the elbow. A long-term follow-up study. Clin Orthop. 1992;(284):156–60.
38. Churchill RW, Munoz J, Ahmad CS. Osteochondritis dissecans of the elbow. Curr Rev Musculoskelet Med. 2016;9(2):232–9.
39. Mihara K, Tsutsui H, Nishinaka N, Yamaguchi K. Nonoperative treatment for osteochondritis dissecans of the capitellum. Am J Sports Med. 2009;37(2):298–304.
40. Baker CL, Romeo AA, Baker CL. Osteochondritis dissecans of the capitellum. Am J Sports Med. 2010;38(9):1917–28.
41. Dugas J, Chronister J, Cain EL, Andrews JR. Ulnar collateral ligament in the overhead athlete: a current review. Sports Med Arthrosc Rev. 2014;22(3):169–82.
42. Levine WN, Prickett WD, Prymka M, Yamaguchi K. Treatment of the athlete with multidirectional shoulder instability. Orthop Clin North Am. 2001;32(3):475–84.
43. Caplan J, Julien TP, Michelson J, Neviaser RJ. Multidirectional instability of the shoulder in elite female gymnasts. Am J Orthop Belle Mead NJ. 2007;36(12):660–5.
44. Gaskill TR, Taylor DC, Millett PJ. Management of multidirectional instability of the shoulder. J Am Acad Orthop Surg. 2011;19(12):758–67.
45. Lawrence JP, Greene HS, Grauer JN. Back pain in athletes. J Am Acad Orthop Surg. 2006;14(13):726–35.
46. Hutchinson MR. Low back pain in elite rhythmic gymnasts. Med Sci Sports Exerc. 1999;31(11):1686–8.
47. Kruse D, Lemmen B. Spine injuries in the sport of gymnastics. Curr Sports Med Rep. 2009;8(1):20–8.
48. Haus BM, Micheli LJ. Back pain in the pediatric and adolescent athlete. Clin Sports Med. 2012;31(3):423–40.
49. Standaert CJ, Herring SA, Pratt TW. Rehabilitation of the athlete with low back pain. Curr Sports Med Rep. 2004;3(1):35–40.
50. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. Sports Med Auckl NZ. 1992;14(2):82–99.
51. Sands WA. Injury prevention in women's gymnastics. Sports Med Auckl NZ. 2000;30(5):359–73.
52. Lowry CB, Leveau BF. A retrospective study of gymnastics injuries to competitors and noncompetitors in private clubs. Am J Sports Med. 1982;10(4):237–9.
53. Bale P, Goodway J. Performance variables associated with the competitive gymnast. Sports Med Auckl NZ. 1990;10(3):139–45.
54. Sands WA, Shultz BB, Newman AP. Women's gymnastics injuries. A 5-year study. Am J Sports Med. 1993;21(2):271–6.
55. Pettrone FA, Ricciardelli E. Gymnastic injuries: the Virginia experience 1982–1983. Am J Sports Med. 1987;15(1):59–62.
56. Esposito PW, Esposito LM. The reemergence of the trampoline as a recreational activity and competitive sport. Curr Sports Med Rep. 2009;8(5):273–7.
57. Trampolines at home, school, and recreational centers. American Academy of Pediatrics. Committee on Injury and Poison Prevention and Committee on Sports Medicine and Fitness. Pediatrics. 1999;103(5 Pt 1):1053–6.
58. Ling D, Sleeper M, Casey E. Identification of risk factors for injury in women's collegiate gymnastics with the gymnastics functional measurement tool. PM R. 2020;12(1):43–8.
59. Sleeper MD, Kenyon LK, Casey E. Measuring fitness in female gymnasts: the gymnastics functional measurement tool. Int J Sports Phys Ther. 2012;7(2):124–38.
60. Hutchinson MR, Tremain L, Christiansen J, Beitzel JE. Improving leaping ability in elite rhythmic gymnasts. Med Sci Sports Exerc. 1998;30:1543.