

University of Groningen

## Biomechanical Determinants of the Jumper's Knee in Volleyball

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# **GENERAL INTRODUCTION**

The University Center for Sport, Exercise and Health is a joint venture of the Center of Human Movement Sciences and the Center of Sports Medicine of the University Medical Center Groningen, University of Groningen (see Box 1.1). One of the main purposes of this center is facilitating research that investigates the causal mechanisms of chronic sports injuries. More insight in the casual mechanisms will lead to new possibilities in the areas of prevention and treatment. Jumper's knee is such a chronic sports injury. On behalf of the University Center for Sport, Exercise and Health we started this research thesis in September 2002 entitled 'Biomechanical determinants of the jumper's knee in volleyball', which was established through grants from the Dutch ministry of Health, Welfare and Sport (VWS).

### **University Center for Sport, Exercise and Health – Groningen**

Some people do not exercise enough. Others exercise too much or inappropriate. The University Center for Sport, Exercise and Health – Groningen (UCSEH) is interested in both these groups of people. The center is the focal point for the close collaboration between medical practitioners and scientific researchers. The goal is to contribute to knowledge about healthy and unhealthy movement and exercise. With that knowledge we can, for instance, develop programs to make people more physically active. Furthermore, it will help injury prevention and the development of innovative treatment of (sport) injuries. The UCSEH is a joint venture of the Center for Human Movement Sciences and the Center for Sports Medicine of the University Medical Center Groningen, University of Groningen. The research center represents an interdisciplinary group, addressing a) basic and applied research into the relationship between sport and exercise and health, and b) the effects of innovations in treatment, health care services and evaluation on the efficacy of sport medicine health care. The general aim of the UCSEH is to establish a firm scientific base for sport science and clinical sports medicine research and to facilitate the strategic application of research output to promote sport and life long physical and mental health. The UCSEH is a member of LOSO (the National Platform for Sports and Exercise Medicine Research).

Box 1.1. Background information of the University Center for Sport, Exercise and Health - Groningen. Source: <http://www.rug.nl/umcg/onderzoek/faciliteiten/ucsbg>

### **1.1. Injury mechanism of the jumper's knee**

Tendon injuries account for a substantial proportion of overuse injuries in sports (Josza & Kannus, 1997), especially in explosive sports where a high demand of force, speed and power are asked for good performance, like in volleyball and basketball.

Athletes are exposed to high loads of their leg's quadriceps extensor mechanism to perform the spike and block jumps and their subsequent landings. These continual ballistic movements of the knee (Figure 1.1) make this sport dangerous concerning overuse injuries.

During these activities the patellar tendon is mechanically loaded according to a characteristic stress-strain curve (Josza & Kannus, 1997) where physiological forces usually cause less than 6% strain of the tendon (Sheehan & Drace, 2000). During play, the extensor apparatus of the athlete is repeatedly subject to continuously high stress and makes the bone tendon junction, being the weakest point, susceptible to lesion. Cumulative microtrauma may occur which weakens collagen cross-linking and finally results in mucoid degeneration of the tendon (Khan et al., 1998). This repeated activity is often eccentric by nature, and given the fact that the eccentric force production during the movement can potentially be three times the concentric force production, these types of movements are believed to be a primary cause of these cumulative microtraumas (Stanish, 1985). When not fully recovered after training activity, the adaptive and reparative ability of the tendon can not cope with the severity and quantity of microtraumas, with the chronic overuse injury jumper's knee as a result (Kannus, 1997; Leadbetter, 1992). Conclusively, overuse is simply a mismatch between stress on a given tissue and the ability of that tissue to withstand the stress (Fredberg & Bolvig, 1999). This process is schematically presented in Figure 1.2. The cause of pain suffered from chronic tendinosis is subject to debate, but there are indications that neovascularisation and neural ingrowth in the structurally changed tendon play a role (Alfredson et al., 2003).

### **1.2. Epidemiology**

The overuse injury located at the patellar tendon is often called 'jumper's knee', or clinically termed patellar tendinopathy (Cook et al., 2001; Khan et al., 1998; Khan et al., 1999). In this thesis both terms will be used. The highest prevalence rates of jumper's knee were reported in volleyball, where more than 40% among male elite volleyball players reported current symptoms or were previously injured (Ferretti et al., 1990; Lian et al., 2005). Supplementary, Gisslen et al. (2005) found a prevalence of 34.5% among male elite junior volleyball players, contrary to 7.1% among female elite junior volleyball players. Numbers of sub-elite level are noted in a study by Weesepeol (unpublished data, 2002), where the prevalence of the jumper's knee ranged from 8.8% to 21.4% for respectively 4th class and sub-elite level volleyball players. Again, the prevalence among female players was significantly lower, namely 5.9% among sub-elite level players.

The jumper's knee mostly leads to tenderness, pain and functional deficit, which can result in a reduced performance level, absence of training, or can even be the primary cause of ending a sports career (Kettunen et al., 2002). Several numbers of absence of sport activities caused by overuse knee

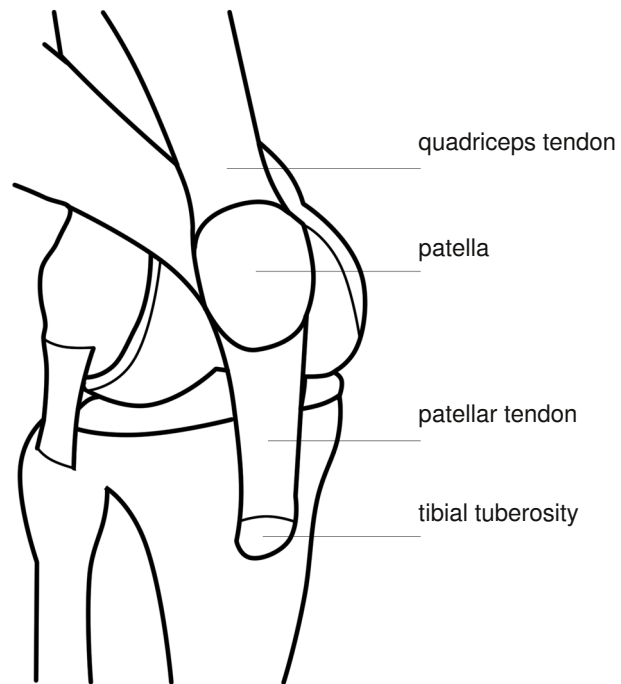


Figure 1.1. The human knee.

injuries are known. Verhagen et al., (2004) reported an average of 2.9 weeks of absence of sport activities. Even more disturbing numbers were found by Cook et al. (1997), who found among 100 jumper's knee patients that 67% of these participants could not play or practice for more than four weeks, 33% were absent for at least six months and even 18% for more than one year. Probably equally important side-effects are the consequences for activities in daily life, which can be affected unfavourably. Problems in stair climbing and prolonged knee flexion, like in prolonged sitting, are well known problems jumper's knee patients have to deal with.

All these epidemiological data strengthen the need for more preventive knowledge to make sports participation healthier by reducing the incidence of chronic knee injuries.

The research of this thesis will focus on the etiological risk factors and the underlying mechanisms of the jumper's knee in volleyball. This is an essential step in future development of preventive measures (Van Mechelen et al., 1992) to lower the jumper's knee incidence among volleyball players.

### **1.3. Clinical examination for diagnosis of jumper's knee**

When an athlete visits a sports physician for clinical examination with the symptoms of a jumper's knee (patellar tendinopathy), history and location of pain are discussed. The actual physical findings during the clinical examination are localized palpation tenderness at the inferior patellar pole and a positive score (i.e. pain) on the single-leg decline squat (Cook et al., 2000(b); Cook et al., 2001; Purdam et al., 2003; Zwerver et al., 2007). For diagnosis confirmation purposes ultrasonography can increase the likelihood of patellar tendinopathy (Cook et al., 2000(a); Warden & Brukner, 2007).

In the diagnosis procedure of the severity of overuse injuries and specifically jumper's knee, categorical classifications are used by most sports physicians (Blazina et al., 1973; Lian et al., 1996; Roels et al., 1978). Stage I represents athletes with pain at the infrapatellar or suprapatellar region after their training or competition. When the pain appears at the beginning of the activity, and subsequently disappears after warm-up and reappears after ending the activity, the athlete's knee is diagnosed with a stage II jumper's knee. The stage III affection is subdivided into i) pain during and after activity, but the patient is able to participate in sports at the same level, and ii) pain during and after the activity, but the patient is unable to participate in sports at the same level. Stage IV is the rarely seen complete rupture of the tendon.

Supplementary to this general classification the more recently developed Victorian Institute Sports tendon Assessment (VISA) score is often used. It was specifically designed for rating symptoms, functionality and athletic activity in patellar tendinopathy and has been tested for inter- and intratester reliability (Visentini et al., 1998).

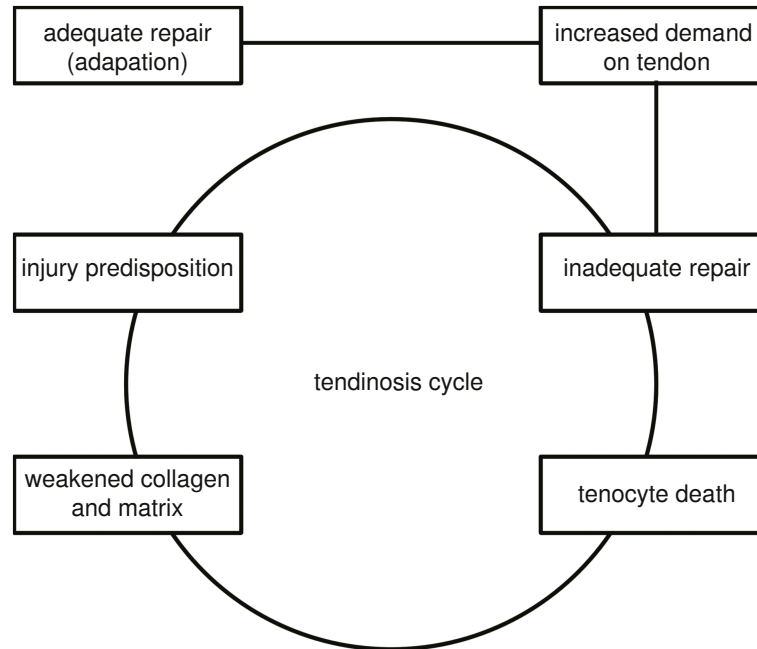


Figure 1.2. Theoretical model that illustrates the tendinosis cycle. Modified from Leadbetter (1992).

#### **1.4. Risk factors to develop a jumper's knee in volleyball**

The generally accepted view of the onset of the jumper's knee originates from repetitive loading of the quadriceps extensor mechanism (e.g. patellar tendon) during the jump-landing sequence. As a result, it would be quite obvious that the amount of training hours and the intensity during play are related to the prevalence of jumper's knee among volleyball players and that would clarify the above mentioned huge differences in incidence between elite level volleyball players and sub-elite and amateur players. Ferretti et al. (1990) were the first who extensively investigated this relation between the incidence of jumper's knee and the frequency of play, supplemented with the type of training, and the influence of years of play and playing surface. Their study showed that frequency of training was linearly related to the incidence rate of jumper's knee. An incidence of 41.8% was reported for volleyball players training more than 4 times a week, 29.1% for the players who trained four times a week, and 14.6% for three training sessions. So, the more training sessions a week, the higher the chance of developing a jumper's knee.

The type of training program followed by the volleyball players seems to influence the prevalence rate of jumper's knee as well. Although Ferretti et al. (1990) did not find support for this finding, Lian et al. (2003) found that the volleyball players with jumper's knee did more specific weight and jump training. Furthermore, the jumper's knee patients performed better at a jump-testing program and developed higher power during take-off. In relation to the development of jumper's knee, this suggests that weight training elicits a higher total loading of the quadriceps extensor mechanism, and the effect of this training could increase muscle mass and jumping ability. This leads to the ability to generate greater forces and this might stress the mechanism and can therefore be a risk factor associated with jumper's knee. Other skill factors, such as quick acceleration, deceleration, malalignment of the knee, and stopping and cutting actions may also predispose to jumper's knee (Pezzullo et al., 1992; Lian et al., 2003).

What goes up must come down, and a volleyball player is of course no exception to the laws of physics. The total amount of energy that has to be dissipated by the quadriceps extensor mechanism during the landing after a volleyball spike or block jump partly depends on the damping characteristics of the floor. Playing on a sandy underground appears to be far less risky because it provides less cases of jumper's knee than the incidence numbers known from indoor volleyball populations (Bahr et al., 2003; Ferretti et al., 1990). So, the harder the floor the higher are the incidence rates of jumper's knee. Probably even more important is the landing technique used by the volleyball players. To absorb the gained kinetic energy from the jump without getting injured requires an appropriate landing technique (e.g. joint flexion). To imply the significance of a good landing strategy to overcome injury risk, multiple studies have already been carried out (Decker et al., 2003; Devita & Skelly, 1992; Dufek & Zhang, 1996; James et al., 2003; McNitt-Gray, 1993; Onate et al., 2005; Reeser et al., 2006; Richards et al., 1996; Richards et al., 2002; Salci et al., 2004; Santello & McDonagh, 1998). For the causal mechanisms one might look in the direction of landing instead of the take-off phase of the jump itself.

Importantly, above mentioned factors influence the chance to get injured, but on an individual basis they do not fully answer the question why an individual develops a jumper's knee and another person does not while training volume is equal. Over time, in literature several intrinsic factors have been assumed to play a role in the overall causal mechanism of the jumper's knee: leg length discrepancy,



pronation of the foot, muscular weakness and imbalance, quadriceps and hamstring flexibility, tibial length to stature ratio, malalignment of the thigh relative to the shank, impingement of the patellar tendon, length of the patellar tendon, and excessive lateral displacement of the patella when eccentrically loaded (Blazina et al., 1973; Cook et al., 2004; Fritschy & de Gautard, 1988; Gaida et al., 2004; Johnson et al., 1995; Kannus, 1997; Kujala et al., 1986; Lorentzon et al., 1998; Martens et al., 1982; McLoughlin et al., 1995; Witvrouw et al., 2001). Concerning these intrinsic risk factors and the role of anthropometrics in the development of jumper's knee there are a lot of conflicting results and up till now there is no reliable evidence to suggest that anthropometrics have a clear causal relationship with the development of the jumper's knee.

### **1.5. Biomechanics and its relationship with chronic sport injuries**

In the search to the causal mechanisms for the development of the jumper's knee, the biomechanics can play an important role, because the forces acting on the quadriceps extensor mechanism (e.g. patellar tendon) which cause the stress associated with jumper's knee can be determined accurately with biomechanical methods.

Biomechanics is the application of mechanical principles to the human body in movement and at rest. Within the area of mechanics, the dynamics is the study of moving bodies, and can therefore be used to discover aspects of the take-off and landing technique related to the jumper's knee. Dynamics in turn, can be subdivided into kinematics and kinetics. Kinematics is the science of motion and deals with relationships between displacement, velocities and accelerations. The kinetics deals with moving bodies and the forces that act on them to produce the motion. These two areas together contain biomechanical principles and form the basis of musculoskeletal function.

Musculoskeletal injuries are dictated by five biomechanical factors: type, magnitude, rate of loading, material properties of the tissue and the structural properties of the tissue. In order to evaluate the effect of forces on the musculoskeletal apparatus, a biomechanical model is used. These models usually consist of a set of rigid bodies (segments) connected at joints, which allow them to transfer intersegmental forces. We can represent these forces acting on the body's segments by using a free body diagram, which starts from the principle that the produced moment around a joint is the multiplication of muscle force and its moment arm.

Intersegmental moments and forces can not be measured directly. This is known as the inverse problem. These measures are determined by observing the characteristics of motion and the external force applied to the body. The inverse problem is subsequently solved by solving the equations of motion in a multi-segment rigid body model. The equations of motion are equations that describe relationships between the forces and moments acting on a body and the motion of the body.

Biomechanical principles form the basis of musculoskeletal function and can differentiate abnormalities in intersegmental moment and forces. Subsequently, these abnormalities can be translated to movement characteristics, like for example joint angles or joint angular velocities.

## 1.6. Outline of thesis

The aim of this thesis is to deliver a contribution in the research field of jumper's knee aetiology. The high prevalence of jumper's knee among volleyball players justifies further research to focus on the underlying mechanism of this chronic sports injury to develop suitable preventive strategies, as stated by the sequence of prevention by Van Mechelen et al. (1992). This thesis will give a deeper insight into the biomechanical risk factors that play a role in the development of the jumper's knee among volleyball players.

In assessing possible biomechanical risk factors for the development of jumper's knee, the knee extensor moment is an important variable, because it represents the joint's load generated by the quadriceps extensor mechanism. In chapter 2 experiments are described to improve the assessment of the knee extensor moment during the impact phase of landing after a jump. This is established by evaluating the effect of different cut-off frequencies in low-pass filtering on the calculation of knee moment. Next to this, we evaluated the effect of accelerometer data of the shank and foot during landing in inverse dynamics.

In chapter 3 normative reference data are presented of the ankle and knee joint dynamics during the landing of the defensive volleyball block and offensive spike jump. In the search of the potential role of ankle and knee joint dynamics related to the overuse injury jumper's knee in volleyball, there is a lack of normative reference data. By analysing the block and spike jump landing a deeper insight can be obtained about which jump type is the most risky to develop a jumper's knee.

In chapter 4 the landing dynamics of drop jumps are examined, in order to see if the landing strategy used by volleyball players might be a risk factor for the development of jumper's knee. In a cross-sectional study design, landing characteristics were compared between three groups: an asymptomatic group of volleyball players with previous jumper's knee, a symptomatic group of volleyball players with recent jumper's knee, and a healthy group of volleyball players.

In chapter 5 the take-off and landing technique of volleyball players during the performance of the spike jump are investigated to find possible risk factors related to the jumper's knee. Ankle and knee joint dynamics of this jump-landing sequence were gathered from asymptomatic volleyball players with previous jumper's knee, and non-symptomatic healthy volleyball players.

In chapter 6 the results of the different studies are combined into a general discussion where conclusions are drawn and recommendations are made for future research.

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