Infection and the Elite Athlete: A Review

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Infection and the Elite Athlete: A Review

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Light to moderate exercise has been associated with an increase in immune function and reduced risk of infectious diseases. Conversely, heavy exercise has been implicated in suppression of many immune parameters and a concomitant increased risk of infectious diseases. Infections can result in lost training time and negatively affect the performance of the elite athlete. Exercising during an infection can also increase the risk of secondary complications, such as viral myocarditis and post-viral fatigue syndrome. In addition to immunosuppression, other factors responsible for increased infection rates among athletes are close bodily contact with other people during training and competition, and environmental factors during the pursuit of sporting activities that increase exposure to pathogens. Although there is a generally higher risk of infection among athletes compared to the general population, some sports are associated with a particularly high risk for certain infections. These are skin infections in rugby and wrestling, infections of the foot in long-distance runners, and ear infections in those involved in water sports. Upper respiratory tract infections are the most frequently reported disability among all athletes and are the cause of more lost training days than all other infections put together. Transmission of blood-borne pathogens, although very uncommon in the athletic setting, are the cause of the most serious infections an athlete may develop. When considering the negative impact of infections on performance, it seems prudent that athletes use interventions to decrease the immunosuppressive effects of heavy exercise, and to minimize exposure to pathogens as far as practically possible. Management of the infected athlete is especially important if there is to be a speedy return to full training, and if the incidence of a relapse or secondary complications are to be minimized.

Keywords elite athlete, infection, immunosuppression

Introduction

Infectious diseases in elite sports can pose considerable problems, either to the individual athlete or to an entire sports team or squad. Substantial quantities of

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time, effort, and money typically are invested in elite athletes and professional sports teams, all of which may prove unproductive if the deleterious effects of infectious diseases on training and competition performance become evident. An infection may result in competing or performing at a subpar level, or may even necessitate pulling out of a competition altogether (Nieman 1997b). For example, numerous athletes were reported unable to compete at past Olympic Games due to infectious illness (Mar 1996; Nieman 1994).

Some infections may be acute in nature (e.g., the common cold), and their effects on physiological status and the transient decrease in functional capacity typically are clearly apparent (Friman and Wesslen 2000). During the symptomatic stages of infection, not only is quality training time lost, but attaining pre-infection performance may take several more weeks after the symptoms of the acute infectious stage have subsided. Additional to acute infections, there are also chronic low-grade infections that can persist for many months (Friman and Wesslen 2000). It is this latter type of infection that has largely been implicated in the prolonged and unexplained loss of form of some elite athletes (Pasvol 1998; Roberts 1985). Chronic infections also have been implicated as a cause of two related conditions: the so-called chronic fatigue syndrome (Derman, Schwellnus, Lambert, et al. 1997; Shephard 2001) and the postviral fatigue syndrome (Budgett 1991; Pasvol 1998), the debilitating effects of which typically last many months (Nieman 1998a, 2000b; Rowbottom, Keast, Green, et al. 1998). As well as physiological factors, due to the pressure to perform well, the elite athlete is more likely susceptible to negative psychological perturbations if training is not going well or has to be temporarily suspended due to infection.

It is possible that the elite athlete of today is more predisposed to contracting an infectious disease than his or her counterpart of past decades. This may be as a result of greater training loads and an increased susceptibility to overtrain, increased incidence of training and competing in foreign locations, increased crowding in sporting venues and public transport, and an increased exposure to air-conditioned environments (Pyne, Gleeson, McDonald, et al. 2000). Consequently, prevention and control of infectious diseases in the elite athlete of today warrants considerable attention, if both short- and long-term interruptions of training are to be minimized and individual or team peak performance attained. The purpose of this present article is to provide information relating to the types of infection and risk factors pertinent to elite athletes, and to provide practical recommendations for athletes and their coaches in relation to applying interventions in an attempt to reduce the incidence of infection and help manage the infected athlete.

Incidence of Infection and Immunological Factors

Individuals who exercise regularly often believe that this exercise promotes increased resistance to infection (Mackinnon 2000; Nieman 2000e). Indeed, research has indicated that light- to moderate-intensity exercise may enhance the function of certain immune parameters (Nieman 2000a; Shore, Shinkai, Rhind, et al. 1999) and lead to a decrease in the incidence of infectious episodes in individuals who regularly engage in such exercise, compared to more sedentary individuals (Nieman, Johanssen, and Lee 1989). Conversely, individuals who engage in prolonged moderate- to high-intensity exercise are thought to be at higher risk for contracting numerous infections than either sedentary individuals or individuals engaging in light to moderate recreational exercise (Beck 2000; Gleeson, Blannin, Sewell, and Beck 1995; Mackinnon 2000; Weidner 2001). The paradoxical relationship between exercise workload and infection risk is highlighted by the J-shaped curve (Figure 1), which shows the relationship between exercise workload and the incidence of upper respiratory tract infections (URTIs), with elite athletes positioned at the far right of the curve. A recent study by Novas, Rowbottom, and Jenkins (2002) provided support for the J-curve model by demonstrating increased incidence of URTIs in subjects with either low or extremely high total daily energy expenditures, and the lowest URTI incidence in subjects with moderate expenditures.

High infection rates among athletes have been reported in the literature. Elite swimmers, for example, undertaking 20–25 hr × wk^{-1} of pool training and 5 hr × wk^{-1} of dry land training were found to have an increased incidence of infection when compared to controls (Gleeson, McDonald, Pyne, et al. 1999). Similarly, in a study by Mackinnon and Hooper (1996), 10 of the 24 elite swimmers (42%) taking part experienced a URTI during a 4-week overtraining period. A large study by Nieman, Johanssen, Lee, et al. (1990) involving 2,311 participants in the Los An-

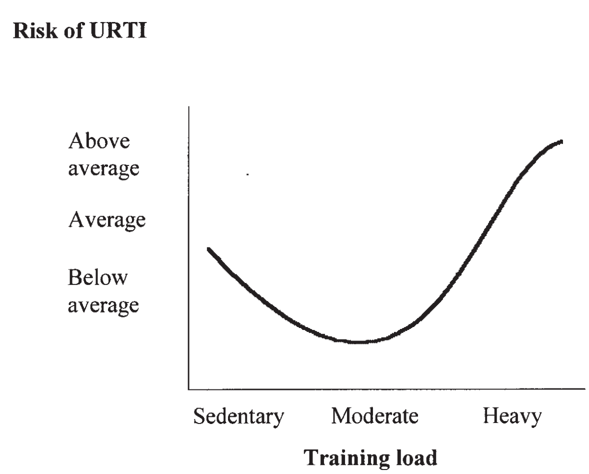

Figure 1. The “J”-shaped curve demonstrating a decreased risk of URTI in individuals engaging in light-to-moderate exercise, and an increased risk in those engaging in heavy exercise compared to sedentary individuals (adapted from Nieman, 1999).

geles Marathon demonstrated that runners training 97 km × wk^{-1} or more (training loads close to that of some elite endurance runners; Berg, 2003; Billat, Lepretre, Heugas, et al. 2003) had almost double the infection rates of those running less than 32 km × wk^{-1}. Furthermore, of the 1,829 participants sick-free one week before the race, 12.9% became sick during the week following the race. This compared to 2.2% of 134 runners who remained sick-free before the race, but chose not to participate. This indicates that additional to high training loads, the physiological and psychological stresses of competition are important factors in increasing the incidence of infection. Reports of higher incidences of infection other than URTIs in athletes compared to nonathletes have also been documented (Choe, Hwang, and Hong 2002; Lacroix, Baspeyras, de La Salmoniere, et al. 2002).

Although higher infection rates among elite athletes compared to controls have not always been found (e.g., Gleeson, Pyne, McDonald, et al. 1996; Mueller, Villiger, O'Callaghan, et al. 2001; Pyne, Baker, Fricker, et al. 1995), it is possible that certain preventative measures and lifestyle factors common to many elite athletes (but not to sedentary individuals used as controls) could attenuate any immunosuppressive effects of training and reduce any associated increased risk of infection. Mueller, Villiger, O'Callaghan, et al. (2001), for example, found that athletes in their study had a preseasonal influenza vaccination. Elite athletes also are more likely to consume nutrient-dense diets and nutritional supplements such as antioxidants and to engage in psychological techniques to reduce sociopsychological stress, all of which may negate any immunosuppressive effects of high training loads. Additionally, many studies examine only immune responses to single bouts of exercise or short training periods. Although depressed immune function may occur after a few days of intense training, a review of the literature by Gleeson (2000b) indicated that longer periods of training (such as greater than 3 months) are required to elicit significant immunosuppression.

The increased susceptibility to infection found in some elite athletes has been largely related to both transient and long-term immunosuppression as a result of intense or prolonged exercise, or both (Nieman 2000b). Moreover, there is general agreement that periods of vulnerability are more evident during the high training loads typically undertaken close to or during competition (Gleeson 2000a). This has been supported in a study by Foster (1998), which showed that 84% of illnesses in a group of experienced athletes could be explained by a preceding spike in training load. The overtrained state may be an especially important factor in the development of suppressed immunity and increased infection risk (Beck 2000; Eichner 1995). In fact, it has been suggested that an increased susceptibility to infection is one of the most common symptoms of overtraining (McKenzie 1999). Disturbances in specific immune parameters as a result of intense exercise have been extensively reviewed (e.g., Mackinnon 1998; Nieman 1997a, 2000d; Pederson and Hoffman-Goetz 2000). Nieman (1997a) and Brenner, Shek, Zamecnik, et al. (1998) have suggested that exercise-related immunosuppression may be related to elevated corticosteroids and depressed androgen levels, which have been associated with intense, prolonged exercise (McMurray and Hackney 2000) and periods of overtraining (Bird, Black, and Newton 1997).

Infection Types and Risk Factors

With an ever-increasing range of sports, increasing participant numbers, and increased travel associated with participation in these sports, almost every known infectious human disease is a potential threat to the elite athlete. The environments and situations in which athletes find themselves, through the pursuit of training and competing in their chosen sport, along with the increased incidence of immunosuppression, often place the elite athlete at a much higher risk for contracting more infectious diseases than the nonathlete. A list of risk factors for infectious diseases common to elite athletes is presented in Table 1.

Table 1
Risk Factors That May Predispose the Elite Athlete to Increased Incidence of Infections

General risk factor	Specific risk factor
Sporting facilities	Communal changing and showering areas. Enclosed training and competition areas with inadequate ventilation. Sharing of exercise mats and other exercise/sports equipment.
Accommodation	Communal living quarters. Communal dining rooms.
Travel to and from training and competitions	Air conditioned coaches and planes. Training and competing in foreign places.
Nature of sport	Close contact with training partners and opponents. Risk of blood letting (especially in contact sports). Sweating for long periods combined with warm conditions on skin. Porous equipment that cannot be washed (e.g., leather boxing gloves).
Miscellaneous	Athletic clothing, especially sports footwear. Exercise-induced immunosuppression.

Skin Infections

Skin infections represent some of the most common dermatological problems in athletes (Adams 2001). Not only are athletes at a general high risk of exposure to skin infections, but certain sports or events carry a higher risk than others for specific infections. Marathoners, for example, are at a particularly high risk for tinea pedis (Lacroix, Baspeyras, de La Salmoniere, et al. 2002), wrestlers for tinea corporis (Kohl and Lisney 2000), rugby players for herpes simplex and staphylococcal infections (Stacey and Atkins 2000), and athletes involved in water sports for otitis externa (swimmer's ear; Beck 2000). In fact, many skin infections are commonly known by their sport-related pseudonyms, such as scrum-pox (Shute, Jeffries, and Maddocks 1979), scrum strep (Dorman 1981), tinea gladiatorum (Kohl and Lisney 2000), and herpes rugbeiorum (Verbov and Lowe 1974), among others. Although many of these infections are often regarded as a mere nuisance, they also can be associated with performance-debilitating systemic symptoms such as fever, malaise, and myalgia (Stacey and Atkins 2000), and other significant problems, such as follicular conjunctivitis and photophobia (Beck 2000). Skin infections also have the potential to significantly disrupt entire sports teams or athletic squads (Adams 2002).

Wrestlers and rugby players appear to be at greatest risk for skin infections, due to the close skin contact between players during training and competition, and in particular rugby players involved in scrums. The high risk of skin infection among rugby players is exacerbated by players who purposely compete with unshaven faces, which often leads to the traumatized skin of opponents, brought on by an abrasive effect of facial stubble (Stacey and Atkins 2000), thus reducing physical protection against pathogens (Caputo, De Boulle, Del Rosso, et al. 2001). The medical literature has cited several outbreaks of skin infections among rugby clubs (Dorman 1981; Ludlam and Cookson 1986; Shute, Jeffries, and Maddocks 1979; Verbov and Lowe 1974) and a wrestling team (Cohen, Schmidt, and Hopkins 1992), and in most cases these infections have been attributed to the bacteria Streptococcus pyogenes and Staphylococcus aureus, and the Herpes simplex and Herpes zoster viruses.

Upper Respiratory Tract Infections

From a human perspective, viruses are the most infectious agents known (Weidner, Anderson, Kaminsky, et al. 1997). Perhaps more significant to the athlete, they are the cause of most URTIs seen in the athletic setting (O'Kane 2002; Wilson 2001). It has been documented that URTIs are the illnesses to which athletes are most susceptible (Mackinnon 2000). They are the most frequently reported disability among athletes and cause more lost training days than all the other infectious diseases combined (Beck 2000; Weidner 2001). A review of the literature by Nieman (2000b) highlighted that the increased risk of URTIs was highly correlated with heavy physical exertion, such as intense exercise, an inherent component of the elite athlete's training program. Furthermore, athletes in an overtrained state may be especially susceptible to URTIs (Eichner 1995).

Somatic symptoms associated with URTIs are fatigue, joint pain, muscle weakness/myalgia, headaches, cough, sinus pain, a sore or scratchy throat, a mild chill, congestion, itchy eyes, and lymphadenopathy (O'Kane 2002; Pasvol 1998; Weidner 2001). During a URTI, some of these symptoms may or may not be present, and they collectively peak 3 to 4 days after initial infection (Weidner, Cranston, Schurr, et al. 1998). The presence of some of these symptoms can have a profound negative impact on performance (Roberts,1985), especially when systemic involvement is present (Friman and Wesslen, 2000). Furthermore, URTIs may persist for 10–20 days (Shephard 2000), and therefore have the potential to significantly disrupt the athlete's training schedule. The causes of the high incidence of URTIs in athletic populations can be inferred, when consideration is given to the modes of transmission of the viruses involved (i.e., inhalation of aerosol droplets and inoculation through hand contact with the eyes or nose; Wilson 2001) and many of the environmental factors are highlighted in Table 1. These factors act together with transient periods of immunosuppression, especially low salivary IgA concentrations (Gleeson, McDonald, Pyne, et al. 1999), to place the athlete at a particularly high risk for URTI. Other factors suggested to increase susceptibility to URTIs are exposure to novel pathogens, lack of sleep, malnutrition and weight loss, and severe mental stress (Nieman 2000a), such as the stress associated with athletic competition (Brenner, Shek, and Shephard 1994). Additionally, it is likely that any sociopsychological stressors will increase the susceptibility to URTI, as these have been shown to compromise immune function (Pasvol 1998). This latter point has been supported in a study by Cohen, Tyrell, and Smith (1991) that demonstrated that psychological stress increased the incidence of respiratory illness in 394 healthy subjects inoculated with one of five different respiratory viruses, even when the results were controlled for confounding variables (e.g. age, gender, allergic status).

Infections From Blood-Borne Pathogens

Although infections among athletes derived from blood-borne pathogens during sporting activity are relatively uncommon and infection risk extremely small (Anderson, Griesemer, Johnson, et al. 1999; Mast and Goodman 1997) or negligible (Dorman 2000), they represent some of the most serious infections the elite athlete could potentially contract. Serious infections derived from blood-borne pathogens associated with athletes documented in the literature are hepatitis B and C viruses and the human immunodeficiency virus (HIV). Athletes at greatest risk of exposure to these viruses are those competing in contact sports such as wrestling, rugby, and boxing. Although the incidence of athletes being infected with blood-borne pathogens is extremely low, it is not unheard of. For example, HIV-1 seroconversion between two Italian soccer players, during a collision that resulted in both players bleeding copiously from the eyebrows, has been reported (Torre, Sampietro, Ferraro, et al. 1990). Similarly, a vigorous fistfight between a wedding guest and an intruder at a wedding reception resulted in profuse bleeding from the face of both men and HIV-1 seroconversion (O'Farrell, Tovey, and Morgan-Capner 1992). Although this latter example is not sport-related, it has direct implications for sports such as boxing and contact martial arts.

Another source of risk of infection from blood-borne pathogens is the use of anabolic steroids, used by many elite athletes to enhance performance (Bahrke and Yesalis 2002). The risk of infection comes from athletes who reportedly share needles and syringes for intramuscular injections (Nemechek 1991). Infection risk may be increased due to the stigma, secrecy, and nonsupervision of anabolic steroid use in athletes (Rich, Dickinson, Feller, et al. 1999), factors that likely increase the use of contaminated syringes and drug preparations, and nonsterile injection technique (Rich, Dickinson, Flanigan, et al. 1999). To date, one incident of an anabolic steroid user presenting with HIV infection has been reported in the literature (Sklarek, Mantovani, Erens, et al. 1984). Additionally, a review of the literature by Rich, Dickinson, Feller, et al. (1999) highlighted several reports of hepatitis B and C infection from injecting anabolic steroids. The apparent low incidence of infection from blood-borne viruses among anabolic steroid users may be misleading. In their review of the literature relating to infections in anabolic steroid users, Aitken, Delande, and Stanton (2002) highlighted that there is a lack of research in this area and, as a result, this has likely resulted in substantial underreporting. Although HIV and hepatitis infections in athletes have been more widely publicized, likely due to their more serious nature, it has been recognized that most infections relating to anabolic steroid injection are abscesses caused by bacteria (Rich, Dickinson, Flanigan, et al. 1999). Additionally, anabolic steroids at supraphysiological doses may cause immunosuppression (Hughes, Fulep, Juelich, et al. 1995), possibly increasing risk of infection to unrelated infections such as URTI, although research is required to substantiate this hypothesis, as little has been published in this area (Hughes, Fulep, Juelich, et al. 1995).

Reducing Infection Risk in Elite Athletes

Transmission of Infectious Agents

By examining the factors that predispose the athlete to an increased risk of infection (Table 1), it becomes clear that certain simple measures can be undertaken to significantly reduce this risk. The most effective way of reducing infections in athletes is to minimize exposure to pathogens (Shephard and Shek 1994). In the athletic setting, exposure and resultant transmission of infectious agents are generally by direct contact with an infected object or person, or through the inhalation of pathogens suspended in the air. Contact is generally the most common method of transmitting infection, especially via the hands (McCulloch, Finn, and Bowell 2000).

Proper hand washing with bactericidal hand wash and avoiding touching the nose, eyes, and mouth with the hands are thus effective measures in minimizing infection by this method. Transmission may also occur via contact with infected towels, razors, and sports equipment, and thus it is generally recommended that these should not be shared with other athletes (Stacey and Atkins 2000; Weidner 2001). Avoiding crowded, enclosed areas and individuals known to have been infected with a respiratory virus are also major precautions in minimizing exposure to pathogens. Extra vigilance should be exercised for the period several hours postexercise, as this has been associated with a significantly blunted immune response and an increased susceptibility for pathogens to gain a foothold—a period known as "the open window" (Brines, Hoffman-Goetz, and Pederson 1996; Nieman 2000c; Pederson, Rohde, and Ostrowski 1998).

Team sport players and athletes who train in squads or large numbers require special consideration, in that infections can spread rapidly throughout the whole team or squad, and in severe cases may incapacitate a team sufficiently to render it ineffective. Contact sports have received the most notoriety in this respect (Stacey and Atkins 2000), especially with skin infections that can spread rapidly through contact during training. Respiratory viruses are potentially problematic for athletes who change and shower in large numbers and participate in team talks and other forms of intercourse involving large numbers in confined spaces (Madeley 1998). With sports teams or squads, the role of the trainer or team physician may be more prominent in infection control than control measures implemented by individual athletes. This is because control measures undertaken by individual athletes may prove futile if teammates do not themselves undertake any precautionary measures, possibly leading to a high incidence of infections within a team and a high risk of exposure in teammates who have yet been infected. The team physician can monitor for signs of infection in team members. This may involve periodic skin inspections or sending blood samples for analysis, although this latter procedure is both time-consuming and expensive (Nash 1994). Upon identification of any infection, measures can be implemented to prevent the spread of the infection among the team or squad. This may involve isolating these athletes from uninfected ones (e.g., separate training days or times until the infection has subsided), or in the case of a skin infection, adequately covering the skin lesion while it is in the infectious state. Procedures and rules also can be implemented and nonconformity could lead to punishment, such as a fine or temporary suspension from the team. Examples of rules that could be implemented are: no training with facial stubble (contact sports), immediate reporting of any suspected infections, the wearing of shower sandals in changing and showering areas, and immediately cleaning sweat off any equipment the athlete has been using. There have even been documented cases of sports clubs implementing mandatory showers that are supervised by the coach in an attempt to reduce the incidence of infections in rugby teams (Kohl and Lisney 2000). Clearly, each professional sports club should have an infection control policy that is specific for its particular circumstances. The importance of a comprehensive and coherent infection control policy for reducing and controlling the spread of infections among sports teams and athletic squads cannot be overstated.

Maintaining Immunocompetence in Elite Athletes

The preparation of elite athletes requires 8 to 12 years of progressively increased training loads that are necessary to elicit the physiological adaptations to compete at the elite level (Zatsiorsky 1995), with many elite athletes training more than 20 hours per week (Foster, Daniels, and Seiler 1999). Unlike recreational athletes, elite athletes do not have the option of engaging in only moderate training (Nieman 1994), but instead continually challenge the balance between a well-trained and an overtrained state (Kuipers 1996). In fact, a prerequisite of becoming an elite athlete is likely to be a high capacity to tolerate extreme training loads. As the high incidence of infection among athletes has been largely attributed to suppression of various immune parameters, it would seem prudent to focus attention on improving immune function in an attempt to decrease infection rates. A major factor in the development of suppressed immune function in athletes appears to be the engagement in periods of intensified training, most notably during competition periods (Gotovtseva, Surkina, and Uchakin 1998), which may be exacerbated when performing under extreme environmental conditions (Pyne, Gleeson, McDonald, et al. 2000) often engaged in by some elite athletes. To minimize immunosuppression during the training year, it is imperative that training variables are carefully controlled with adherence to sound training principles. Basic considerations and recommendations for manipulating training to maintain immunocompetence are shown in Table 2. (See Bompa 1999, Dick 2002; Foster, Daniels, and Seiler 1999, and Norris and Smith 2002, for comprehensive recommendations on training principles.)

Perhaps the most important training principle in relation to maintaining immunocompetence while training to compete at the elite level is that of individuality. A retrospective study by Fricker, Gleeson, McDonald, et al. (2000) found that, although the average incidence of URTIs among elite swimmers was 2.5 episodes/year/athlete, individual incidence ranged from 0 to 10 per year. Not only do athletes respond differently to similar training loads (Hawley and Burke 1998), but current research indicates that susceptibility to infections is largely genetic (Cooke 2001), possibly explaining some of the large differences in incidence of infections among elite athletes. It is possible that athletes possess individual training load "thresholds" above which immunosuppression and infection risk are significantly increased (Foster 1998). Moreover, there are likely to be differing responses to interventions used to maintain immunocompetence. It is thus important to individualize both training programs and interventions used in an attempt to maintain immunocompetence. As well as controlling training-related variables, competition frequency also should be controlled. The psychological stress close to important competitions, as well as the physiological and psychological stress associated with the competition itself, may further compromise immune function and result in a

Table 2
Recommendations for Manipulating Training Parameters to Maintain Immunocompetence

Training parameter	Recommendations
Training load	Commence training with low weekly loads and steadily increase.
Training volume	Increase volume gradually using a periodized approach.
Training intensity	Increase intensity after training volume using a periodized gradual approach. Hard training sessions should not add up to more than three per week and be interspersed with light sessions.
Recovery	Ensure adequate recovery between hard sessions. Schedule complete rest periods, preferably spending time pursuing a nonphysical pastime or short holiday.
Environmental factors	Ensure gradual exposure to adverse training environments.

period of heightened susceptibility to opportunist infections. Consequently, the stress of too frequent competitions is likely to result in insufficient time for the immune system to recover and may lead to increased infection incidence during subsequent heavy training. As transient immunosuppression after competition has been found to last between 1 and 8 days (Shinkai, Kurokawa, Hino, et al. 1993), it is recommended that whenever practically possible only very light training is performed during the week after a competition, especially if the competition involved prolonged exertion. A long training taper (e.g., 2 weeks) may also be desirable before competitions that involve periods of intense precompetition training, as this has been associated with lowered plasma cortisol concentrations (Mujika, Goya, Padilla, et al. 2000) and favorable psychological and physiological responses in highly trained athletes (Mujika and Padilla 2003), which may help maintain immunocompetence.

The development of immunosuppression is likely related not just to high training loads as a sole antecedent, but to the total amount of stressors the elite athlete is exposed to, a similar situation to the development of the overtraining syndrome (Hardy, Jones, and Gould 1996). Consequently, interventions that reduce stress will likely prove valuable in maintaining immunocompetence and reducing infection risk (Pyne, Gleeson, McDonald, et al. 2000). These interventions may include meditation, progressive relaxation, imagery, hypnosis, massage, sauna, hydrotherapy, counseling, scheduling adequate sleep, or acquisition of time management skills. Individuals responsible for overseeing travel and accommodation plans for traveling athletes should ensure athletes have minimal stress and disruption during traveling and comfortable and quiet accommodation at the training or competition location.

Apart from training and competition, other factors can influence immune function, such as age, lifestyle, circadian rhythms, and diet (Smith 1995). Consequently, many factors can be manipulated in the elite athlete in an attempt to maintain immunocompetence. Nutrition may be one of the most important aspects of maintaining immunocompetence and warding off opportunist infections in elite athletes, as abundant epidemiological evidence and clinical data indicate that nutritional deficiencies may cause immunosuppression and increase infection risk (Gleeson and Bishop 2000b; Kohut 2001). The importance of adequate carbohydrate (CHO) to support the high training loads of elite athletes is well known (Graham and Adamo 1999; Jacobs and Sherman 1999); however, CHO availability may also be an important factor in maintaining immunocompetence. Low CHO diets are associated with higher plasma cortisol levels both during resting conditions (Anderson, Rosner, Khan, et al. 1987) and exercise (Gleeson and Bishop 2000a; Mitchell, Pizza, Paquet, et al. 1998), which in turn exerts a negative impact on immune function (Brenner, Shek, Zamecnik, et al. 1998). High plasma cortisol concentrations are associated with an inability to maintain blood glucose homeostasis during prolonged exercise (Felig, Cherif, Minagawa, et al. 1982).

Several recent studies (Henson, Nieman, Parker, et al. 1998; Nehlsen-Cannarella, Fagoaga, Nieman, et al. 1997; Nieman, Nehlsen-Cannarella, Fagoaga, et al. 1998) demonstrated that CHO ingestion during prolonged severe exercise resulted in higher blood glucose and lower plasma cortisol concentrations compared to ingestion of a placebo. It has also been suggested that the benefits of CHO ingestion during prolonged training sessions may be accrued in the athlete engaged in periods of heavy training loads (Maughan 2000). Consequently, apart from adequate total daily CHO intakes to help maintain adequate muscle and hepatic glycogen concentrations, it is recommended that CHO be ingested during training sessions of more than 60 min of moderate to intense exercise, in an attempt to maintain blood glucose homeostasis. Total daily CHO intakes that are generally regarded as adequate for athletes in heavy training are 7–10 g CHO $\times$ kg^{-1} BM $\times$ d^{-1} (Burke 2000; Kuipers 2000; Sherman, Jacobs, and Leenders 1998), and this amount is also recommended for the purpose of helping maintain immunocompetence.

Research has indicated that dietary fat plays a role in selectively modulating immune function (Erickson and Hubbard 1993) and consequently may be an important factor in maintaining immunocompetence in elite athletes. Athletes are typically advised to consume high-carbohydrate, low-fat diets, with 10%–15% of total caloric intake derived from fat (Pendergast, Leddy, and Venkatraman 2000). Although high-fat intakes have been associated with immunosuppressive effects (Venkatraman and Pendergast 1998), excessively low-fat intakes may exert similar effects (Venkatraman, Leddy, and Pendergast 2000). It has been suggested that for the purposes of maintaining immunocompetence, fat intake should not represent less than 20% of the athlete's total caloric intake (Venkatraman and Pendergast 1998). Additionally, athletes should be advised to ensure adequate ingestion of foods containing essential fatty acids that are essential to proper immune functioning (Pyne, Gleeson, McDonald, et al. 2000).

Inadequate protein intakes have been associated with impaired host immunity (Gleeson and Bishop 2000b). Except for those on low-energy or low-CHO diets (Lemon 1998, 2000), protein intakes of athletes are usually adequate (Tarnopolsky 2000), and therefore incidence of immunosuppression from protein deficiency in the elite athlete is likely to be low. However, in athletes who are considerably restricting energy intake, attention to daily protein intake is needed, and additional protein is likely to be required due to increased rates of protein oxidation in the energy restricted state (Bender 1997).

Low caloric intakes and rapid weight loss have been associated with immunosuppression (Nieman 1998b, 1998c), possibly due to an inadequacy in energy, protein, or vitamin and mineral intakes during food restriction (O'Connor, Sullivan, and Caterson 2000). Athletes in weight-class sports may be at particular risk due to the high prevalence of rapid weight loss in these sports (Fogelholm and Hiilloskorpi 1999). Athletes should be advised to lose weight slowly and preferably during periods of low training loads, such as during the off-season, in an attempt to avoid immunosuppression.

Transient reduced serum glutamine concentrations have been implicated as a cause of immunosuppression after prolonged, heavy exercise (Castell and Newsholme 2001). Glutamine is not only an important fuel source for lymphocytes, it is also required for purine and pyrimidine nucleotide synthesis necessary for lymphocyte proliferation (Castell 2002). Glutamine supplementation after prolonged exercise has been shown to increase plasma glutamine concentrations (Castell and Newsholme 2001; Rohde, MacLean, and Pederson 1998) and has thus been suggested to be valuable in attenuating immunosupression caused by exercise-induced reductions in plasma glutamine. However, a review of the literature by Kohut (2001) highlighted equivocal findings relating to the effects of glutamine supplementation on immune function and reducing the incidence of infection in athletes, and at present the value of glutamine supplementation in maintaining immunocompetence in elite athletes is unclear. Although routine glutamine supplementation may be not warranted, present data suggest that supplementation may be beneficial in athletes found to have a true glutamine deficiency (Burke, Desbrow, and Minehan 2000). Other amino acids that may prove valuable in maintaining immunocompetence and attenuating infection risk during heavy training periods are arginine (Field, Johnson, and Pratt 2000) and the branched chain amino acids (Bassit, Sawada, and Bacurau, et al. 2000). However, recommendations for elite athletes to supplement with these latter amino acids are likely unjustified, until further research has been conducted that support their efficacy.

Other interventions that may prove valuable in maintaining immunocompetence are maintaining adequate micronutrient intakes (Gotovtseva, Surkina, and Uchakin 1998), in particular vitamin C (Kohut 2001; Nieman 1998c); immunization (Strikas, Schmidt, Weaver, et al. 2001); immunomodulators and antiviral preparations (Gotovtseva, Surkina, and Uchakin 1998); and adaptogens (e.g., Eleutherococcus senticosus; Mar 1996). Flu shots have been particularly recommended for athletes who are competing during the winter months (Nieman 1998c). Athletes traveling to some foreign countries may also require special measures, such as specific vaccines and antimalarial drugs (Sharp 1994). Caution should be exerted when considering administering vaccinations, immunomodulators, and antiviral agents to athletes, as the side effects of these during periods of intense training have currently not been adequately researched (in most cases not at all). Additionally, immunizing athletes just prior to competitions will likely negatively affect performance, especially if the athlete is immunocompromised. It is far more prudent to immunize athletes during periods of low training loads (e.g., off-season), and also to experiment with immunomodulatory agents during such periods.

Athletes and persons responsible for overseeing training (e.g., coaches, exercise physiologists, sports psychologists) should endeavor to include as many of these interventions as possible in the lifestyle and training programs of the athlete or sports team member. It is also recommended that implementation of these interventions should be "stepped-up" during particular heavy training periods or when time between competitions is relatively short.

Management of the Infected Athlete

Correct management of the infected athlete is essential if delayed recovery is to be minimized and potentially fatal complications avoided. Unfortunately, there is a belief among many individuals that exercising during an infection will help the athlete "sweat it out" (Bird, Black, and Newton 1997), and athletes with this misconception should be appropriately informed. At present there is little data regarding the effects of exercise on the course of particular infections (Nieman 2000b); consequently, recommendations relating to exercise during an infectious episode should be approached cautiously. Using the limited data available, several authors have provided general guidelines for exercise during an infection (see Table 3). It should be noted, however, that these are general guidelines only and should be used with a flexible approach, taking into account the nature of the sport, the athlete's training status, and the medical history of the athlete. It should also be noted that symptoms may change abruptly in the infected athlete, and thus initial recommendations may need revising. A major problem with the infected athlete is that identification of the specific pathogen responsible for the infection is not often practically possible, resulting in the need for a conservative approach to prevent relapse, worsening of the infection, or secondary complications (Nieman 1997b). Often a prodromal period occurs during some infections that is characterized by early, milder symptoms (Tortura, Funke, and Case 1995). If symptoms indicate that an infection is impending, the athlete should immediately reduce training loads (especially training intensity) to allow time for the full severity of the infection to manifest itself. This will also allow the immune system to direct its resources to combating the infection during its early stage (Nieman 1994). In any instance, a team physician or suitably knowledgeable GP should be consulted so that the athlete can be physically examined and professional advice obtained.

Table 3
General Guidelines for Athletic Participation During the Acute Stages of an Infection (Friman and Wesslen, 2000; Nieman, 1999, 2000b; O'Kane, 2002; Primos, 1996; Pyne, Gray, and McDonald 1995; Weidner, 2001)

Symptoms	Guidelines
Feeling of getting ill	Reduce training load for 1 or 2 days (especially intensity).
Upper respiratory tract infection with no systemic involvement (e.g. stuffy or runny nose, sneezing, mild headache, itchy eyes, or sore throat).	Light exercise can be performed throughout, with full training resumed 1-3 days after resolution of symptoms. If symptoms are aggravated by exercise reduce or stop activity.
Fever, extreme tiredness, myalgia, deep cough, wheezing, shortness of breath, severe headache, chills, or lymphadenopathy.	No exercise during symptomatic stage, with light exercise resumed when symptoms have subsided, and a gradual build-up to full training loads over 2-4 weeks after the disappearance of symptoms.
Diarrhoea and/or vomiting	Resume activity 1-2 days after symptoms have subsided in the case of mild illness and up to 2-4 weeks in the case of serious infection. In all cases, ensure properly hydrated before and during exercise, especially if exercising in hot conditions.

Note. Caution should be exercised over the first 1-3 days of symptoms, until the severity of the infection can be ascertained. If symptoms worsen or are aggravated by exercise, training loads should be reduced accordingly, or exercise stopped altogether. Athletes should be instructed to be aware of "body signals" that may indicate a poor exercise response.

Table 4
Summary of Guidelines for Maintaining Immunocompetence and Reducing Infection Risk in Elite Athletes

Factor	Recommendations
Transmission	Avoid confined and overcrowded places
	Avoid infected individuals as much as practically possible
	Avoid habitually touching hands to mouth, nose and eyes
	Avoid sharing towels, razors, toothbrushes, water bottles, equipment
	Wear shower sandals in communal changing and shower areas
	Avoid team baths and Jacuzzis
	Ensure all wounds are properly cleansed and covered
	Avoid abrasion of the skin
	Ensure exercise mats and other surfaces are properly disinfected
	Report any athletes known or suspected of having an infection
Personal hygiene	Avoid "hanging around" in sweaty clothes during and after training
	Have plenty of showers and dry body properly afterwards
	Consider periodic application of antifungal powders for the feet
	Ensure clothing and training equipment is properly cleaned
Training	Space hard workouts with less-intense or shorter duration ones
	Minimize number of competitions involved in (mainly track/field athletes)
	Reduce training loads if there is onset of symptoms indicative of an infection
	Taper training prior to competitions and train lightly post-competition
Diet	Eat a well-balanced diet containing a wide variety of foods
	Ingest sufficient calories
	Ingest enough carbohydrates to replete glycogen stores
	Ingest carbohydrates during exercise, especially hard training sessions
	Do not let daily fat intake drop below 20% of total caloric intake

(Continued)

Table 4 ***(Continued)***

Factor	Recommendations
	Consider supplementation with glutamine and immunomodulators Consider antioxidant supplementation
Lifestyle	Keep sociopsychological stressors to a minimum Obtain adequate sleep (both duration and quality) Practice relaxation techniques
Prophylactic measures	Immunization Immunoglobulins and antiviral agents Antimalarial drugs Insect repellents Protective clothing or equipment

Engaging in intense exercise during an infection has been associated with increased severity of the infection and increased risk of heat exhaustion (Primos 1996), post-viral fatigue syndrome (Budgett 1991), and viral myocarditis (Bird, Black, and Newton 1997). This latter condition can lead to permanent damage to the heart, arrhythmias, and death (Friman and Wesslen 2000). Another potentially fatal condition reported in the literature may result from infectious mononucleosis, caused by the Epstein Barr virus, cytomegalovirus, or Toxoplasma gondii (Bryan and Barton 2002). In this infection, the spleen may become enlarged and susceptible to rupture (MacKnight 2002), even with minimal or no trauma (Burroughs 2000). Thus, athletes suffering from this condition should not be allowed to engage in contact sports, or any other sports in which impact with the spleen is possible, until advised to do so by a suitably qualified physician.

Athletes considering taking medications to alleviate the symptoms of an infection should obtain medical advice from a suitable, qualified physician, as these may modify the exercise response and produce negative and possibly dangerous side effects. Medications used to treat cold and flu symptoms, for example, often contain antihistamines, which may lead to impaired thermoregulation due to their anticholinergic effects (Weidner 2001), increasing the risk of heat stress. Additional to possible negative physiological effects, some medications billed as "cold remedies" contain substances such as ephedrine that are banned by certain governing athletic bodies (Cowan 1998).

Conclusion

It is generally accepted that elite athletes are at increased risk for infection, and that this increased risk is due to a combined effect of suppressed immunity during periods of heavy training and competition and environmental factors associated with the pursuit of their sporting activities that increase their exposure to pathogenic microorganisms. When considering the negative impact of infections on sports performance, it is advisable that athletes and coaches employ appropriate interventions in an attempt to reduce the immunosuppressive effects of heavy exercise loads. Additionally, athletes should strive to minimize exposure to pathogens by avoiding infected people as much as practically possible and by maintaining high levels of personal hygiene. A summary of the guidelines for maintaining immunocompetence and reducing infection risk is provided in Table 4. Team physicians—or those responsible for overseeing training in sports teams, clubs, or squads—should endeavor to educate team members on self-management skills relating to infection control. An infection control policy may also prove invaluable in this respect.

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