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Sport, Exercise and COVID-19, the Disease Caused by the SARS-CoV-2 Coronavirus

Sport und COVID-19, die Krankheit, die von dem SARS-CoV-2-Coronavirus verursacht wird

REVIEW

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Summary

› **No health emergency** in living memory has ever had greater repercussions for our health, economy and the way we live than the COVID-19 pandemic caused by SARS-CoV-2, commonly referred to as the "coronavirus".

› **COVID-19** has many links to sport and exercise: sports events such as the champions league quarter final between Atalanta Bergamo and FC Valencia on the 19.02.2020 have contributed to the virus spread; control measures such as lockdowns and closures of gyms and other sport facilities have altered our exercise behaviours; major sporting events including the Tokio Olympics have been cancelled or postponed; sports and fitness providers such as sports clubs, gyms and swimming pools have been hard hit.

› **In this review,** we will answer five questions in relation to COVID-19 from the perspective of sport and exercise. The questions deal with 1) how SARS-CoV-2 targets ACE2-expressing human cells via its spike protein, 2) the COVID-19 disease caused by it, 3) the COVID-19 pandemic and attempts to control it, 4) how the immune system responds to SARS-CoV-2 and how the immune system is affected by exercise training, 5) advice for exercise during the pandemic for healthy adults, athletes and elderly, and possible control measures to help to return to normal sport and exercise at the end of the pandemic before herd immunity or mass vaccination has been achieved.

KEY WORDS:
Pandemic, Physical Activity, Detraining, Risk Group

Zusammenfassung

› **Keine Gesundheitskrise** in den letzten 100 Jahren hatte größere Auswirkungen auf unsere Gesundheit, Wirtschaft und Lebensweise als die durch SARS-CoV-2 (Coronavirus) verursachte COVID-19-Pandemie.

› **COVID-19** hat viele Implikationen für Sport und Bewegung: Sportereignisse wie das Viertelfinale der Champions League zwischen Atalanta Bergamo und dem FC Valencia am 19.02.2020 haben zur Verbreitung des Virus beigetragen. Kontrollmaßnahmen wie Schließungen von Fitnessstudios und anderen Sportanlagen haben unser Bewegungs- und Sportverhalten verändert. Sportveranstaltungen wie die Olympischen Spiele in Tokio wurden abgesagt oder verschoben. Sport- und Fitness- und Freizeitanbieter wie Sportvereine, Fitnessstudios und Schwimmbäder sind stark betroffen.

› **In dieser Übersicht** werden wir aus der Sicht des Sports fünf Fragen in Bezug auf COVID-19 beantworten. Die Fragen befassen sich damit 1) wie SARS-CoV-2 über sein Spike-Protein ACE2-exprimierende menschliche Zellen infiziert, 2) wie SARS-CoV-2 die COVID-19-Krankheit verursacht, 3) wie die COVID-19-Pandemie verlief und wie versucht wird, die Pandemie zu kontrollieren, 4) wie das Immunsystem auf SARS-CoV-2 reagiert. 5) wie gesunde Erwachsene, Sportler und ältere Menschen von der Pandemie betroffen sind und darauf reagieren können und wir diskutieren auch Kontrollmaßnahmen, mit denen Sport und Bewegung vor Ende der COVID-19-Pandemie ermöglicht wird, vor einer Herdenimmunität oder Massenimpfungen.

SCHLÜSSELWÖRTER:
Pandemie, Körperliche Aktivität, Detraining, Risikogruppen

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What Do We Know about SARS-CoV-2, the Virus that Causes the COVID-19 Disease?

The world is in the midst of the COVID-19 (coronavirus disease 2019) pandemic that is caused by SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2, often shortened to "coronavirus"). This is having a greater impact on human health and the global economy than any other health crisis in the last 100 years. The aim of this review is to answer questions that are currently being asked by athletes, coaches, exercisers, physicians, sports functionaries and owners and users of sports facilities.

On the 30.12.2019 a cluster of pneumonia cases of unknown cause was reported on the ProMed-mail website (a website for monitoring emerging diseases). This outbreak was linked to a seafood market in Wuhan, China. On the 8.1.2020, ProMed-mail then reported that the outbreak was linked to a novel coronavirus (6). The risk that coronaviruses in wild animals can cause zoonotic, species-switching diseases in humans had been highlighted thirteen years before the current outbreak in a review that ›

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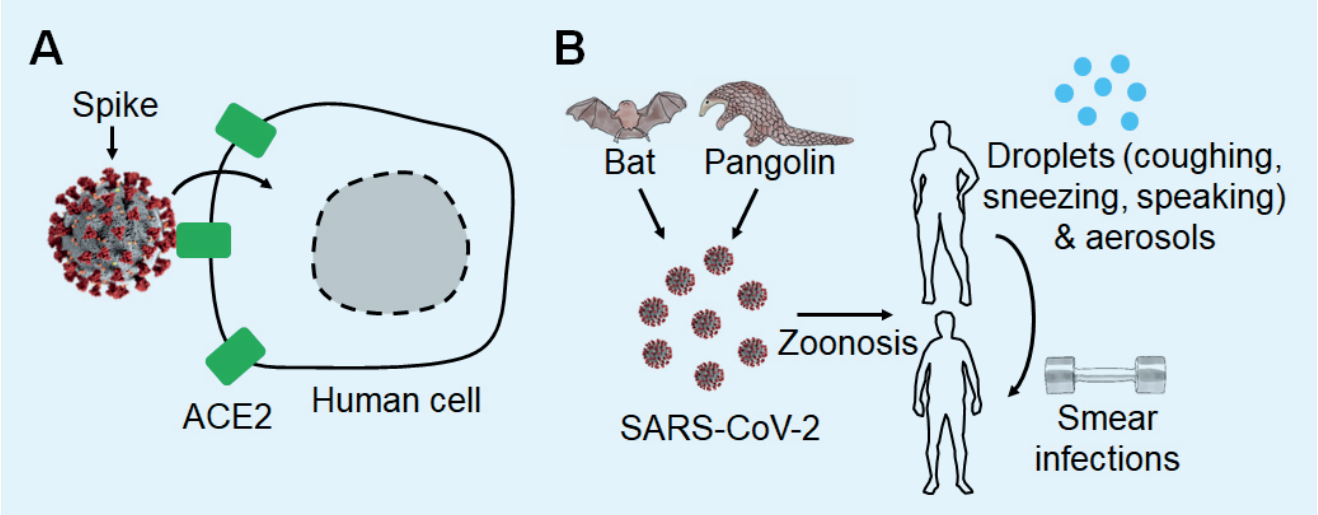

Figure 1

A=The Spike protein of SARS-CoV-2 binds ACE2 on the surface of human cells to initiate entry. B=The SARS-CoV-2 coronavirus probably moved from bats or pangolins into humans (zoonosis). In humans, SARS-CoV-2 infections occur via aerosols or smear infections.

concluded "The presence of a large reservoir of SARS-CoV-like viruses in horseshoe bats, together with the culture of eating exotic mammals in southern China, is a time bomb" (13). That prediction has now become true.

Based on RNA sequence comparison, the genome of SARS-CoV-2 is 96% identical to a bat coronavirus termed BatCoV RaTG13 (87). SARS-CoV-2 also has close sequence similarity in some genome locations with a coronavirus in pangolins (pangolins are scaly anteaters) (42). In China, both bats and pangolins are eaten or used for Chinese medicine and sold in enterprises like the seafood market in Wuhan. This suggests that the virus is originally derived from bats or pangolins (Figure 1).

SARS-CoV-2 is a member of the betacoronavirus genus. Coronaviruses are widespread in nature, infecting both humans and animals. Four of the known coronaviruses that infect humans cause mild disease in the form of common colds. A related but dangerous coronavirus termed SARS-CoV-1 caused the SARS outbreak from 2002 to 2004 (18). Currently a disease known as Middle East Respiratory Syndrome (MERS) is caused by the MERS-CoV coronavirus, which is a serious, infectious disease that has spread to many countries, although fortunately the number of infections is relatively low (18). Coronavirus genomes are of the positive strand RNA class, and have by far the largest genome of all the positive strand RNA viruses. When SARS-CoV-2 infects a human it binds via its "Spike" protein to the angiotensin-converting enzyme 2 (ACE2) protein which is the receptor on the surface of human cells. ACE2 binding of the virus then triggers a membrane fusion event that allows the virus to enter cells (84).

How do people become infected with SARS-CoV-2? Infection can occur mainly via respiratory droplets (water particles >5 µm) from coughing, sneezing or talking (9). In addition to the likely major transmission via droplets, individuals may become infected through aerosol (water particles ≤5 µm which can travel longer distances) or when touching SARS-CoV-2-contaminated surfaces (9, 71). SARS-CoV-2 can be detected for several hours in aerosols and for up to 48 h on plastic, similar to SARS-CoV-1 (71).

Importantly, individuals without any COVID-19 symptoms can infect others (2). Specifically, in one study it has been estimated that 44% of infections occur before SARS-CoV-2-infected individuals develop symptoms (29). This is a major problem because asymptomatic, infectious individuals can only be identified through testing and not e.g. by measuring temperature or looking for other COVID-19 symptoms. It is unclear whether COVID-19 is seasonal like influenza outbreaks. Limited evidence suggests cold and dry conditions may increase the spread of SARS-CoV-2 but the effect is probably small (7).

Do genetics, drugs or exercise affect the risk of a SARS-CoV-2 infection and the severity of COVID-19 by altering the ACE2 receptor? There are genetic variants of the human ACE2 gene but so far there is no evidence to associate any of them with infection resistance or disease severity (8). A 2005 study has shown that the ACE inhibitors Lisinopril and Lorsartan increase the expression and activity of ACE2 in the hearts of Lewis rats (21). This has triggered a debate whether these ACE inhibitors are safe to prescribe as higher amounts of ACE2 on target cells might increase the risk of SARS-CoV-2 infection and COVID-19 severity (40). A recent observational study of more than 12,500 patients, however, found no association between ACE inhibitors and similar drugs with being tested positive for COVID-19 nor a substantially higher risk for severe COVID-19 (61). A second study in over 8,000 patients found no association between ACE inhibitor medication, other drugs and COVID-19 mortality (52).

Interestingly, especially high intensity exercise increases the concentration of plasma ACE2 in some individuals (mean increase 28% (49)). This could potentially be beneficial if increased plasma ACE2 occurs through release from membranes into the plasma, or detrimental if exercise increases the overall levels of ACE2 in both target cell membranes and plasma. To understand this, we urgently need to investigate how exercise affects ACE2 concentrations in the membranes of target cells and in plasma and whether such changes alter infection risk and COVID-19 severity.

What Do We Know about the COVID-19 Disease and are there Links to Exercise?

COVID-19 can be suspected from the symptoms that we discuss below but SARS-CoV-2 infection is most reliably diagnosed with RT-PCR. This method involves copying a segment of SARS-CoV-2 RNA that is unique to this virus into a DNA copy. This DNA fragment is then amplified by the polymerase chain reaction (PCR) to enable its detection (63). RT-PCR for SARS-CoV-2 is sensitive and

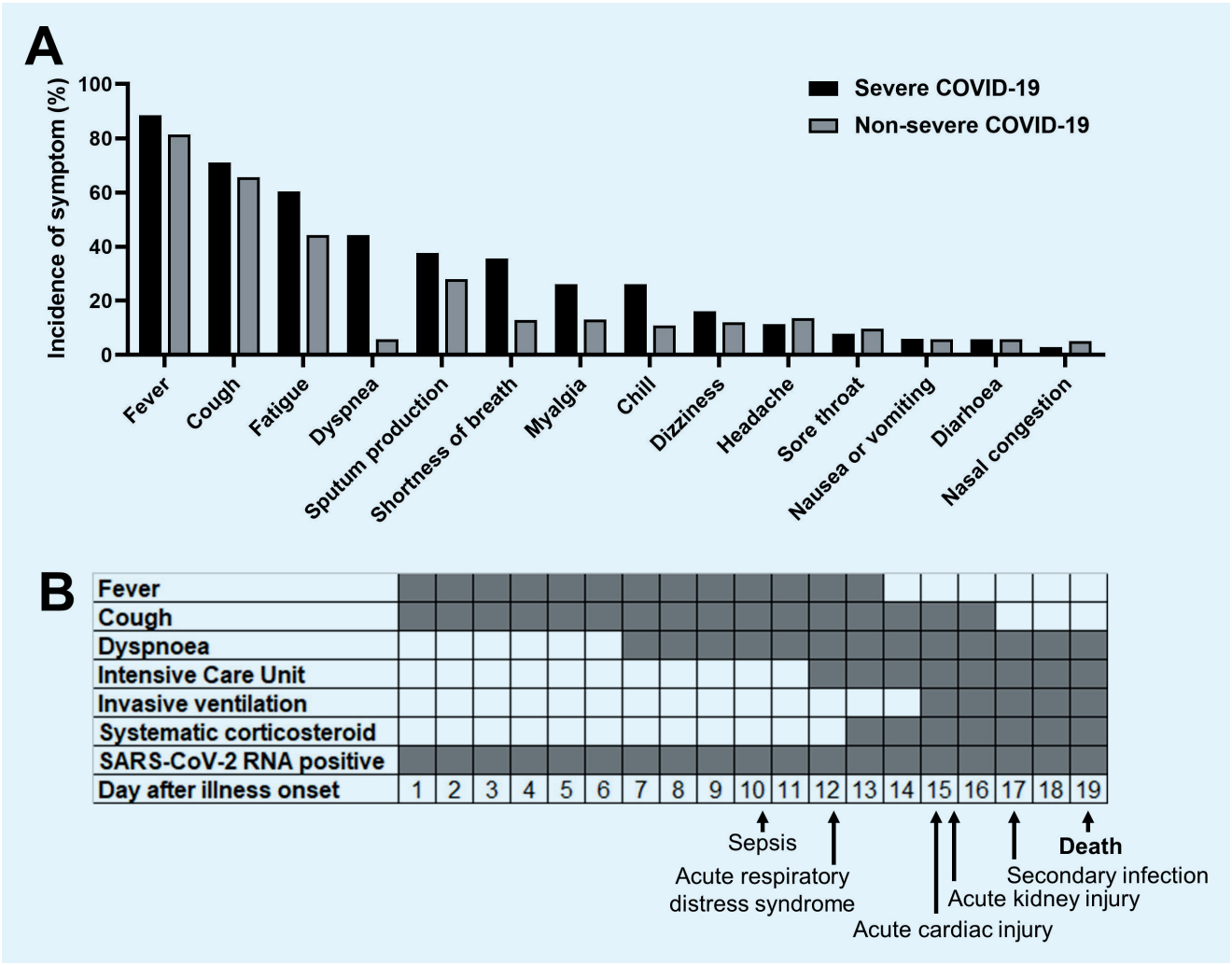

Figure 2

A=COVID-19 symptoms in severe and non-severe COVID-19 cases (57). B=Median duration of symptoms during hospitalized, lethal COVID-19 patients (85).

reliable but requires specialist staff, consumables, and equipment. Properly conducted, these tests are unlikely to record a false positive but poor practice during the taking of samples risks a false negative result (68). The test will not record a positive result if the patient has been infected and cleared the virus, and there is a risk of a false negative result in the earliest stages of an infection.

Antibody-based tests (63) are quicker and can be easy to perform but are at present less reliable. There are two type of antibody tests. The first type of test detects the SARS-CoV-2 virus itself although this will be less sensitive than the RT-PCR test. The second type of test responds to IgM or IgG antibodies that are developed by SARS-CoV-2-infected patients as part of their immune response which is termed seroconversion (68). Seroconversion-related tests are unlikely to give a positive result until about two weeks after the onset of symptoms and they can be complicated by false positive results because of inappropriate design and/or antibodies in a patient directed against other circulating coronaviruses (68). This is a fast-moving field of enquiry but as yet no such tests suitable for mass population screening have been described. Generally, RT-PCR or antibody-based tests are important in identifying, isolating and treating SARS-CoV-2-infected patients. This has helped Singapore, Taiwan, South Korea and Hong Kong limit the initial spread of COVID-19 despite their proximity to China (63).

What are the symptoms of COVID-19? COVID-19 symptoms and outcomes are highly heterogeneous and range from unnoticeable to death (Figure 2A (57)). Since COVID-19 shares many symptoms with the flu, a common cold (19), and even allergies such as hay fever (35) a reliable diagnosis solely based on symptoms and without RT-PCR or antibody-based test (see above) is almost impossible. This applies in particular because COVID-19 symptoms can be mild and differ between patients. People with fever, cough and dyspnea including a shortness of breath, labored breathing, and tightness in the chest should seek medical attention. As illustrated in figure 2A the COVID-19 symptoms differ from common allergy symptoms, which typically include sneezing and an itchy, running nose, or itchy red rash, but typically do not include fever (35). The symptoms of severe cases and their median duration in patients that survive or die are illustrated in Figure 2B. Severe symptoms are associated with the production of high concentrations of cytokines (11, 31).

Why can SARS-CoV2 cause such variation in symptoms? Key factors are age and health status (85). Also relevant are lifestyle factors such as smoking (72), SARS-CoV-2 viral load (which can be 60 times higher in severe than in mild cases (45)), different SARS-CoV-2 variants (67) and, based on what we generally know about viral diseases, probably genetic differences that vary infection susceptibility or immune responsiveness (37).

How is COVID-19 treated? The WHO and other health authorities have issued guidelines for treating patients with COVID-19 (80). In addition, intensive efforts are underway to develop drugs against SARS-CoV-2 and to repurpose ›

existing drugs that might be effective (88). The anti-malarial drug chloroquine phosphate has been reported to be beneficial (23) but the evidence so far is inconclusive. Remdesivir (which inhibits RNA polymerases and was developed as a treatment for Ebola) and chloroquine inhibit SARS-CoV-2 in cultured laboratory cells (77) as does a protease inhibitor against TMPRSS2 (30). There are some hints that remdesivir may improve clinical outcomes in some COVID-19 patients (24).

The major goal for COVID-19 treatment, however, is to develop an effective vaccine. Researchers have solved the structure of the SARS-CoV-2 Spike protein and have shown that antibodies from infected patients can stop Spike protein function. This means that an effective vaccine is possible (76).

What is known about exercisers, athletes and COVID-19? Might athletes be protected from severe symptoms because of their cardiorespiratory fitness? What are the long-term effects of COVID-19 on exercise capacity? Anecdotal evidence suggests that fit individuals and Olympic athletes can suffer a severe infection:

- "Patient 1" of the Italian COVID-19 outbreak was a 38 year old Marathon runner who spent more than two weeks in intensive care with severe pneumonia (59).
- Mark Stubbs, a fit 28 year old Marathon runner, also required intensive care (34).
- Former Olympic Gold & Silver medalist swimmer Cameron Van der Burgh Tweeted on the 22nd March 2020 that "I have been struggling with Covid-19 for 14 days today. By far the worst virus I have ever endured despite being a healthy individual with strong lungs (no smoking/sport), living a healthy lifestyle and being young (least at risk demographic)".

Whilst these reports are anecdotal, they show that athletes per se are not protected from a severe course of COVID-19.

A second point is whether COVID-19 reduces physical performance in the long term. It has been claimed in a newspaper article that some COVID-19 patients have a 20-30% reduction in lung function (14). This is anecdotal and should not be over interpreted as there was no evidence that lung function was measured pre and post COVID-19. However, a 2 year analysis of SARS-survivors found that 52% still had a reduced lung diffusion capacity (DLCO) and that exercise capacity and health status was lower than in controls (56). Thus, negative long-term effects on lung function and exercise capacity cannot be excluded at this stage.

What Do We Know about the COVID-19 Pandemic, What Was the Role of Sport, How Will it Progress, and How Will it End?

The zoonotic move of SARS-CoV-2 into humans from probably bats and/or pangolins has hit a global population with no specific immune defenses. Since the initial, local outbreak could not be contained this triggered a global pandemic that is the worst since that of the 1918 infuenza outbreak that killed an estimated 50-100 million patients worldwide (28). It has been estimated that COVID-19 would, without mitigation, infect ≈90% of the world population and kill 40 million people in 2020 alone (32). To avoid such an outcome, early public health interventions such as social distancing have been implemented to try to "flatten the curve". Such interventions aim to avoid exceeding the capacity of health services to treat severe cases of COVID-19, and to win time to allow the development of drugs and vaccines that will reduce the overall number of deaths (32, 33).

What factors will determine how the COVID-19 pandemic will progress? How is this modelled? The key measure of virus transmission is the basic reproduction number R_0 ("R naught") which denotes how many people become infected by one infected individual (15). R_0 depends on the infectiousness of the virus and on human behaviour, because it will decrease if people travel less, practice social distancing and increase hygiene measures such as hand washing. Early estimates of R_0 for SARS-CoV-2 without mitigation were between 2.2 and 2.7 (44) , i.e. less than Measles (R_0 of ≈10; (25)), but greater than that of 1.3 for seasonal influenza (15). It has been estimated that a related variable, the median daily reproduction number Rt (Rt is how many people are infected by one individual in a certain time in contrast to R_0 which is how many people become infected by a carrier overall) declined from 2.35 to 1.05 when travel restrictions were introduced in China (39). These values for R_0 derived from the Chinese studies (and any others come to that) depend on substantial assumptions as the actual number of infected people remains unknown. Report thirteen from the Imperial College team estimates that measures introduced in March 2020 such as banning of public events, school closures, self-isolation, social distancing and lockdowns have reduced Rt-values from an estimated ≈3-4 to ≈1 in eleven European countries (33). If these numbers are maintained then the pandemic can be contained.

How did COVID-19 spread so dramatically in Europe and what is the role of sport events? The initial European cases appear to be related to a Chinese individual who had infected several employees of a company near Munich in late January 2020 (62). Health officials then tried to identify and quarantine these individuals and all their contacts until they were no longer infectious. Unfortunately this did not fully work. For example, Italian "patient 1" probably became infected in Munich, moved to Northern Italy and then met an estimated 600 people (59). This started or accelerated the Italian outbreak. Similar phenomena took place in other countries. Like other mass gatherings, sports events have contributed to the acceleration and geographical spread of SARS-CoV-2. We discuss two examples. On the 19.2.2020 Atalanta Bergamo played FC Valencia in a Champion's League quarter final in Milan. As the number of cases in Bergamo has increased faster and has been consistently higher than in the rest of the country, this football game has probably greatly accelerated the outbreak in Northern Italy (60). At the same time, it may have also contributed to the outbreak in Spain. Indeed, on the 16.3.2020, Reuters reported that more than a third of the Valencia playing and backroom staff had tested positive for SARS-CoV-2 (65). This example shows how quickly the virus could spread amongst a group of people, none of whom knew they were infected at the time. A second example for a sports-related spread of SARS-CoV-2 is that linked to the Austria ski resort of Ischgl. On 01.03.2020 officials in Iceland discovered that 14 out of 15 passengers who tested positive for SARS-CoV-2 had been in Ischgl. Moreover, Norway stated in its daily report on the 18.03.2020 that 531 (40%) of its 1326 positive cases at the time had probably become infected in Austria (36). These two examples highlight how sports events accelerated and increased the geographical spread of SARS-CoV-2 in the early phase of the COVID-19 pandemic.

How will the COVID-19 pandemic end? The aforementioned mitigation measures have lowered the peak infection and death rates but will prolong the first wave of the pandemic (32). Eventually, sustained R_0 values close to 1 resulting from mitigation, the development of herd immunity (53), warmer weather (7) and the development of a vaccine will cause the Covid-19

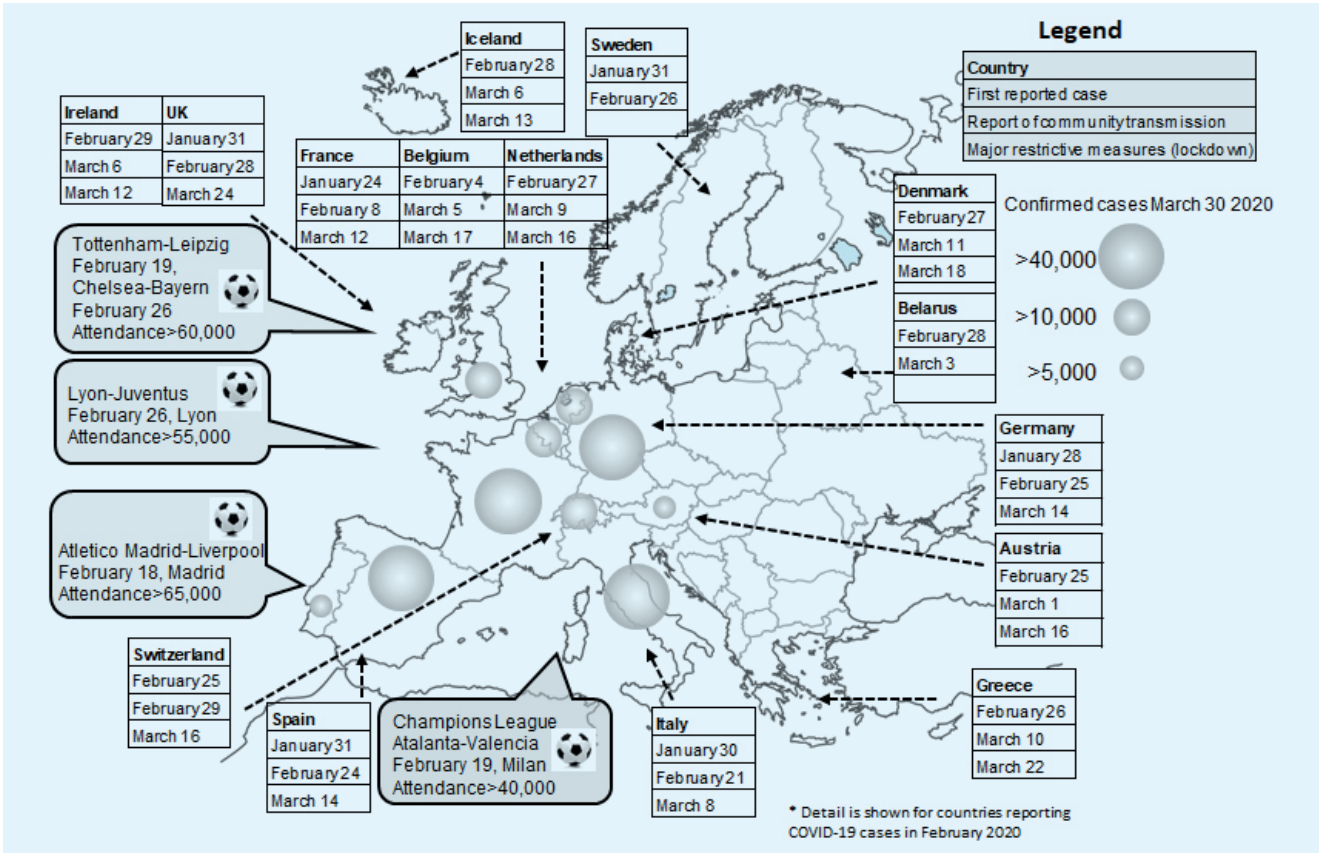

Figure 3

Early COVID-19 pandemic in Europe and international football games.

pandemic to peter out. The future presence of SARS-CoV-2 in the human population will depend on factors such as the duration of immunity after an infection and on the seasonality of the virus (38).

How Does the Immune System Respond to SARS-CoV-2 and How Can We Prevent a SARS-CoV-2 Infection?

There are two main strategies to avoid a SARS-CoV-2 infection. Firstly, we can prevent SARS-CoV-2 from entering our bodies by social distancing and hygiene such as thorough hand washing for 20-30 s and not touching our face. Secondly, if we have become infected, we can try to boost the immune response through a healthy lifestyle. Before discussing whether we can help our immune system to fight an infection, we will first review how our immune system responds to infection. The SARS-CoV-2 coronavirus infects primarily the upper and lower respiratory tract and both the fast innate and slower adaptive immune system will respond. Specifically, infection will lead to the production of so-called "pathogen-associated molecular patterns" (PAMPs) that are detected by receptors on target cells. This in turn initiates a downstream signaling cascade and causes cells to produce inflammatory cytokines such as type I interferons. These cytokines are hormone-like signalling molecules that change gene expression to trigger anti-viral defenses within cells that will restrict many different RNA and DNA viruses and cause inflammation (17). This occurs not only within the infected cell itself, but also in nearby cells which are therefore forewarned and forearmed against the virus. This innate immune response against SARS-CoV-2 also includes immune cells such as macrophages, neutrophils, and natural killer cells (NK cells) which help to limit early viral spread.

The secretion of cytokines by NK cells also stimulates the slower but virus-specific adaptive immune system. This produces virus-specific killer T-cells, termed CD8, which are able to kill virus-infected cells through cytotoxicity (79). In addition, B lymphocytes will produce specific antibodies against the virus which help to detect and fight it (41). In mild COVID-19 cases, the adaptive immune response will eliminate the virus and the patient recovers. In more severe cases, lower amounts of type I interferon are released which reduces not only early viral control but also causes hyperinflammatory neutrophils, monocytes, and macrophages to invade the respiratory system. This in turn can then cause a "cytokine storm" which is a massive release of inflammation-stimulating cytokines by the hyperinflammatory cells (11). Such a cytokine storm contributes to severe COVID-19 symptoms such as pneumonia and/or the acute respiratory distress syndrome (Figure 2) and can cause organs to fail and the patient to die (10, 11).

We often hear that exercise boosts the immune system. So does exercise really help our immune system to fight off a SARS-CoV-2 infection? While there is no clear evidence that exercise reduces the number of acute respiratory infections, regular activity decreases the severity of infectious episodes and the number of symptom days (90). For example, regular exercise is associated with a 6-9% lower excess risk of influenza-associated mortality (83). This association finding is supported by a study in mice that found that moderate exercise in the initial days after an influenza virus infection reduced mortality, suggesting causation (47).

The exact mechanisms by which exercise affects infections are still unclear. Moderate and vigorous endurance exercise, both short term and extended, that lasts less than 60 min stimulates NK cell cytotoxicity (89). Whilst mild exercise may ›

boost the immune system, exhausting exercise may weaken it. This has been termed "open window syndrome" but it is unclear whether exercise to exhaustion itself or other factors that increase the probability of exhaustion weaken the immune system. Nonetheless, athletes who train very hard typically suffer more frequent infections probably because their high training load increases psychological stress and interrupts their circadian rhythms (64). Insufficient sleep in particular can worsen infection risk (16).

Echinacea, elderberries, garlic, curcumin, vitamin C, vitamin D, selenium, probiotics: an unsystematic internet search in April 2020 reveals many supplements that are supposed to boost the immune system to help fighting off a SARS-Co-V-2 infection. But do they really work? With the exception of vitamin D there is no evidence that any of these substances meaningfully reduce the risk of viral infections. A meta-analysis of the risk of acute respiratory tract infection using data from 25 randomised controlled trials with 10,933 participants and found that vitamin D supplementation significantly reduced infection symptoms by 12% (adjusted odds ratio 0.88, 95% confidence interval 0.81 to 0.96) when compared to placebo. The authors concluded that vitamin D supplementation is safe, protects against respiratory tract infection and is most helpful in vitamin D deficient individuals (50). For individuals that are home-bound due to lockdowns and receive less sunlight, vitamin D supplementation might have a minor, beneficial effect.

Probiotics are another supplement that have been suggested to affect infections. Here, a meta-analysis of 12 trials with 3,720 participants suggests that probiotics reduce upper respiratory tract infections by about 47%. Unfortunately, the quality of the trials was poor (26). In contrast, a meta-analysis of data from 15 studies with 5,916 participants with a mean age of 75 years concluded that probiotics were no different than placebos in reducing infection frequency (73). Thus, the evidence for any beneficial effect of probiotics is poor.

In summary, from the perspective of the immune system, we can make a number of recommendations during the COVID-19 pandemic. First, social distancing and hygiene reduce the risk of SARS-CoV-2 infection so this is the most important intervention. To protect the immune system, avoid exhaustive exercise as this may weaken the immune system. Second, ensure to sleep more than 7 h and eat a healthy diet as e.g. recommended by the German society for nutrition. Especially in countries with little sunlight or if a lockdown reduces sunlight exposure consider taking vitamin D supplements (e.g. 4000 UI of vitamin D3 per day) which can reduce infections symptoms by ≈10% or more. Avoid taking other supplements as they probably will not help and some may harm you.

How Should We Exercise during the COVID-19 Pandemic and how Can We Return Safely to Normal Exercise and Sport after the Peak of the Pandemic?

To lower infection rates, in March 2020 European and many other countries introduced far-reaching mitigation strategies including lockdowns of variable severity (33). The extent of the lockdown measures in early April 2020 varied from home isolation with only trips for food and medicine in Italy, to lockdowns that allow some outdoor exercise e.g. in Germany and the UK, to mere recommendations in Sweden. Whilst there are no studies yet on how different types of lockdown affect physical activity, it is clear that less physical activity or exercise training will cause detraining which is a loss of exercise adaptations (54). Here we discuss likely effects of COVID-19 restrictions and countermeasures on healthy adults, athletes and the elderly. We also discuss ways to minimize the detrimental effects of reductions in a normal exercise routine.

Healthy adults: Because of COVID-19 lockdown regulations, gyms and swimming pools have temporarily closed and group exercise is prohibited. This not only means lost income for exercise providers but also radically alters exercise and physical activity behaviour for healthy adults. Especially in countries with a rigid lockdown this will cause detraining and worsen risk factors. For example, reductions in daily step count from 10,000 to below 1,500 reduced insulin sensitivity in adults, while the consequence of fewer than 2.000 steps was a loss of 2.8% of muscle mass within 2 weeks (4, 58, 66). To prevent a loss of endurance, muscle mass and strength, a worsening of risk factors and sub-optimal immunity, we recommend home-based endurance and resistance exercise training plus weight monitoring in those countries where outdoor exercise is prohibited (12). Digital offers such as exercise livecasts by gym instructors have increased and allow healthy adults to continue guided exercise programs at home (46).

Athletes are particularly affected by COVID-19; for example soccer/football leagues and the 2020 Tokyo Olympic Games have been cancelled or postponed. Moreover, team training is impossible and outdoor training has been prohibited by some countries. Where that is the case, athletes such as swimmers, cyclists and team athletes especially may suffer large detraining effects. This will cause inequalities between athletes in different countries depending on whether or not outdoor training is allowed. Moreover, anti-doping testing has stopped (75) and this may be exploited by rogue athletes. We recommend that athletes do not train exceptionally hard whilst the COVID-19 pandemic is ongoing to avoid compromising immunity (see above). Given that mass sports events have helped to spread SARS-CoV-2, it seems unlikely that major, international sports events with spectators will resume before herd immunity or mass vaccinations have been achieved.

The Elderly: Because the elderly and patients with conditions such as diabetes mellitus are at a higher risk of serious COVID-19-related disease and death, it seems likely that many will stay at home and reduce physical activity. There is the danger that reduced physical activity may accelerate the normal musculoskeletal ageing processes such as sarcopenia, worsen health, reduce physical function and bring forward the loss of independent living. To avoid this, a non-peer reviewed article recommends the following for the elderly during COVID-19 (27):

- A mixture of resistance, strength and balancing exercises. Recommendations for home-based resistance exercises for the elderly (69) and the prevention and treatment of sarcopenia exist (74).
- A social element should be added to exercise as this may improve adherence and motivation and also reduce the risk of depression and anxiety.
- Exercise programs for the elderly can be supported by the internet, video games, media broadcasts or phone calls.

The almost impossible challenge, however, is to implement these recommendations early enough so that the elderly benefit whilst the COVID-10 pandemic is still ongoing.

How can our sport and exercise culture return to normal after the COVID-19 lockdowns and before herd immunity or mass vaccination is achieved? There are several possible lockdown exit scenarios that aim to keep the infection risk low whilst allowing more economic and other activities (55). To achieve this, the cited report recommends tracking apps in

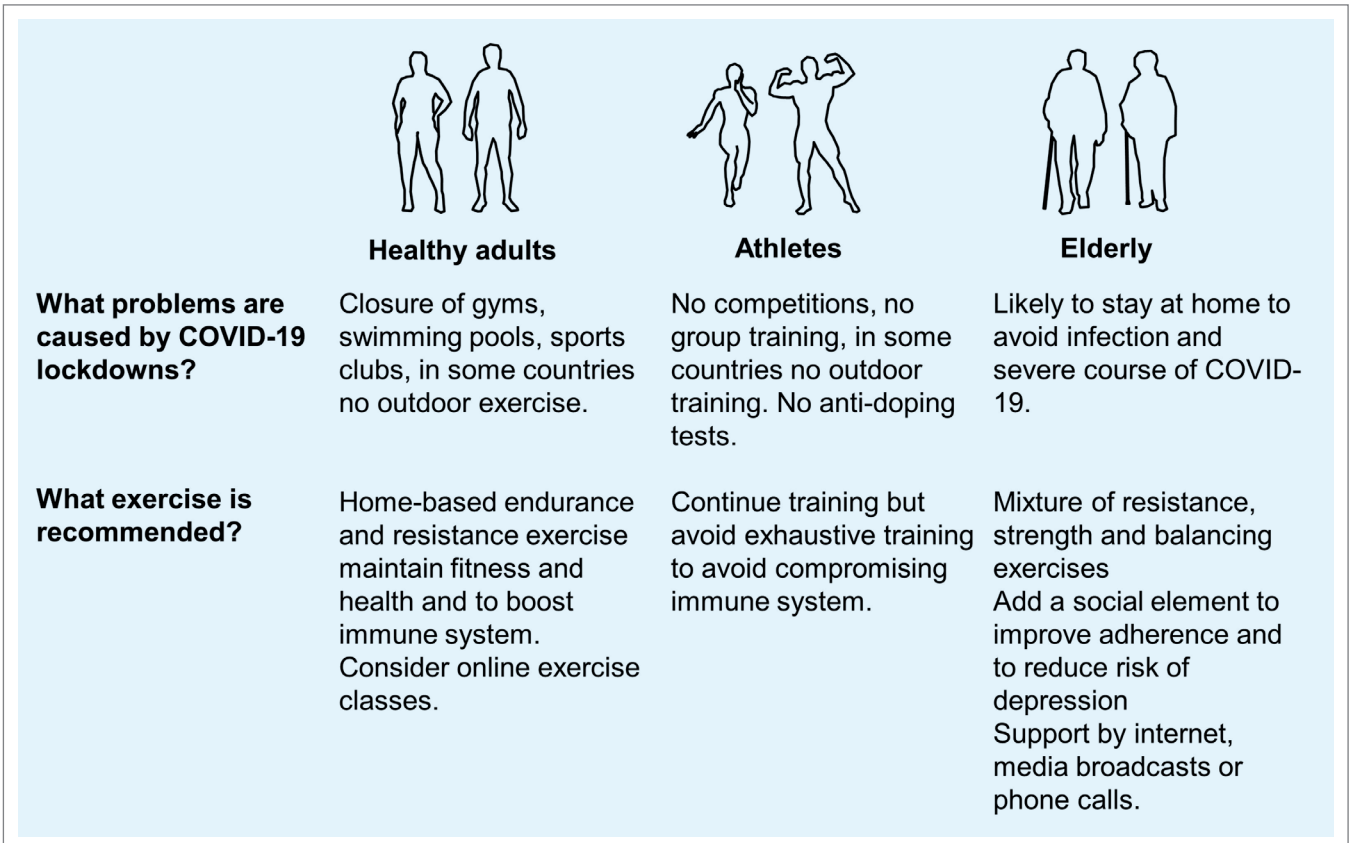

Figure 4

Problems caused by COVID-19 lockdowns and exercise recommendations for healthy adults, athletes and the elderly.

combination with frequent and massive SARS-CoV-2 testing (22). Once anyone develops symptoms, they should be rapidly tested then anyone they came into close contact with on previous days are traced via the tracking app and isolated. If this strategy works then it could replace lockdowns for the whole population. It does, however, require a degree of surveillance of individuals that would be unprecedented in the modern era in European countries, with a high degree of compliance.

At some stage gyms, swimming pools and sports clubs will be allowed to reopen. If this happens when there is still transmission of COVID-19 within that community, then exercise providers will need to risk assess their operation and introduce containment strategies to limit the infection risk and to shield risk groups. We now discuss possible strategies to achieve that goal.

Firstly, exercise facility managers should educate themselves, staff and clients about COVID-19 and must know the principles of controlling hazards and risks. There will need to be formal risk assessment procedures, perhaps adopted at a national level to ensure consistency. Secondly, exercise facilities need to follow COVID-19-specific disinfection rules, for example those published by the European Centre for Disease Prevention and Control (ECDC) for general settings. These include using a neutral detergent for surfaces, virucidal disinfectants for toilets and personal protective equipment such as uniform and gloves for cleaning personnel (20). If clients share equipment such as dumbbells, barbells or ergometers, then these should be disinfected after every user to avoid transmission by SARS-CoV-2 contaminated surfaces.

Exercise facilities should also limit exercise types, enforce social distancing and consider mandatory face masks. Ventilation can increase from 5 l/min to more than 100 l/min during maximal exercise. For this reason it seems likely that an asymptomatic, infectious individual will spread SARS-CoV-2 to a greater degree during high intensity exercise than at rest. If there is still some COVID-19 community transmission in an area, exercise providers should therefore consider limiting indoor exercise to low-intensity activities such as yoga, resistance training and low-intensity aerobic training whilst avoiding high intensity exercise classes such as spinning or exercise to music. All exercise spaces should be well ventilated as poor ventilation is a risk factor for infections and aerosol may persist for longer if the ventilation is poor (1).

In a review, face masks have been recommended for the public during the COVID-19 crisis (22) and the use of face masks could prevent the transmission of coronaviruses during rest. In a recent study, researchers quantified the amount of respiratory virus RNA in exhaled breath of patient with acute respiratory illnesses, during 30 min. Without face masks, in 30% of droplet samples and 40% of aerosol samples coronavirus RNA was detectable, whereas it was undetectable in samples taken from patients wearing surgical masks (43). As a consequence of increased breathing during exercise it is expected that face masks absorb an increased amount of moisture, and lose their protective effect after 10-15 min (66). This would restrict the period for a protective effect and more than one mask should be available during training activities. However, face masks may also induce a false sense of security if they are incorrectly fitted, not renewed frequently enough, or if any virus caught within the mask is transferred to the person's hands during removal.

Another point is that social distancing rules of 1-2 m distance may not be enough to prevent SARS-CoV-2 infections when exercising. A non-peer-reviewed paper has recommended a distance of >4.5 m behind a person while walking, >10 m when running and >20 m when cycling outdoors (data will be different for indoor exercise, as exercisers are not actually moving (5)). However, these experiments just investigate how

water particles travel and so these distancing guidelines seem premature. Finally, special rules are needed for swimming pools and saunas. Water disinfection with chlorine inactivates viruses such as SARS-CoV-2 (70, 78) but there is evidence that one individual has infected eight others with SARS-CoV-2 in a public bath in China via an undefined route (48).

What are the criteria for mass sports events during the COVID-19 pandemic and during possible future outbreaks? Mass sports events have accelerated the global spread of Covid-19 (Figure 3), and therefore, international sporting events such as the Olympic games have the potential to spread SARS-CoV-2 during the event, followed by a new global COVID-19 outbreak when spectators and athletes travel back to their home countries. The WHO has issued specific risk assessments guidelines for mass gatherings during the COVID-19 pandemic (51, 81, 82). Whilst mass gatherings may be too risky during the global COVID-19 pandemic, sporting events without spectators such as so-called ghost games could allow sports events with a controlled SARS-CoV-2 infection risk. This is especially true if athletes are screened for SARS-CoV-2 infection and COVID-19 symptoms before each game. However, pre-participation screening of each athlete e.g. by RT-PCR testing for SARS-CoV-2 would be too expensive for most sports federations and it is no substitute for strict quarantine once an infected athlete has been identified.

Conclusion and Take Home Messages

COVID-19 is a disease caused by the coronavirus SARS-CoV-2. The global COVID-19 pandemic of 2020 has been accelerated by sports events and it affects all aspects of life including work, travel as well as sports and exercise. Whilst social distancing and hygiene are key to avoiding infections, moderate exercise, sufficient sleep can reduce the risk of a SARS-CoV-2 infection or symptom duration and severity further. On the other hand, exhausting exercise should be avoided. Measures such as lockdowns have been used to reduce infection rates successfully but result in detraining especially in countries where outdoor exercise is prohibited. Home-based exercise can reduce the detrimental fitness and health effects of detraining. Until herd immunity, which probably will be time-limited or mass vaccination is achieved, exercise providers and sports mass gathering organisers need to risk assess their operation and use special hygiene, social distancing, face masks and other measures to reduce the risk of renewed outbreaks. The duration of immunity after a SARS-CoV-2 infection and on the seasonality of SARS-CoV-2 infections will determine the frequency and strengths of future outbreaks and it seems likely that new COVID-19 outbreaks will occur for many years to come (38).

Conflict of Interest
The authors have no conflict of interest.

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Sport und COVID-19, die Krankheit, die von dem SARS-CoV-2-Coronavirus verursacht wird

Sport, Exercise and COVID-19, the Disease Caused by the SARS-CoV-2 Coronavirus

Design der Arbeit

In diesem narrativen Review beantworten wir die folgenden fünf Fragen zum SARS-CoV-2-Coronavirus, der dadurch hervorgerufenen COVID-19-Infektionskrankheit und zu Sport:

1) Was wissen wir über das SARS-CoV-2-Coronavirus, das die COVID-19-Krankheit verursacht?
2) Was wissen wir über die COVID-19-Krankheit und wird sie durch körperliche Belastung beeinflusst?
3) Wie hat sich die COVID-19-Pandemie entwickelt, was war die Rolle des Sports und was ist die Zukunft des Coronavirusses?
4) Wie reagiert das Immunsystem auf SARS-CoV-2 und können wir durch körperliches Training und anderweitig eine SARS-CoV-2-Infektion verhindern?
5) Wie sollten wir uns während der COVID-19-Pandemie sportlich betätigen und wie können wir nach dem Höhepunkt der Pandemie sicher zu normaler Bewegung und Sport zurückkehren?

Ergebnisse und Diskussion

Das SARS-CoV-2-Coronavirus wurde 2019 erstmals von Tieren auf Menschen übertragen und danach auch von Mensch zu Mensch. SARS-CoV-2-Infektionen geschehen primär über beim Husten, Niesen und Sprechen generierte Tröpfchen, durch das Berühren von SARS-CoV-2-kontaminierten Oberflächen (z. B. Sportgeräte wie Hanteln) und wahrscheinlich auch über Aerosol (kleinste Flüssigkeitspartikel von ≤5 µm Durchmesser). Nach aktuellen Schätzungen geschehen fast die Hälfte der Neuinfektionen durch Personen ohne spezifische Krankheitssymptome. Daher sollten alle Kontaktpersonen beim Sport oder in anderen Situationen wie potentielle Infektionsüberträger behandelt werden.

SARS-CoV-2 ruft die COVID-19-Infektionskrankheit hervor, die ein variables Krankheitsbild bis hin zu schweren Lungenentzündungen mit Todesfolge durch multiples Organversagen hervorruft. Besonders gefährdet sind ältere Menschen über 65 Jahre mit kardiovaskulären, respiratorischen und/oder metabolischen Vorerkrankungen. Zwar haben jüngere Sportler und Sportlerinnen ein niedriges Risiko für einen schweren COVID-19-Verlauf, doch es gibt Ausnahmen, die intensivmedizinisch behandelt wurden. Rückblickend haben Sportevents, wie das Fußballspiel zwischen Atalanta Bergamo und FC Valencia, die Ausbreitung von SARS-CoV-2 regional und international beschleunigt. Zukünftige Sportgroßereignisse, wie z.B. die olympischen Spiele in Tokio 2020, wurden wegen der SARS-CoV-2-Pandemie verschoben. Sorgfältige Hygiene, wie gründliches Händewaschen, „Social Distancing" (größere Distanzen zu anderen Personen insbesondere bei intensiven Aktivitäten) sowie das Tragen von Gesichtsmasken (Mund-Nasen-Schutz) sind wichtig, um SARS-CoV-2-Infektionen zu verhindern. Während es keine Daten zum SARS-CoV-2-Infektionsrisiko bei sportlich aktiven Personen im Vergleich zu inaktiven Menschen gibt, kann ein sportlich aktiver Lebensstil bei anderen Infektionserkrankungen die Schwere des Krankheitsverlaufs sowie die Krankheitstage reduzieren. Es gibt keine Evidenz dafür, dass eine Supplementation von Vitamin C, D oder anderen Mikro- oder Makronährstoffen die Häufigkeit von Atemwegsinfektionen reduzieren kann. Interventionen wie „Lockdowns" und „Home Office" haben das Sport- und Bewegungsverhalten von Erwachsenen, Leistungssportlern und –Sportlerinnen sowie älteren Menschen unterschiedlich verändert. Dopingkontrollen wurden während der Pandemie nicht mehr durchgeführt. Die Rückkehr zum gewohnten Sport- und zur Bewegungskultur sollte schrittweise unter Einhaltung des Infektionsschutzes erfolgen, um neue Infektionsherde beim Sport zu vermeiden.

Fazit für die Praxis

1) Da möglicherweise fast 50% der COVID-19-Infektionen durch Personen ohne Symptome erfolgen, sollten Sportler und Sportlerinnen andere Personen als mögliche SARS-CoV-2 Überträger behandeln.
2) SARS-CoV-2-Infektionen werden vor allem über sorgfältige Hygiene wie Händewaschen, Physical/Social Distancing und Gesichtsmasken (Mund-Nasen-Schutz) vermieden. Es gibt keine Evidenz dafür, dass körperliches Training oder die Supplementation von Vitaminen wie C oder D oder andere Mittel das SARS-CoV-2-Infektionsrisiko reduzieren.
3) Einige Sportmassenveranstaltungen waren „Katalysatoren" für die Ausbreitung von SARS-CoV-2. Basierend auf diesen Erfahrungen erscheint es als schwierig, vor der Entwicklung von Impfstoffen internationale Sportgroßveranstaltungen mit hohen Zuschauerzahlen bei einem akzeptablen SARS-CoV-2-Infektionsrisiko durchzuführen. Mögliche Übergangslösungen sind Sportveranstaltungen ohne Zuschauer oder eine Quarantäne für Sportler, Sportlerinnen, Offizielle und Zuschauer.