Imaging of Triathlon Injuries

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The modern triathlon is a race in which athletes swim, cycle, and run in succession, and their overall time includes the transition time between each sport. Triathlons have become a popular athletic event both in the United States and worldwide. In the United States there are about 300,000 athletes performing triathlons every year, with more than 1000 races, including approximately 15 Ironman-length events per year.1,2

Triathlon races can be variable in length, ranging from a “sprint triathlon,” to the longer Olympic length, to Ironman, and to even ultradistance. These races became popular after the original Hawaii Ironman Triathlon was established to combine into a single race the Waikiki 2.4-mile “Roughwater swim,” a 112-mile bike race around Oahu, and a 26.2-mile marathon. However, the most popular triathlons are the shorter sprint triathlons, which usually involve a 750-m swim, a 20-km cycling course, and a 5-km run. Although termed a “sprint,” this race is really an endurance event, which requires training and stamina.

INJURY OVERVIEW

The modern triathlon was devised by runners who were cross-training in swimming and cycling to provide a variety to their workouts and to reduce overuse injuries due to running.2 When the first triathlons began, many believed that training in the 3 disciplines would mean fewer injuries than in athletes who train in a single sport. In fact, overuse injuries among triathletes are more common than injuries in single-sport athletes.1,3–5 This higher incidence is thought to be for 2 reasons. First, triathletes train for more hours on average than single-sport athletes, averaging 10 to 14 hours of training per week.6,7 As discussed in this article, the 3 disciplines can contribute to some of the same overuse injuries. Second, triathletes sometimes have poorer technique or equipment than dedicated single-sport athletes, which has been shown to predispose them to more overuse injuries.1,2 An example is the distance runner who decides to train for an Ironman triathlon but has a poorly fitted bike and develops patellar tendinosis.

There are several medical issues that can occur in people either training for or racing in a triathlon (Box 1). In this article, the main focus is on those musculoskeletal injuries that may require medical imaging.

About 90% of actively training triathletes will have an acute or overuse injury over the course of the year.3,8,9 An injury is typically defined as a musculoskeletal symptom that causes an unplanned stop in training or failure to complete a race, or leads the individual to seek medical care.1,2 Acute injuries in triathletes include, for instance, an acromioclavicular (AC) joint separation from falling off a bike. Overuse injuries have an insidious onset and are much more common in triathletes, representing 75% to 80% of injuries.1,2,6 Overuse injuries usually occur during training, but 15% to 25% of injuries either present during a race or are exacerbated during the race to a point that it forces the athlete to discontinue.1,2,6

The most common site of injury in a triathlete is the knee, accounting for over a quarter of all injuries.1,2,6,10 Foot, ankle, lumbar spine, and shoulder injuries are also common (Table 1). Although overlap exists, the 3 different sports tend to be associated with somewhat distinct injuries. Running has the highest triathlete injury...
rate and swimming the lowest (Fig. 1), although most of the training hours are typically spent cycling.\textsuperscript{1,2,11}

In this article, the imaging appearance of injuries in triathletes commonly seen with each of the 3 sports is discussed. The authors highlight those injuries that are associated with more than one of the disciplines, which often lead to the triathlete seeking medical care because they significantly affect their training regimen. This article also discusses injuries that tend to occur with one sport but are then exacerbated by training in the other disciplines.

SWIMMING

Acute injuries are rare during swim training or during the swim leg of a triathlon.\textsuperscript{1,2,6,8} One of the most serious concerns is drowning, because triathletes often train and compete in open water where the underwater visibility is poor.\textsuperscript{12} Acute musculoskeletal injuries from shark attacks have also been described in triathletes training in the ocean (http://www.msnbc.msn.com/id/24313314/).

Overuse injuries from swimming are less common than injuries from cycling and running, accounting for only 5\% to 10\% of injuries in triathletes.\textsuperscript{1,2,13} Most clinical complaints are of shoulder tendinitis and impingement pain.\textsuperscript{1,2,14} The swimming motion involves repetitive extremes of abduction, flexion, and extension, and “swimmer’s shoulder” is common in competitive swimmers. Swimmer’s shoulder refers to a combination of rotator cuff tendinosis/impingement and laxity from stretched anterior glenohumeral ligaments.\textsuperscript{15} Shoulder impingement pain in triathletes can be exacerbated during cycling when using aerobars, in which the cyclist leans forward and rests the elbows on a pad to maintain an aerodynamic position. This position causes the humeral head to compress against the supraspinatus tendon and subacromial bursa, and may aggravate impingement symptoms.

In one of the few imaging articles on triathletes, shoulder magnetic resonance (MR) imaging findings of triathletes at the Hawaii Ironman Race were assessed.\textsuperscript{14} These investigators performed MR imaging scans on athletes with shoulder symptoms and found rotator cuff tendinopathy in 50\%, AC joint marrow edema in 62\%, and partial

Box 1
Examples of injuries and illnesses in triathletes

Nonmusculoskeletal
- Dehydration
- Hyperthermia
- Blisters
- Abrasions
- Muscle cramps
- Female athletic triad (anorexia, amenorrhea, osteoporosis)

Musculoskeletal, nonimaged
- Short-duration low back pain
- Muscle strains
- Ulnar neuropathy (cyclist’s palsy)

Musculoskeletal, imaged
- Rotator cuff impingement
- Stress fractures
- Tendinosis
- Plantar fasciitis
- Radiculopathy
- Osteitis pubis
- Meniscal tear
- Iliotibial band syndrome

Table 1
Site and percentage of injuries in triathletes

<table>
<thead>
<tr>
<th>Site</th>
<th>Percentage of All Injuries (%)</th>
</tr>
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<tbody>
<tr>
<td>Foot</td>
<td>10–15</td>
</tr>
<tr>
<td>Ankle</td>
<td>10–15</td>
</tr>
<tr>
<td>Lower leg</td>
<td>5–10</td>
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<tr>
<td>Knee</td>
<td>25–30</td>
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<tr>
<td>Thigh</td>
<td>5–10</td>
</tr>
<tr>
<td>Hip/groin</td>
<td>5–10</td>
</tr>
<tr>
<td>Shoulder</td>
<td>10–15</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>10–15</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 1. Percentage of injuries in triathletes that occur from the 3 sports.
thickness rotator cuff tears in 19%. From MR imaging, tendinopathy was defined as abnormal signal intensity on short echo-time (TE) images without a defect in the tendon on fluid-sensitive sequences (Fig. 2). Partial-thickness rotator cuff tears were defined as high-signal defects in the tendon on T2-weighted images (Fig. 3). In this study, 29% of asymptomatic triathletes also had rotator cuff tendinopathy, 71% had AC marrow edema, and 29% had partial-thickness rotator cuff tears on MR imaging (Fig. 4). It is difficult to know if these MR imaging abnormalities are actually the cause of shoulder symptoms or if many triathletes ignore minor shoulder pain.

**CYCLING**

Cycling injuries are relatively uncommon, considering the number of hours triathletes spend on the bike, but they are more common than swimming injuries and represent 10% to 20% of injuries.1,2,6 Acute injuries during cycling are mainly falls from a bike, with about one-third of triathletes experiencing a fall each year. The most common time to fall is during a race, occurring in 1 out of every 250 competitors. This incidence is probably a result of the higher speeds during the race, and cycling more aggressively down hills and around turns.

Although most falls result only in abrasions and contusions, more serious injuries such as head trauma can also occur. The most common musculoskeletal injury after a fall is to the shoulder, mainly clavicle fractures and dislocations of the AC or glenohumeral joint (Fig. 5).1,2,6 Serious triathletes become accustomed to training despite pain, so even grade 1 AC separations can progress to chronic injuries if they are not rested, leading to posttraumatic osteolysis (Fig. 6).

The most common site for overuse injuries during cycling is at the knee. Knee injuries are more common if a bike is not properly fitted, such as with a seat positioned too low or too far forward for the size of the rider.2 The major overuse injuries around the knee are patellar tendinosis, patellofemoral stress syndrome, and ITBS, all 3 of which can also occur from running.16 Patellar tendinosis is the most common cause of anterior knee pain during cycling, and results from the

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**Fig. 2.** A 39-year-old man with shoulder pain when swimming and lifting weights. Oblique coronal fat-suppressed T2-weighted MR image shows increased signal within the supraspinatus tendon (arrow) consistent with rotator cuff tendinopathy. The finding is common in symptomatic and asymptomatic triathletes.

**Fig. 3.** A 38-year-old man with shoulder pain while training for a triathlon. (A) Oblique coronal fat-suppressed T1-weighted MR arthrogram image shows contrast extending into the articular surface of the supraspinatus tendon (arrow). (B) Oblique sagittal fat-suppressed T1-weighted MR arthrogram image confirms the articular surface partial thickness rotator cuff tear (arrow). Impingement and rotator cuff pain is usually worse during swimming but can be exacerbated while cycling when leaning onto aerobars.
high extension forces during the down stroke while pedaling. Patellar tendinosis tends to occur at the ends of the tendon near the enthesis, either proximally or distally (Fig. 7). On MR imaging, tendinosis appears as a high signal on T2-weighted images, while on ultrasonography (US) it appears...
as a hypoechoic region within the tendon, usually with increased Doppler flow (Fig. 8).

Patellofemoral stress syndrome, or "biker’s knee," is seen more often in female triathletes and results from the repetitive loading of the patellofemoral joint. The higher incidence in women is mainly because of the greater Q angle and resultant lateral displacement forces on the patella. Patients may have abnormal patellar tracking on physical examination tests, such as a positive “J” sign, which refers to the lateral deviation of the patella at full knee extension. Imaging in patients with patellofemoral stress syndrome is usually limited to radiography, including an axial or “sunrise” view of the knee. Although most triathletes with patellofemoral stress syndrome have normal radiographs, some can have patella alta, lateral subluxation, or a shallow trochlear groove. Treatment usually consists of vastus medialis strengthening and an orthotic sleeve, but adjustments to the bicycle seat height or interpedal width may also be helpful.

ITBS is also seen in cyclists and is caused by the friction of the iliotibial band tendon across the lateral femoral condyle with the knee in 10° to 30° of flexion. Although less common than in runners, ITBS occurs in cyclists because of the high number of repetitions of the knee in the “impingement zone” near the bottom of the stroke cycle. ITBS is exacerbated when the seat is too high or too far back. ITBS manifests as a T2 high signal between the iliobial band and the lateral femoral condyle on MR images, as an obliteration of the fat distal to the vastus lateralis, and occasionally as an adventitial bursa (Fig. 9). Although all 3 of these overuse knee injuries can present while cycling, they are often exacerbated by running.

Overuse injuries at the ankle can also result from cycling. The most common ankle injury is Achilles tendinosis, which makes up about 5% of injuries in triathletes. Achilles tendinosis from cycling results from the repetitive plantar flexion against resistance during the down stroke and, in general, is more common in older athletes. Achilles tendinosis in triathletes is thought to be exacerbated by having to cycle immediately after the foot has been held in plantar flexion for several hours during the swim portion of the race.

Achilles tendinosis is divided into 2 main types: hypoxic and mucoid. The hypoxic type involves focal thickening of the Achilles tendon, which appears as a low signal on T1- and T2-weighted sequences and has relatively normal echogenicity.
on US (Fig. 10). The hypoxic type usually presents with a painless lump in the tendon, and there is little risk of progressing to tendon rupture. The other type of tendinosis is the mucoid type, which appears on T2-weighted MR images as a thin linear high signal within the tendon and on US as similar linear anechoic areas (Fig. 11). The focal thickening of the tendon in the mucoid type is usually painful, and there is increased risk of progressing to a tear, so triathletes with this condition may have to modify their workout. Raising the seat height to reduce the amount of ankle dorsiflexion and the stretch on the ligament can help relieve symptoms.

Pain in the low back or neck is also common during cycling in triathletes. O’Toole and colleagues surveyed Hawaii Ironman Triathlon competitors and found that 78% had experienced back or neck overuse injuries in the year before the race. Lumbar pain during cycling is thought to result partly from holding the trunk in an aerodynamic flexed position for an extended period. The pain is typically of a muscular or ligamentous origin because in three-fourths of triathletes the pain resolves in a few weeks. However, 25% of those with back pain have either radiculopathy or pain for longer than 3 months. Although there is little literature on imaging regarding the prevalence of structural abnormalities in this population, back pain for longer than 3 months is suggestive of an abnormality such as disk or facet disease or unrecognized spondylolysis. Low back pain can be exacerbated when running and, if severe enough, may limit training in both disciplines.

Fig. 10. A 49-year-old man with a lump in the Achilles tendon. (A) Sagittal T1-weighted image shows focal thickening of the Achilles tendon (arrow). (B) Axial proton-density (left) and fat-suppressed T2-weighted (right) images show low signal in the thickened tendon (arrow) consistent with hypoxic tendinopathy.

Fig. 11. A 63-year-old man with a painful lump in the Achilles tendon. (A) Sagittal fat-suppressed T2-weighted image shows focal thickening and high-signal striations within the Achilles tendon. (B) Axial fat-suppressed T2-weighted image confirms the mucoid tendinopathy (arrow) of the Achilles tendon.
Neck pain is common in single-sport cyclists and therefore, not surprisingly, is also seen in triathletes. Neck pain is less common than low back pain, seen in about 45% of triathletes at some time during their competitive years. Neck pain and cervical disk disease from cycling is probably caused by maintaining hyperlordosis of the neck while riding in the aerodynamic position with the trunk low and the head looking forward. Similar to low back pain, radiculopathy or neck pain for longer than 3 months suggests a structural abnormality such as a cervical disk disease, and 10% to 20% of triathletes with neck pain have pain for this duration and therefore may undergo imaging (Fig. 12).

RUNNING

The running stage of a triathlon is considered to be the most important leg of the race. Most triathletes are former distance runners, and the run time is the best predictor of the overall triathlon success. The running portion is also the most common stage in the race during which an athlete is forced to drop out from an overuse injury. In addition, it is the final stage of the triathlon, and therefore competitors experience the most fatigue and muscle tightness. Running is also associated with most injuries during training, accounting for two-thirds to three-fourths of all skipped workouts.

Knee injuries account for more than one-third of all running injuries in triathletes. Many of the knee injuries from running are the same as those seen while cycling, including patellofemoral stress syndrome, ITBS, and patellar tendinosis. Patellofemoral stress syndrome, called biker’s knee when seen in cyclists, is also called runner’s knee and is usually worse when running on hills. ITBS tends to be aggravated by running on a laterally sloped surface, such as a steeply crowned road. Patellar tendinosis appears to be associated with a rapid increase in mileage, especially if running on a hard surface. Patellofemoral stress syndrome and ITBS are more common in female distance runners, while patellar tendinosis is more common in men. When severe, knee injuries may limit training in both running and cycling.

Meniscal tears in triathletes almost exclusively occur as a result of their run training. These tears are usually overuse tears from the repetitive impaction forces across the meniscus, and are more common in older triathletes who have started to develop myxoid change within the meniscus. Meniscal tears are most common in the posterior...
horn of the medial meniscus and appear as an increased signal unequivocally extending to an articular surface on a short TE sequence and on at least 2 images (Fig. 13).

Foot and ankle injuries are also most common during running, and account for 15% to 25% of running injuries in triathletes.\textsuperscript{1,2,6} Foot pain can also develop during a race and may be due to worsening of a preexisting metatarsalgia or metatarsal stress reaction. Ankle pain from Achilles tendinopathy can occur while running in addition to cycling, and is more common in older triathletes.

Plantar fasciitis accounts for half of all running foot and ankle injuries.\textsuperscript{1,2,6,23} Plantar fasciitis is a tendinopathy or partial tearing of the medial plantar aponeurosis, and is usually an overuse stretch injury.\textsuperscript{25,26} The MR imaging findings are T2 high signals within and around a thickened medial plantar aponeurosis. US is also useful in evaluating for plantar fasciitis and demonstrates thickening of the aponeurosis greater than 5 mm, occasionally with increased Doppler flow around the ligament (Fig. 14). Plantar fasciitis is treated initially with padded heel cups and stretching exercises, such as rolling the foot across a cold soda can. Refractory cases may benefit from injection, including injection of platelet-rich plasma (PRP).\textsuperscript{27} Quality running shoes are also important to prevent or allow healing of plantar fasciitis.\textsuperscript{28}

Another common injury of the foot during distance running is metatarsalgia. Metatarsalgia is a clinical term for pain near the metatarsal heads and includes conditions such as tendinitis, metatarsal-phalangeal joint synovitis or capsulitis, and Morton neuroma. Some investigators also include metatarsal stress reaction and sesamoiditis.\textsuperscript{1,2} Actual stress fractures of the metatarsals can also be seen in triathletes,\textsuperscript{29} although some studies have reported that they are less common than tibial and femoral stress fractures in distance runners.\textsuperscript{23,30} The second and third metatarsals are the most vulnerable to stress injuries, and treatment usually consists of wearing a stiff shoe until the symptoms subside. Stress reaction appears on MR images as T2 high signal within the bone marrow without a cortical abnormality, while stress fractures also have a focal cortical abnormality (Fig. 15).\textsuperscript{30}

Lower leg (calf/tibia/fibula) injuries are also common during run training in triathletes, accounting for about 10% of triathlete injuries.\textsuperscript{1,2,13} The 2 main injuries are medial tibial stress syndrome (shin splints) and stress fractures.\textsuperscript{31} Shin splints are thought to be a part of a continuum of overuse injury to the tibia and may be caused by periostitis, stress reaction, and/or repetitive traction tendinopathy by the tibialis posterior muscle. MR images may be normal in triathletes with mild shin splints or can show T2 high-signal periosteal reaction along the tibia at the site of pain (Fig. 16). Tibial stress fractures

![Image](https://example.com/image1.png)

**Fig. 14.** A 23-year-old person with heel pain when running. (A) Longitudinal US image shows a 7.9-mm thick, heterogeneous, hypoechoic plantar aponeurosis (arrow) that was tender to palpation with the ultrasound probe, consistent with plantar fasciitis. (B) Longitudinal US image during injection of platelet-rich plasma (PRP) shows the needle (arrows) and the hyperechoic PRP within the tendon (curved arrow).

![Image](https://example.com/image2.png)

**Fig. 15.** A 28-year-old person with foot pain when running. There is a metatarsal stress fracture (arrow) with surrounding marrow edema on a fat-suppressed T2-weighted image.
can be difficult to distinguish clinically from medial tibial stress syndrome, so MR imaging is very helpful in making the diagnosis. On MR imaging, stress fractures demonstrate a cortical abnormality between an area of periostitis and T2 high signal within the marrow (Fig. 17).

Another appearance of the tibial stress injury is cortical resorption cavities, typically in the anterior “keel” of the tibia. These cavities appear on computed tomography as linear longitudinal regions of nonmineralized tissue within the cortex. On MR imaging, these linear resorption cavities are high signal on T2-weighted images. Resorption cavities may be an isolated finding on MR images or may be associated with other more typical stress injury findings.

Upper leg, hip, and groin injuries account for 10% to 20% of injuries in triathletes and usually result from run training. Stress fractures of the proximal femur are always a concern in triathletes with hip pain, and typically occur along the medial concave portion of the femur in the region of the lesser trochanter. Thigh pain in triathletes can result from overuse injuries of the hamstrings, typically tendinopathy at the hamstring origin. These injuries appear on MR images as T2 high signal in the proximal tendon, and can be treated with an image-guided injection of anesthetic and corticosteroid or PRP (Fig. 18). Gluteus medius pain from distance running is more common in women. Finally, triathletes can develop groin pain due to osteitis pubis. Osteitis pubis results from the repetitive vertical shear forces across the pubic symphysis that occurs with the alternating foot strike during distance running (Fig. 19).

![Fig. 16.](image1)

![Fig. 17.](image2)
Injuries in triathletes are common and are mostly overuse injuries. Rotator cuff tendinitis is the most common complaint from swimming, but the incidence of tendinopathy and rotator cuff tears on MR imaging is comparable in triathletes without and with shoulder pain. Cycling injuries are mainly to the knee, including patellar tendinosis, ITBS, and patellofemoral stress syndrome, and to the cervical and lumbar spine. Running is associated with most injuries in triathletes, during both training and the event, causing the person to discontinue a triathlon. In addition to knee injuries from running, foot and ankle, lower leg, and hip injuries are also seen. Some injuries in triathletes may be mainly symptomatic during 1 of the 3 sports but are also exacerbated by one or both of the other disciplines.

Fig. 18. A 45-year-old woman who competes in Ironman and ultradistance triathlons. (A) Coronal fat-suppressed T2-weighted image shows increased signal in the proximal hamstring tendons (arrow). (B) Anteroposterior fluoroscopic image shows a needle placed into the abnormal area of tendon for injection of anesthetic and corticosteroid. Two weeks after the injection, this woman set a course record in the Hawaii Ultraman World Championship triathlon.

Fig. 19. A 47-year-old man with groin pain while training for a triathlon. (A) Coronal short-tau inversion recovery image shows edema around the pubic symphysis (arrow) consistent with osteitis pubis. (B) Anteroposterior fluoroscopic image during an injection of anesthetic and corticosteroid shows the needle in the pubic symphysis with contrast in the joint (arrow). This man went on to finish an Ironman triathlon race several months later.

SUMMARY

Injuries in triathletes are common and are mostly overuse injuries. Rotator cuff tendinitis is the most common complaint from swimming, but the incidence of tendinopathy and rotator cuff tears on MR imaging is comparable in triathletes without and with shoulder pain. Cycling injuries are mainly to the knee, including patellar tendinosis, ITBS, and patellofemoral stress syndrome, and to the cervical and lumbar spine. Running is associated with most injuries in triathletes, during both training and the event, causing the person to discontinue a triathlon. In addition to knee injuries from running, foot and ankle, lower leg, and hip injuries are also seen. Some injuries in triathletes may be mainly symptomatic during 1 of the 3 sports but are also exacerbated by one or both of the other disciplines.

REFERENCES


