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Summary

Ankle osteoarthritis (OA) is common among young and active people. The majority of the affected population are physiologically young and used to be sports active, which make their expectations of the treatment higher than hip and knee OA population. Non-surgical interventions sometimes can be a short-term solution, but surgical procedures such as Total Ankle Arthroplasty (TAA) are considered in end-stage OA.

Until recently, sports and exercise restriction has been widely recommended by surgeons for patients with ankle OA, to avoid increasing pain or further joint damage. The published studies showed that sports activities can be used as a treatment or at least as an adjunct in the management plan. Patients with TAA are classically advised to avoid sports participation for fear of implant failure. However, surprisingly some articles reported a good influence of sports activity on the functional TAA outcome. Up to date, guidelines and recommendations for intensity and types of sports to be practiced by TAA patients are scanty. In this article, sports activities in relation to Ankle OA and TAA will be comprehensively discussed.

Keywords
Total ankle arthroplasty – ankle arthrodesis – sports injury – ankle osteoarthritis – sports

Sport, Arthrose des Oberen Sprunggelenks (OSG) und OSG-Totalprothese

Zusammenfassung

Arthrose des oberen Sprunggelenks (OSG) tritt häufig bei jungen und aktiven Menschen auf. Die Mehrheit der betroffenen Bevölkerung ist physiologisch jung und war sportlich aktiv, weshalb ihre Erwartungen an die Behandlung höher sind als die der Arthrose-Population an Hüfte und Knie. Nichtchirurgische Eingriffe können manchmal eine kurzfristige Lösung sein, aber

REVIEW / SPECIAL ISSUE

Sports, Ankle Osteoarthritis, and Total Ankle Arthroplasty

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Introduction

Sports activity is an important and integral part of the modern life. It reflects and affects the general state of health. The elderly population is more concerned about regular sports practice to maintain healthier life style. In 2017, individuals older than 65 represented 19.7% of the population in the European union and 15% of United States population.[1] This explain the increasing rates of degenerative joint osteoarthritis (OA) with the subsequent increase in joint replacement surgeries. The British national joint register recorded 252'251 joint replacement surgeries in 2017 including 734 ankle arthroplasties.[2]

During daily activities, ankle joint bears approximately 4-5 times body weight during stance phase that will increase during sport activity like running, jogging and sprinting up to 13 times body weight.[3] In one experimental study, 83% of this load was carried by the tibiotalar joint, nearly 77% -90% carried across talar dome and the remaining distributed between the medial and lateral surfaces. The load on the talus is distributed to different parts throughout the gait cycle in an arc shape. During gait cycle and under static load the contact pressure will be higher in plantarflexion than in dorsiflexion. Furthermore, ankle joint expose to more force per square centimeter compare to hip

chirurgische Eingriffe wie die OSG-Totalprothese werden bei OSG-Arthrose im Endstadium in Betracht gezogen.
Bis vor kurzem wurde Sport- und Bewegungseinschränkungen von Chirurgen für Patienten mit OSG-Arthrose allgemein empfohlen, um zunehmende Schmerzen oder weitere Gelenkschäden zu vermeiden. Die veröffentlichten Studien zeigen, dass sportliche Aktivitäten als Behandlung oder zumindest als Ergänzung im Managementplan eingesetzt werden können.
Patienten mit einer OSG-Totalprothese wird klassisch geraten, aus Angst vor Implantatversagen die Teilnahme am Sport zu vermeiden. Überraschenderweise berichteten einige Artikel über einen guten Einfluss der sportlichen Aktivität auf das funktionelle Ergebnis von OSG-Totalprothesen. Auf dem neuesten Stand sind Richtlinien und Empfehlungen für Intensität und Sportarten, die von OSG-Totalprothese-Patienten ausgeübt werden sollen, dürftig. In diesem Artikel werden sportliche Aktivitäten in Bezug auf OSG-Arthrose und -Prothese ausführlich besprochen.

Schlüsselwörter
OSG-Totalprothese – OSG-Arthrodese – Sportverletzung – Sprunggelenksathrose – Sport

and knee joint due to smaller contact area and high level of congruency.[4]
Professional or recreational athletes may develop early ankle OA during their life. The role of sports activities in development and acceleration of ankle OA is not clearly described in the literature. However, sport activities could be modified to prevent or treat existing symptomatic OA. Ankle OA might be treated conservatively for short time including, physiotherapy, foot orthotics, bracing, injectable steroid therapy, hyaluronic acid injections, and Platelet-Rich Plasma injections. But, in most of the cases, these options are only considered an obligatory step on the road to surgery.
Many surgical procedures and approaches have been developed to treat different stages of ankle OA. Total Ankle Arthroplasty (TAA) became a valuable treatment option for end-stage ankle OA. Although TAA has been a more popular procedure, surgeons lack the guidance and recommendation about sports and physical activity following this procedure.
In this review article, we will discuss the sports related causes of ankle OA, sport activity in patients with ankle OA, and finally sport activity after TAA.

Ankle Osteoarthritis due to Sports and Sports Injuries

Ankle OA prevalence is estimated to be 1% of the world's adult population. Unlike hip and knee, ankle OA is posttraumatic in 70-90% of cases. Valderrabano and colleagues conducted a study on 390 patients (406 ankles) with ankle OA, they found that posttraumatic ankle OA accounted for 78% with majority due to malleolar fractures and ankle ligamentous injuries. [5,6] The ankle is the most common joint to be injured during sports activities, with $>$ 300,000 ankle sprain injuries reported yearly in the US, and an estimated 5.23 ankle injuries per 1000 exposure in high school-aged athletes, ankle injuries were most commonly diagnosed as ligament sprains (83.4%), followed by fractures (5.2%), incomplete ligament tear account 25% of all recurrent ankle injuries.[7]
Underestimation of sports related ankle OA is a result of the fact that athletes who suffer from OA may retire early and stop participating in sports activity. Multiple studies showed that forceful long-term physical activity could cause ankle OA. One study compared former professional soccer players to their age matched control group: the professional soccer players showed more incidence of knee (40-80%) and ankle (12-17%) OA and a higher need of hospital care.[8] Similarly, pediatric sports injuries can be a leading cause of future ankle OA. Ekstrand and colleagues observed a rate of lower extremities injury of 87% in seven consecutive seasons for European professional soccer players, ankle sprain occurred in 7% of lower extremity injuries.[9] These injuries can happen due to increased stresses at the ankle joint during sprinting, cutting, sudden change of direction, tackling and the actual kicking maneuver. Vincelette and colleagues, determined that 90% of football players with average of 23 years of age showed a degenerative change in the ankle joint compared to the control group.[10] Zinder and colleagues studied the prevalence of ankle OA in retired professional football player. They found that the players, whom sustain single ankle sprain in their duty, had 2.3 chance (8.3%) to develop ankle OA.[11]

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Losifidis and colleagues, studied the prevalence of clinical and radiological OA in 218 former elite males from many sports activities (soccer, volleyball, martial arts, track and field, basketball and skiing). The prevalence of clinical and radiological OA was 15.6% and 36.6% respectively; the ankle joint was affected in 3.6% of the cases.[12]

Furthermore, Knobloch and colleagues, investigated the long-term effect of high intensity physical training in long distance runner on early ankle OA. Twenty-seven track and field long-distance runners and orienteers and 9 bobsledders with the main age of 42 years compared to a control group. The long-distance runners had higher prevalence of early ankle OA.[13]

Schmitt and colleagues, studied the ankle OA in 40 former elite high jumpers, 2.5% of these jumpers were diagnosed with ankle OA at mean age of 41 years.[14]

Ankle ligament instability represent a typical sports injury in soccer, football, basketball and tennis. It occurs in about 25% of injuries with runners, jumpers, athletes and 11% with soccer players.[15] Rupture of lateral ligament which occurs in a rate of 1 per 10000 on daily basis, will end up with chronic ankle instability in 20-40% of cases as described by Valderrabano and colleagues.[16,17]

When comparing the incidence of osteoarthritic changes between acute and chronic ankle instability in case of posttraumatic OA, literature reported that 47% of acute sprains with residual symptom and 78% of chronic ankle instability. These degenerative changes can be explained by mechanical imbalance leading to unequal load distribution on the ankle joint, which in turn will cause cartilage damage. This imbalance might be a result of muscle weakness, joint laxity, and abnormal joint biomechanics that happen frequently in chronic ankle instability.[18]

Deltoid ligament injury is more frequent than expected, the common mechanism of its injury happens with a combination of plantarflexion and inversion during rotational impact, usually the medial talar osteochodral lesion (OCL) is associated with this type of injury.[19,20]

Chondral and osteochondral lesions (OCL) result from shear and compressive forces on the articular surface that create stress fractures through the cartilage matrix and the underlying bone. Chronic OCL of the talus are commonly seen in sports participants, especially in sports that involves frequent jump and land on one foot or make sharp cutting moves (like in basketball, soccer, football, and volleyball). OCL is a common source of persistent pain after ankle sprain.[21] Rolf and colleagues, in his prospective study reported 43% of 61 soccer players sustaining ankle OCL treated with arthroscopic debridement had residual symptoms.[22] In a study done by Sugimoto and colleagues, they found that OCL existed in 77% of recurrent ankle instability cases.[23]

Isolated syndesmotic injury is another factor that predispose to ankle OA. It occurs more frequently in athletes with high impact sports such as hockey, soccer, and football. Ankle OCL is commonly seen with this type of injury, as described by Brawn and coworkers in their retrospective MRI study, 28% of the syndesmotic injuries were associated with ankle OCL. Chronic pain and ankle OA may happen with missed syndesmotic injury or diastasis more than 2 mm.[24–26]

Majority of ankle fractures occur during competitive activity; it accounts for 36% of all lower extremity fractures. In the literature, 37% of posttraumatic ankle OA are due to fractures around the ankle. Lubbeke and colleagues, investigated the incidence of posttraumatic ankle OA after ankle fracture in 108 patients over 18 years. They founded 36% of the patient develop posttraumatic ankle OA.[27,28]

Impingement syndrome affect many athletes (e.g. soccer, ballet dancers, runners, volleyball etc.). The primary cause of anterior impingement are repetitive mechanical stresses between the anterior distal tibial rim and talar neck, that happen during maximum dorsiflexion of ankle joint like in runners, dancers and high jumpers. Furthermore, direct impact force onto the anterior aspect of ankle like in soccer player can cause anterior impingement and formation of tibiotalar osteophyte ("soccer ankle"). On other hand, forced plantar flexion and repetitive traction and compression forces in posterior ankle compartment like in ballet dancers and runners results in posterior impingement and formation of osteophytes and loose bodies at posterior distal tibial rim and hypertrophied posterior talar process.[29,30] Chronic ankle instability is associated significantly with osteophytes formation that lead to impingement.[31]

In terms of clinical outcome, the latency time is the clinical parameter that is used to estimate the time between injury and painful end-stage ankle OA. For example, for posttraumatic ligamentous ankle OA, the latency time is 30 years according to the retrospective study of Valderrabano et al.[18] Similarly, Horisberger and coworkers, reported 20.9 years as an average latency time for ankle fracture.[32]

The incidence, type and mechanism of ankle injuries, and incidence of sport related ankle OA are summarized in Table 1.

Table 1: Sports, Ankle Injuries, and Incidence of Ankle Osteoarthritis

Table 1. Sports, Ankle Injuries, and Incidence of Ankle Osteoarthritis.

Sport	Incidence of ankle injury (%)	Type of ankle injury	Mechanism of sport induced ankle injury	Persistent symptom (%)	Incidence of ankle OA (%)	References
American football	17	Sprain (94.4) Syndesmotic (10-24) Fracture (1.3)	external rotation with dorsiflexion	23	33	[33]
Badminton	23	Sprain (86.5) Fracture (8.6)	sudden direction change fast acceleration and deceleration	57	N/A	[34]
Baseball	3.5	Sprain (14)	contact with opponent players while shooting	N/A	N/A	[35]
Basketball	15.9	Sprain (91.0) Fracture (2.1)	-landing on inverted ankle - cutting or pivoting	51	32-67	[36]
Dancing	17.4	Sprain (50.5) Fracture (5.6)	Excessive twisting poor joint control weak peroneal muscles	N/A	N/A	[37]
Gymnastics	32.3	Sprain (44.4) Fracture (1.2)	Equipment stumbles Twisting moves	64	2.5	[38]
Handball	13.5	Sprain (100.0)	Contacts/tackles Shooting jumps	40		[15]
Martial arts	21.1	Sprain (91.7) Fracture (8.3)	N/A	N/A	N/A	[36]
Mountaineering	40	Fracture (65) Sprain (35.0)	N/A	N/A	N/A	[39]
Orienteering	29.8	Sprain (100.0)	Running on uneven ground	33.3	N/A	[40]
Roller skating	7.5	Fracture(86.5) Sprain (13.5)	Twisting injuries	N/A	N/A	[41]
inline skating	3.6	Fracture(83.3) Sprain (16.7)	N/A	N/A	N/A	[41]
Rugby	11.6	Sprain (74.9) LCL inj. (29) syndesmotic injuries (11)	contact or landing from a jump	N/A	N/A	[42]
Running	20.2	N/A	N/A	20	N/A	[43]
Soccer	21.2	Sprain (76.8) Fracture (1.1)	-Sprinting loads -Cutting or pivoting - tackles	57	53%	[36]
Skateboarding	13.1	Fracture (46%)	Twisting inj.	N/A	N/A	[41]
Skiing (alpine)	7.6	Sprain (76.9) Fracture (11.0)	-Twisting inj. -Binding mechanism failure	N/A	N/A	[44]
Snowboarding/ snowblading	15.6	Sprain (53.6) Fracture (42.5)	Inversion dorsiflexion inj.	N/A	N/A	[44]
Tennis	47.2	Sprain (66.7)	The sudden change of direction, fast acceleration and deceleration moves	N/A	N/A	[34]
Squash	12.6	Sprain (100.0)		N/A	N/A	[34]
Volleyball	45.6	Sprain (99.3) Fracture (0.7)	(Actions of blocking and spiking)	N/A	N/A	[36]

Sports with and as Treatment of Ankle Osteoarthritis

The majority of patients with post-traumatic asymmetrical ankle OA are young and active. During the early stages of ankle OA they will need different treatment modalities to ensure a decent level of sports participations. However, they may experience a reduction in walking speed, limitation in the range of motion in all three planes, especially the sagittal plane, shortening of stance phase and stride length, and muscle weakness that may be lead to more stresses on the adjacent joints.[45]

Valderrabano and coworkers, found in their study 36% of patient with ankle OA participated in moderate sports level, as biking and swimming. In ankle OA, high impact activities associated with repetitive loads are advised to be reduced or replaced by low impact activities with low intensity, rate and frequency. These types have a minimal impact or torsional loading that decreases the risk of further joint injury.[18]

The implementation of therapeutic exercise programs that contain muscle strengthening, muscle stretching and aerobic activities either water or land based showed clearly in the literature a reasonable pain improvement and an increase in muscle function.[46,47] In contrast, there is a strong relation between OA and muscle weakness or atrophy.[46] In addition, it is currently founded that muscle weakness can be a major risk factor to develop joint OA.[47] However, muscle forces are adapted to change joint loading in magnitude and location. These effects vary between the muscle groups and depend on muscle position during gait cycle. Therefore, training and conditioning program that concentrates on muscle strengthening and increasing neuromuscular control of joint loading can prevent or slow OA. For instance, gastrocnemius and soleus were found to shift the load toward posterior and lateral. Hence, strengthening of these muscles will shift the loads away from the anteromedial area of the ankle where a higher percentage of OA were documented.[48,49]

Injury prevention methods and athlete education can improve the quality of life of the sports participants with ankle OA. One of these methods is altering the loads on the affected joint using orthotics, including ankle braces, ankle foot orthosis (AFO) and insoles (shock-absorbing, wedges). AFO controls ankle joint movement and alignment by maintaining the talus in neutral position which helps decreasing pain.[50]

Pain relief is a crucial element to help ankle OA patients achieving satisfactory levels of activity. Oral nonsteroidal anti-inflammatory drugs (NSAIDs) play a reliable role in relieving the acute pain that is associated with ankle OA subsequently facilitating mobility. Hyaluronic acid (HA) injections are commonly used in treatment of ankle OA. Witteveen et al, observed in their prospective study improvement of the pain during walking activities after HA injections which can help the athletes to perform their sport activity with less discomfort.[51,52]

In general, sports as recreational activity cannot be a risk factor for development of OA. Nevertheless, professional athletes are more prone to have osteoarthritis related injury. However, sports can be practiced at any stage of ankle OA although the intensity and frequency have to be adjusted to the individual capability. Actually, a positive effect of low impact sports like swimming, cycling and walking was reported in many studies on well-established joint OA. Moreover, joint pain was relieved 100% in patients who were treated with aquatic exercises. Another study stated a good improvement of gait speed, joint stiffness and pain with stationary cycling.[53,54]

Sports with Total Ankle Arthroplasty (TAA)

As mentioned earlier, ankle OA has a different epidemiology compared to hip and knee joints. The fact that 70-90% of cases are posttraumatic, explains that ankle OA patients are relatively young. The demands and expectation of ankle OA patients is different as most of them are willing to return to their previous levels of activities.

Ankle arthrodesis and TAA are the major procedures to treat end-stage ankle OA. There is a lot of arguments and discussion in the orthopaedic community whether TAA or ankle arthrodesis (AA) should be the treatment of choice for end-stage OA.

Richman et al, retrospectively compared TAA patients (N = 62) to AA patients (N = 51) regarding their post-operative level of activity. The minimum follows up was 2 years and they used SF-12 Health Survey and the revised Foot Function Index (FFI-R) preoperatively and at final follow-up. In addition, activity levels were evaluated using a (Return to Activities Following Surgery questionnaire) that was administered at final follow-up. This form contained a Visual Analog Scale for Pain (VASP), satisfaction questions, and a list of 25 activities. In the AA group 88% of the patients returned back to work in opposition to 92% in the TAA group. The TAA group significantly experienced lower pain levels. The TAA patients reported significant increase in activities type including tennis, hiking, jogging and yoga. The overall results showed TAA patients were significantly more satisfied with their surgical outcome compared to AA patients.[55]

Jastifer et al. reported better Buechel-Pappas scale and AOFAS scores in the TAA cohort over the AA cohort.[56]

Saltzman et al. reported in their study significant improvement in efficacy and overall success rate in the Pivotal STAR group over the AA group.[57] In a later study, he reported better outcome in TAA over AA for SF-36 MCS and AOS-pain scale.[58]

With new revolution in TAA represented by mobile-bearing

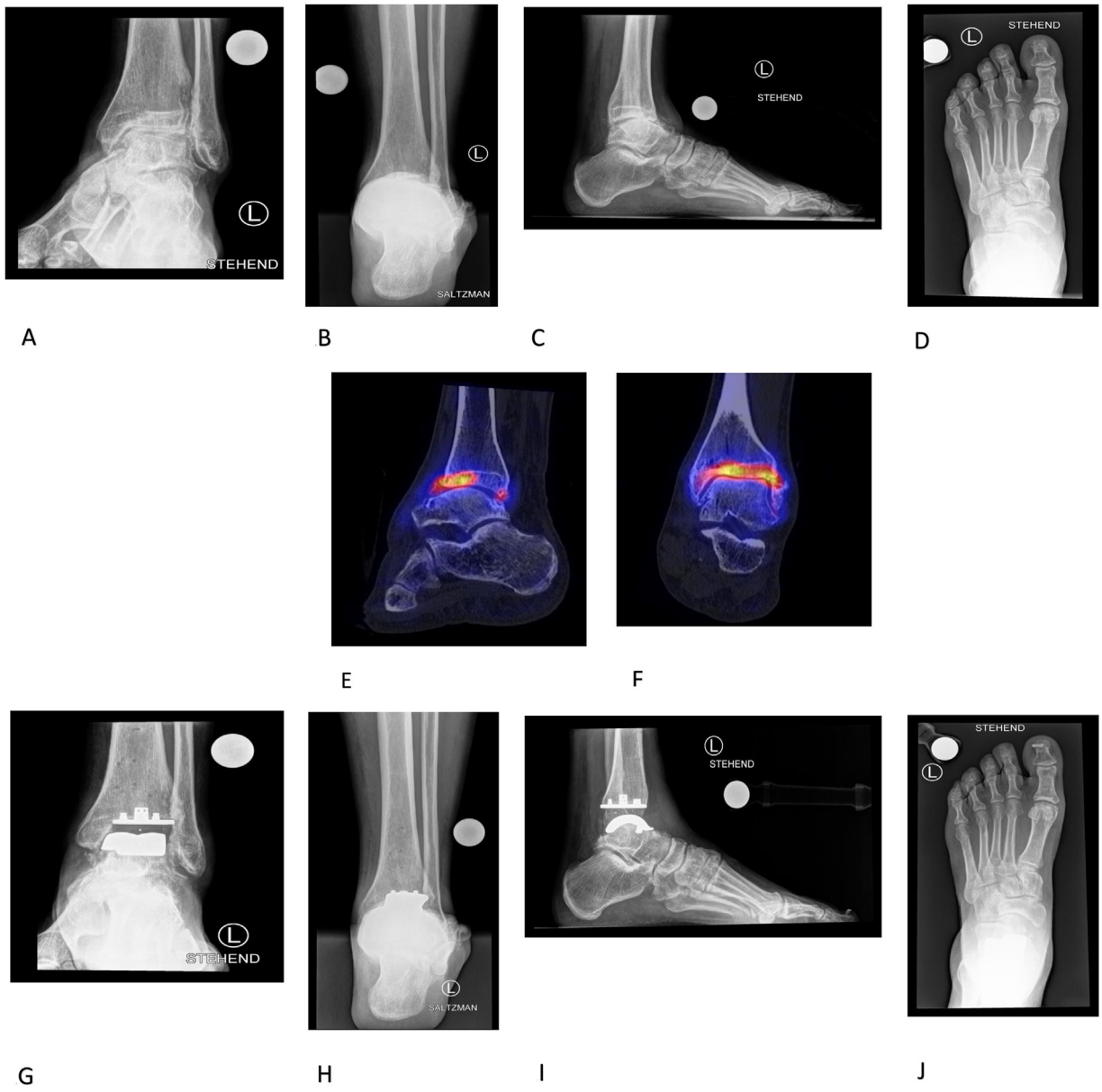

Figure 1
Treatment of posttraumatic ankle osteoarthritis by mobile total ankle arthroplasty.
Pre-operative X-rays and SPECT-CT for left side posttraumatic ankle osteoarthritis of a 55 years old tennis coach (A-F). Post-operative X-rays with left side total ankle arthroplasty (Vantage Mobile, Exactech, Gainesville, USA) (G-J).

implants (Figure 1), the return to recreational activities with improved quality of life is possible according to Bonnin and colleagues, in their retrospective study.[59] Although TAA became a popular procedure to treat endstage ankle OA, unfortunately clinical participants have little guideline and recommendation for physical activity and sport participation following this procedure. In gait analysis study, Valderrabano and coworkers, concluded that after 12 months of rehabilitation TAR had similar temporospatial variables to normal ankle, improve walking speed and partial improvement in 6 of gait variables.[32] These biomechanical improvements decrease patient's disability and bring the gait characteristic toward normal ankle.

However, many factors must be taken into account before allowing

TAA patients to participate in sports. Polyethylene wear, mechanical loads and prosthesis design are all crucial to determine post TAA activities. Limiting wear is a main factor in the improvement of prosthesis survival.[60] On the other hand, excessive sports activities may lead to change in joint contact pressure which can be exacerbated by malalignment of TAA, which can increase polyethylene insert wear and failure that leads to aseptic loosening.[61] Another major complication related to excessive activity is fracture of the mobile bearing that was observed in 3 components prosthesis design which occurs in 14% of patients. High energy sports activity can be a reason for periprosthetic TAA fracture which is difficult to be treat.[62]

It is believed that physical activity has a positive effect on TAA. It increases bone quality which improves prosthesis fixation and decreases the incidence of early implant loosening. Valderrabano and colleagues, have found in their case series of 147 patients who underwent TAA, a statistically significant increase in patients' sport participation from 36% preoperatively to 56% postoperatively with a main follow up of 2.8 years. These patients showed high functional (The mean American Orthopedic Foot and Ankle function score, AOFAS) for the hindfoot compared to patients who were non-active in sports. The most reported sports activity in their study was hiking: with 53% postoperatively compared to 26% preoperatively.[63]

Furthermore, Naal and colleagues, concluded in their case series of 101 patients at mean of 3.7 years follow up after TAA, neither sports participation nor increased level of activity had a relation with presence of peri-prosthetic radiolucency.[64] Also, Horterer et al, conclude in their prospective study which included 772 TAA, that the intensity of sport activities were not an identifiable risk factor for TAA failure. Even though, they did not recommend participation in high compact sports which justified by high axial forces driven by excessive sport activities result in abnormal joint reaction pressure. Furthermore, excessive sport activity may increase polyethylene wear resulting into TAA failure.[65]

Wang et al showed that TAA patients restore planter flexors functionality within 3 months of the procedure. This leads to improvement of peak planter flexor moment which in turn enhance the forward body movement. These results that reflect good pain score and range of motion encourage patient to participate in sports and recreational activity.[66]

Usuelli et al, retrospectively evaluated a cohort of 76 patients with mobile baring TAA with a focus on sports activity pre and post-surgical intervention. Unlike most of studies that use AOFAS and VAS as an indicator of improvement, they added University of California at Los Angeles (UCLA) activity scale to detect the change of activity following the procedure. Results showed a rise of sports participation from 11.7% before surgeries to 49.9% post recovery. The most practiced sports activities were dancing, jogging, biking, and skiing; a group of patients (N = 14) participated in impact sports such as jogging (13 patients) and martial arts (1 patient) in spite of adverse medical advice.[67]

Sports and recreational activities, were compared in patients who underwent TAA vs. ankle arthrodesis AA in a retrospective study by Schuh et al. This was a relatively small cohort with twenty patients in each group with a mean follow up of 2.9 years. The most common postoperative sport activities in AA group were cycling (45%), swimming (45%), hiking (25%), Nordic walking (20%), and skiing (15%). In the

Table 2. Guidelines for sports practice with Total Ankle Arthroplasty.

Recommended/allowed	**Possible with caution**	**Not recommended**
Low Impact	**Medium Impact**	**High Impact**
Aerobic activity	Low-impact Gymnastics	High-impact aerobics
Stationary biking	Hiking	Baseball
Ballroom dancing	Rowing	Basketball
Bowling	Downhill skiing	Football
Golfing	Doubles tennis	Handball
Swimming	Sailing	Volleyball
Walking	Tennis	Hockey/Ice skating
		Horse riding
		Jogging
		Squash
		Rock climbing
		Soccer
		Singles tennis
		Water-skiing
		Martial arts
		Mountain biking
		Skydiving
		Rugby
		Windsurfing

These guidelines are based on Vertullo and Nunley[69], Valderrabano et al[63], Usuelli et al[67]

TAA group the most common sport activities were cycling (38%), hiking (43%), skiing (38%), swimming (38%), and gymnastics (19%).[68] Patients with TAA should be educated regarding the detrimental effects of certain types of sports on the implant longevity. Sports that include high impact and greater rotation should be avoided as rotation was found to cause more wear compared to other types of loading. Table shows different sports types and their suitability with TAA.

Table 2. Guidelines for sports practice with Total Ankle Arthroplasty. These guidelines are based on Vertullo and Nunley[69], Valderrabano et al[63], Usuelli et al[67]

Conclusion

Ankle OA is a predominantly posttraumatic sequela that affects the patients' activities along with their wellbeing. The majority of the affected population are physiologically young and used to be sports active, which make their expectations of the treatment higher than hip and knee OA population. TAA might give those patient another chance to continue their activities and to keep the desired healthy life style compared to other treatment options. Our experience in addition to the above mentioned studies demonstrate that sports after a TAA can be achieved within limits. We need more studies to focus on sports practice following the ankle replacement surgery to help creating a solid based guideline that address the types and intensity of activities allowed.

Declaration of Conflicting Interests

Prof. Valderrabano is Co-Inventor of the mentioned Vantage Total Ankle Arthroplasty on Figure 1. Otherwise, the authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Conflict of interest

There is no conflict of interest.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.orthtr.2019.06.008.

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