

PATELLOFEMORAL PAIN IN CYCLISTS

A Thesis submitted to the University of Cape Town
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Degree of Master of Philosophy in Sports Physiotherapy

by

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DEDICATION

This dissertation is dedicated to the following:

My grandmother Bettie Diekmann,

My parents Jos and Rita van Zyl, and

All the cyclists who gave of their time to take part in this project.

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DECLARATION

I Elizabeth van Zyl, the undersigned, hereby declare that this thesis is the original work of the author, both in its conception and execution. The results of the work and ideas of others mentioned in the text are fully referenced. Where data, collected with the help of others in collaborative studies, has been reproduced, this has been with their full permission and I have fully acknowledged the source of such data.

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Signed

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Introduction

Overuse injuries has proven to be a challenge to all clinicians, due to the complex involvement of biomechanical factors that is not always well understood. Patellofemoral pain is a classic example of an overuse injury of which the successful management depends not only on symptomatic treatment, but also most importantly on the careful consideration of the biomechanical factors involved.

Knee pain and specifically patellofemoral pain is well documented as a common overuse injury in cycling. However, the aetiology of patellofemoral pain in cycling is not well understood^{12 34 68}. Patellofemoral pain is associated with poor alignment of the patella during the movement of the knee from flexion, to extension. Numerous biomechanical parameters have been associated with malalignment of the patella. These include poor quadriceps function, vastus medialis obliquus insufficiency, excessive subtalar joint pronation, and poor muscle flexibility of muscle groups that affects patellar tracking, and an inflexible lateral patellofemoral retinaculum.

The biomechanics of patellofemoral pain in cyclists can only be understood if all the factors are taken into account. These factors are abnormal lower limb biomechanics, incorrect bicycle and equipment settings, and incorrect training methods. Abnormal forefoot, and rearfoot alignment has shown to maltracking of the patellar, and patellofemoral pain. There is anecdotal evidence that Leg length discrepancies, and varus or valgus malalignment of the knees are also implicated in the development of patellofemoral pain in cyclists^{24 27 49}.

Incorrect bicycle and equipment settings commonly include incorrect saddle height, incorrect cleat position, and the type of cycling shoe.

Training factors that are associated with patellofemoral pain in cyclists are: hill training, cycling with high gears at a low cadence, or a sudden increase in training volume.

Marked medio-lateral deviation of the knee during the down stroke in cycling has been noted in cyclists with patellofemoral pain, when compared to a pain free control group (Hannafor 1986, Milligan 1996). It has been postulated that there is a correlation between structural abnormalities of the lower limb, and excessive medio-lateral deviation of the knee. In a limited case study orthotics, and cleat modifications was use in an attempt to obtain a more linear patter of down stroke (Hannafor 1986). Injured cyclists reported a decrease in knee pain. In other studies, the use of floating supposed to rigid cleats allows for a small degree of movement between the foot and the pedal, and a reduction in high patellofemoral torsion forces.

The aim of this thesis was first to review the current literature that deals with patellofemoral pain in cyclists. The second aim was to investigate the possibility of reducing medio-lateral deviation during the down stroke of cycling, by altering the biomechanics of the lower limb and, to observe the effect of this reduction on patellofemoral pain in a clinical trail.

This thesis is in the format of two papers that is submitted for publication in sports medicine journals. The first paper is a review of the aetiology, biomechanics, diagnosis and management of patellofemoral pain in cyclists. The second is a research paper, titled: correcting lower limb biomechanics decreases patellofemoral pain (PFP) in cyclists.

Chapter 2

Review paper

**Title: A REVIEW OF THE AETIOLOGY, BIOMECHANICS,
DIAGNOSIS AND MANAGEMENT OF
PATELLOFEMORAL PAIN IN CYCLISTS**

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**A REVIEW OF THE AETIOLOGY, BIOMECHANICS,
DIAGNOSIS AND MANAGEMENT OF
PATELLOFEMORAL PAIN IN CYCLISTS**

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Introduction

The sport of cycling has steadily increased in popularity since the 1980s. It is generally perceived as an activity with great potential for fitness and rehabilitation and is an alternative form of training for athletes seeking relief from activities that are associated with repetitive joint impact and subsequent injury. Although cycling is considered to be less damaging to weightbearing joints, there is still potential for the development of overuse injuries ^{49 23}.

There is extensive information available on the dangers of acute accidental trauma in cycling ^{17 63 84 85}, but only limited research has thus far been conducted on the epidemiology of overuse injuries in cyclists. Studies do indicate that knee pain, and specifically the patellofemoral pain syndrome, is the most common overuse injury in cyclists. Patellofemoral pain alone can account for about 25% of all reported overuse injuries in cyclists ^{8 65 45 63 109}.

The aetiology of patellofemoral pain in cycling is best considered by studying the biomechanics of the patellofemoral complex. The study of biomechanics includes both the study of the movement (kinematics) and the forces imposed on joints (kinetics). The optimal pedalling rate during cycling training is at a cadence of 80 - 110 cycles/min ³⁴. It is conceivable that if a minor abnormality in patellar

biomechanics is repeated at this rate, it can result in injury to the patellofemoral joint.

The aim of this paper is to review patellofemoral pain in cycling with specific reference to the biomechanics of the patellofemoral joint, and how this might relate to the aetiology of patellofemoral pain in cycling.

This review will first deal with the definition of patellofemoral pain, and differences in terminology that surround this syndrome. The clinical anatomy of the patellofemoral complex will be discussed briefly, followed by a discussion on the kinetics and kinematics of the patellofemoral joint in cycling. The clinical diagnosis of patellofemoral pain as well as special investigations that assist in the diagnosis of this condition will be reviewed briefly. Finally, the management of patellofemoral pain in cyclists, with specific reference to correction of abnormal biomechanics, will be reviewed.

Terminology and definitions

In the past, chronic knee pain involving the patella and the surrounding structures has vaguely been classified as 'chondromalacia patellae'^{82 31}. However, it is now recognised that this term describes only a specific macroscopic pathological abnormality and not a clinical syndrome. Chondromalacia patella refers to a

softening and fissuring that can be observed on the ventral surface of the patella, and is visualised during open surgery, or during arthroscopy^{5 31 41}.

Patellofemoral pain (PFP) syndrome is a clinical syndrome that has been defined as pain originating from the structures of the patellofemoral joint, due to an abnormality in the biomechanics of the patellofemoral complex²⁶.

Several investigators have proposed that the cause of patellofemoral pain syndrome is related to abnormal patellofemoral mechanics. It has been suggested that abnormalities in the patellofemoral relationship results in abnormal shearing and compressive forces acting on the patellofemoral joint during normal activity^{18 54 57}. For the purpose of this review patellofemoral pain will be defined as anterior knee pain due to the malalignment of the patellofemoral joint.

The epidemiology of patellofemoral pain in cyclists

Cycling related injuries can be classified as acute or overuse injuries. This review focuses primarily on patellofemoral pain, which is defined as an overuse injury. The epidemiology of overuse injuries in cyclists has to date been described from data collected during long distance cycle races, off-road racing events, stage races, or triathlons. Data were mostly collected by means of pre-and post race questionnaires, logbook data, and interviews with cyclists.

In one of the more comprehensive studies conducted during a long distance cycling race, overuse injuries were reported in 86% of 132 the amateur cyclists who took part in the tour. The cyclists (age 41.4 ± 11.7 yrs) with an average training distance of 98.5 miles per week, covered 500 miles over 8 days, and completed an injury questionnaire at the end of the race. The results of all injuries are depicted in Table 1. In this study, knee pain was reported in 35.4% of the cyclists, with 20.7% reporting 'significant' pain. Peri-patellar pain was the most frequently reported site of pain, followed by pain on the lateral, and then the medial aspect of the patella ¹⁰⁸.

A similar study was conducted in a random sample of 89 out of 1200 bike centennial participants, who covered 4500 miles in 80 days. This population of cyclists included 64 males, (mean age 27.9 years) and 25 females, (23.6 years). Data were collected from questionnaires, and interviews. The group was diverse in age, cycling experience, and diverse levels of conditioning prior to the tour. Knee pain was the most common complaint (56%), it was mostly associated with hills, and "pushing high gears". Pain was mostly noted "under the knee cap", or at the patella or quadriceps tendon. Twenty-three (23) cyclists experienced hand numbness, with the most common site over the ulnar distribution. All the cyclists reported mild saddle soreness, and 6 cyclists complained of crotch numbness ⁶⁵.

An epidemiological study of overuse injuries among recreational cyclists was also reported in 294 male (mean age 40.4 years), and 224 female (36.6 years)

recreational cyclists who responded to a mailed questionnaire. In that study, 85% of cyclists reported one or more overuse injury, with 36% requiring medical treatment. The most common anatomical sites for overuse injuries and complaints reported by the male and female cyclists combined were the neck (48.8%), followed by the knees (41.7%), groin/buttocks (36.1%), hands (31.1%), and back (30.3%)¹⁰⁹.

The majority of off-road cycling injuries appear to result from crashes, but these cyclists are also susceptible to overuse injury. In a retrospective study, 30% of off-road cyclists reported a history of chronic knee pain; 19% reported wrist pain, and hand numbness while 37% reported lower back pain. However, in this study few details of the aetiology or the severity of those symptoms were available⁶³.

In a study where triathletes were compared with single-sport athletes (swimming, cycling, and running)^{33 67} it was noted that triathletes average more hours of participation per week than any other group, and that they had a higher incidence of injury per year than single sport athletes⁶⁷. In an epidemiological investigation of training and injury patterns in British triathletes (semi-professional, and professional) conducted over a 8 week period 19% of athletes suffered with knee pain, which was the third most common site of injury. Ankle/foot injuries were the highest (27%), followed by thigh injuries (20%)⁶².

One hundred and fifty five triathletes, classified as recreational, intermediate and

elite, reported injuries sustained during training, or competition over an 8-week period. The mean distance cycled during training was 100.2 ± 70.6 km, distance swam 42 ± 2.6 km, and distance ran 23.4 ± 15.2 km. Thirty-seven percent of participants reported at least one injury. The most frequent reported sites of injury were ankle/foot (27%), thigh (20%), knee (19%), lower leg (16%) and the back (14%). Overuse was the suspected cause of injury in 41% of injuries, with two thirds occurring during running. The average injury rate was 5.4 (4 ± 7.2) injuries per 1000 hours of training $p < 0.05$, and 17.4 (10.9 ± 27.9) injuries per 1000 hours of competition $p < 0.05$ ⁶².

It is clear that knee pain is one of the most prevalent overuse injuries in a variety of cycling events, and that the clinical diagnosis is most often patellofemoral pain.

Anatomy of the patellofemoral complex

The patellofemoral complex consists of the patella, the femoral condyles and the muscles and ligaments around the joint that control patellofemoral joint movement and provide stability. The patella is the largest sesamoid bone in the body. It is complex in form, and variable in size. The ventral articular surface consists of a medial and lateral facet, separated by a central ridge, and an odd facet. The articular cartilage on the ventral surface of the patella is thicker than anywhere else in the body^{38 70}. The surface of the distal part of the femur, which articulates with the

patella, is the trochlea. The shape of the femoral condyles and the flexion / extension motion of the knee dictate the kinematics or gliding motion of the patella.

The functions of the patella are to protect the knee from injury, increase the mechanical advantage by increasing the lever of the quadriceps mechanism, protect the patellar tendon from excess friction, and transmit compressive loads to the underlying hyaline cartilage⁶⁶.

The ventral (femoral) surface of the patella is divided into a medial and lateral facet, separated by a shallow groove that distally becomes the intercondylar notch. Both patellar facets are convex in all directions to articulate with the concave medial and lateral condyles of the femur respectively¹⁰⁷.

The muscles that stabilise the patellofemoral complex are the quadriceps group (anteriorly, medially and laterally), the hamstring muscles (posteriorly) and the iliotibial tract (laterally). The quadriceps insertion into the superior aspect of the patella reinforces the medial and lateral patellofemoral ligaments to form an active decelerator mechanism and to act as a competent static restraint in both a coronal and sagittal plane of the knee joint¹⁰².

The vastus medialis obliquus muscle (VMO) arises from the adductor magnus tendon, and extends distally towards the supero-medial margin of the patella. It inserts in the quadriceps tendon and the medial border of the patella. The function

of the VMO is to realign the patella during extension of the knee, as this muscle is considered to be the only medial stabiliser of the patella^{70 71}.

This medial stabiliser function of the VMO has a strength component, and an activation (control) component. It has been suggested that insufficient strength, or a delayed activation of the VMO can lead to a decrease in control of patellar movement, and an increase in the lateral drift of the patella. Inflexible lateral structures (retinaculum and/or iliotibial band) and a dominant vastus lateralis muscle (VL) have been shown to inhibit the function of the VMO⁷¹. This could lead to the uncontrolled lateral drift of the patella. This drift is thought to be one of the main causes of microscopic injury of the peripatellar tissues^{5 41 88 94}.

The vastus lateralis (VL) muscle forms the middle and outer layer of the quadriceps group, and acts as a patellar stabiliser. The most distal fibres of the VL reinforce the lateral retinaculum of the patella to form a complex and rigid structure that maintains the lateral alignment of the patella^{60 61}. The rectus femoris (RF) muscle inserts onto the superior aspect of the patella. The direction of force of the RF is 7-10° medially in the frontal plane and 3-5° anteriorly in the sagittal plane⁶⁶.

The iliotibial tract is the longitudinal tendinous middle layer of the tensor fascia lata muscle. It separates distally into the iliotibial tract and the iliopatellar band. The iliotibial tract inserts into Gerdy's tubercle and the tibial tuberosity. The tendinous fibres of the antero-medial half of the tensor fascia lata muscle extend down the

thigh and curve anteriorly at the level of the patella to interweave with the lateral patellar retinaculum and the deep fascia of the leg, superficial to the patellar ligament. The tendinous fibres of the postero-lateral half of the tensor fascia lata muscle join the fibres of the longitudinal middle layer of the fibres of the fascia lata (iliotibial tract)¹⁰⁷. The iliopatellar band contributes to the control of knee deceleration and the various layers of the iliotibial tract act in a stabilising capacity as an antero-lateral ligament of the knee. The iliotibial tract then combines with the vastus lateralis muscle to limit medial deviation of the patella during knee flexion³⁵

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Biomechanics of the patellofemoral joint

Introduction

The study of the biomechanics of the patellofemoral joint consists of an analysis of the movement of the joint (kinematics) and the forces (kinetics) imposed on the joint. As has already been mentioned, the function of the patellofemoral joint is to increase the efficiency of the extensor mechanism of the knee by extending the distance of the extensor apparatus from the axis of the knee and the length of the quadriceps moment arm. The patellofemoral joint also alters the direction of the force of the quadriceps muscle from an oblique, superior and slightly lateral force into a strictly vertical force^{38 60}.

There are four important parameters that should be considered in the understanding of the biomechanics of the patellofemoral pain syndrome in cyclists. These are patellar tracking, patellofemoral joint reaction force, patellofemoral contact surface area, and patellofemoral contact stress^{34 28 42 44}. Each of these four parameters will now be reviewed with specific reference to patellofemoral biomechanics in cyclists.

Patellar tracking

Patellar tracking refers to the pattern of movement of the patella in the femoral groove during flexion, and extension of the knee. During normal knee motion, the patella must be aligned so that it can move in the trochlear groove of the femur. Normal patellar motion from full knee extension to full knee flexion follows a concave lateral curve. During the first 20° of knee flexion of an open kinetic chain movement, the tibia derotates medially and the patella is drawn to the trochlear notch where the first articular contact is made. Tibial derotation decreases the Q angle, and therefore the lateral vector. The patella then follows a medial course in the groove until the knee has flexed to 90°. Beyond 90°, the patella again moves laterally over the lateral femoral condyle until, at full flexion, it is completely covered by the patella and the medial condyle is almost totally exposed. The lateral force at the patellofemoral joint is resisted by the medial retinaculum, the vastus medialis obliquus muscle, and in flexion more than 90° by the prominent orientation of the lateral trochlear facet. Patella tracking in a stable patellofemoral joint transmits compressive loads through the patella to the underlying hyaline cartilage^{37 60}.

Patellar tracking is mainly a function of the configuration of the femoral condyles and surfaces of the patella. The quadriceps angle (Q angle) and the dynamic balance of the medial and lateral components of the quadriceps mechanism during contraction, affect patellar tracking to a lesser extent⁶⁶. The range of maximum power output in cycling generated, mainly by quadriceps contraction, is during the downstroke or extension movement of cycling (from 120° to 40° of knee flexion – in a knee flexion to extension movement). Patellar tracking during the downstroke of cycling is therefore relevant in understanding the pathomechanics of patellofemoral pain in cyclists³⁴.

Patellar tracking is affected by intrinsic and extrinsic factors. The intrinsic factors that alter patellar tracking comprise both static and dynamic constraints. Extrinsic factors that affect patellofemoral tracking in cyclists are the settings of the bicycle, cleats, shoes, and the cycling training program. Any factor that causes abnormal patellar tracking during knee extension and flexion movements may be implicated in patellofemoral pain (Table 2)^{12 38 66 70 88}.

Intrinsic factors affecting patellar tracking

Intrinsic factors comprise factors that are intrinsic to the cyclist. There are static intrinsic and dynamic intrinsic factors.

a) Static intrinsic factors that affect patellar tracking

Intrinsic static factors that affect patellar tracking during cycling include the shape, size and position of the patella, the shape of the femoral condyles, the Q angle, the position of the tibial tubercle, the angle of insertion of the patellar tendon on the tubercle, the subtalar joint, and leg length discrepancies^{29 49 68}. The role of each of these factors in patellofemoral biomechanics in cyclists will now be discussed.

i) *The patella*

The shape, size, and position of the patella in relation to the femoral groove can influence patellar tracking. Abnormalities of the patella may cause abnormal patellofemoral tracking and an increase in patellofemoral joint stress. The patella may be variable in size and position, small (patella parva), 'high riding' (patella alta) or low (patella baja). It has been suggested that the length of the patellar tendon can increase patellofemoral contact stress and cause patellofemoral pain. A high-riding patella may be unstable, as it is not stabilised by the lateral ridge of the femoral groove and therefore more prone to subluxation and dislocation. Patella baja recedes lower in the trochlear groove and is the result of adaptive shortening of the patellar tendon. It has been postulated that, in patella baja, contact occurs earlier during the knee flexion, and this could cause patellofemoral knee pain due to

increased patellofemoral contact stress^{38 56 70}. This hypothesis is not supported by the findings of a recent study using cadaver material in which retropatellar contact stress was measured in simulated patella baja. It was hypothesised that in patella baja the patellofemoral contact areas migrate proximally on the patella and are smaller in size with progressive severity of patella baja. However, it was found that the peak and mean retro patellar contact stresses were not increased. It was concluded that in patella baja, patellofemoral contact stress are not elevated appreciably, and that the symptoms associated with patella baja may be due to factors other than local mechanical overload⁷⁴. There is no scientific evidence to support the hypothesis that abnormalities of the patella can cause abnormal tracking or abnormal patellofemoral joint stress during cycling.

ii) The femoral condyles

It has been suggested that the shape of the femoral condyles can alter patellar tracking. A hypoplastic lateral femoral condyle is thought to lead to an increase in lateral tracking of the patella^{1 66}. There is no clear scientific evidence to show that the shapes of the femoral condyles affect patellofemoral tracking in cycling.

iii) Tibial tubercle position

It has been suggested that a laterally displaced tibial tubercle alter tracking of the patella, which may result in patellofemoral pain. In one study computerised tomography (CT) was used to determine the position of the tibial tubercle in female subjects with patellofemoral pain. In this case control study, it was found that

rotation of the tibial tubercle was significantly greater in subjects with patellofemoral pain compared with a pain free control group ⁷⁶.

iv) Quadriceps angle (Q angle)

The direction of the quadriceps force produces a biomechanical variable known as the Q angle. The Q angle is the angle between a line drawn from the anterior superior iliac spine through the centre of the patella, which then intersects a line from the centre of the patella to the tibial tubercle ⁵⁷.

The average Q angle (mean±STD) is $15.8\pm 4.5^\circ$ for females and $11.2\pm 3.0^\circ$ for males ⁵⁰. Clinically, a Q angle greater than 15° and 17° is generally considered to be excessive in males and in females respectively. This is considered by some investigators to indicate severe patellar malalignment and, in patients suffering from patellofemoral pain, is associated with a poor prognosis in response to either conservative or surgical treatment ⁵⁰.

Biomechanical factors that affect the Q angle are pelvic width, femoral neck anteversion, external tibial torsion and the lateral displacement of the tibial tubercle ^{50 56}. The results from studies conducted in the general population, long distance runners and on cadavers suggest that an increase in the Q angle leads to external tibial torsion and therefore causes a lateral displacement of the tibial tubercle. This lateral displacement would increase the lateral force vector on the patella ^{50 52 56 69}.

All investigators¹⁶⁻⁸¹ do not support the importance of the Q angle as a biomechanical factor in patellofemoral pain. A well controlled recent study (Caylor et al)¹⁶ investigated the relationship between the Q angle and anterior knee pain syndrome. The aim of the study was to determine the reliability of the Q angle measurement, and to determine if subjects with anterior knee pain (n=52) have a significantly different Q angle than subjects without anterior knee pain (n=50). It was reported that the intertester reliability was acceptable, and that there was no significant difference in Q angle values found between asymptomatic and symptomatic subjects. This study is preceded with a review that illustrates the controversies in the methodology and outcome in research of the Q angle. These studies were of different design, for example: Horton and Hall⁵⁰ measured the Q angle in standing in only 7 subjects, whereas Insall⁵⁶ in a prospective study, found that chondromalacia patellae was more common in patients with larger Q angles. However, neither of these researchers reported their method of assessing the Q angle.

In one study, the association between static lower limb biomechanical factors, including the Q angle and knee pain in cyclists was investigated. The results of this study showed that there was no significant difference in Q angle measurements when comparing cyclists with knee pain (n=33) to those with no knee pain (n=28)⁶⁸.

V) Leg length discrepancy

Leg length discrepancy is considered by many clinicians to be another important

intrinsic lower limb biomechanical factor that can affect patellofemoral tracking. Typically during cycling only one of the lower limbs would compensate for a discrepancy in leg length. The knee on one side may compensate for a leg length discrepancy by adopting a varus or valgus position. These positions may lead to excessive medio-lateral deviation of the knee during the downstroke of cycling. Alternatively, the shorter side will compensate by excessive knee extension at the bottom of the pedalling stroke. Excessive knee extension may result in mechanical irritation of the iliotibial band as it is stretched over the lateral condyle of the femur. Excessive tension in the iliotibial band can also potentially affect patellar tracking through increased lateral force through the iliopatellar ligament^{29 49}.

All these hypotheses have however not been tested in well-conducted clinical trials in cyclists with chronic knee pain. In one case-control study, where the relationship between static lower limb biomechanical factors and chronic knee pain was documented, it was found that a leg length discrepancy was not more common in cyclists with knee pain (n=33), compared with cyclists with no knee pain (n=28)⁶⁸.

Vi) Forefoot and rearfoot alignment

Forefoot varus or valgus as well as rearfoot varus or valgus are static lower limb biomechanical measurements that can be assessed clinically. An excessive forefoot varus or an increased rearfoot valgus are two static abnormalities that could increase subtalar joint pronation. An increased subtalar joint pronation has been suggested by many researchers as a potential cause of patellofemoral pain in long

distance running and other weight-bearing activities^{26 59 5 70 104}. Several studies in runners also report the benefit of using in-shoe orthotics to correct either forefoot varus or rearfoot valgus and thereby reducing subtalar pronation^{26 25}.

In cycling, the forefoot-pedal interface is particularly important because it may alter the direction of force translation through the patellofemoral joint. Cycling has a weight-bearing component on the forefoot only and an increased forefoot varus could result in increased subtalar joint pronation and result in excessive internal tibial rotation. In turn, excessive internal tibial rotation forces the patellar tendon medially, which in turn results in a rotational force on the patella. This rotational force can alter patellar tracking, cause abnormal shearing forces to the underlying tissue and lateral retinaculum, and may cause patellofemoral pain^{68 106}.

In one case-control study, it has been shown that increased rearfoot valgus and increased forefoot varus were associated with patellofemoral pain in cyclists⁶⁸. These findings support the hypothesis that forefoot varus in cyclists can result in secondary rearfoot valgus and therefore altered patellar tracking during forceful knee extension^{45 34 106}. In a recent study it has been shown that excessive medio-lateral deviation during the downstroke of cycling can be corrected in more than 80% of cyclists with patellofemoral pain by using a medial forefoot wedge. Once excessive medio-lateral deviation has been corrected, patellofemoral pain can be reduced¹⁰⁶.

Apart from using shoe inserts or modifying the cyclist/bicycle set-up, static intrinsic factors affecting patellar tracking can often not be corrected. However, dynamic intrinsic factors that affect patellar tracking can often be reversed and these deserve more discussion.

b) Dynamic intrinsic factors that affect patellar tracking

The two main dynamic intrinsic factors that affect patellar tracking are i) strength and control in muscles that stabilise the patella [vastus medialis obliquus (VMO) muscle], and the pelvis (hip extensor and abductor muscle groups), and ii) muscle flexibility of musculotendinous units in the lower limb⁶⁶.

i) Muscular strength and control as a dynamic intrinsic factor affecting patellar

tracking

Vastus medialis obliquus muscle (VMO)

It has been suggested that muscle weakness, specifically weakness of the vastus medialis obliquus (VMO) can lead to abnormal tracking of the patella. The VMO is the only dynamic medial stabiliser of the patella^{70 94}. The VMO realigns the patella during extension of the knee and is active throughout the whole range of knee extension. A number of factors can cause inhibition of the VMO stabiliser function. These include knee pain¹⁰¹, knee effusion^{100 101}, inflexibility of the lateral retinaculum and increased muscle activity of the vastus lateralis (VL) muscle⁹⁵. Muscle weakness of the VMO will increase the lateral force vector on the patella during flexion and extension of the knee and this will result in abnormal patellar tracking^{70 71 88}.

It can then be hypothesised that weakness or inhibition of the VMO will increase the lateral drift of the patella during the downstroke of cycling. However there are as yet, no well-conducted studies to suggest that abnormal VMO function alters patellar tracking in cyclists. This area requires further investigation.

Hip and pelvic muscle stabilisers

It has been suggested that pelvic, hip, and trunk stabiliser dysfunction can alter the alignment of the lower limb, and therefore patellofemoral tracking^{70 95}. The evidence for this comes from a study in which 11 subjects with patellofemoral pain were found to have a significantly greater hip and knee extensor moment during a squat test in

the neutral and the tiptoe position when compared with a pain free control group ⁴⁸.

It has also been observed that many patients with anterior knee pain have weakness of the external hip rotators of the affected leg ⁷⁰.

Exercises to improve the control of the pelvic stabilisers and hip rotators have therefore been considered as important in the treatment of patellofemoral pain ^{13 70}

⁹⁴. However, most of these hypotheses, even if derived from a sound theoretical model, are based on anecdotal evidence and more controlled clinical research is necessary to verify them.

Abnormal pelvic stabiliser function has never been investigated as a possible cause of patellofemoral pain in cyclists, and there is thus no scientific evidence to support this hypothesis. This area requires further investigation.

ii) Musculotendinous inflexibility as a dynamic intrinsic factor affecting patellar tracking

Inflexibility of the patellofemoral retinaculum, rectus femoris muscle, iliotibial band, hamstring muscle groups and the gastrocnemius muscle can all potentially alter the tracking of the patella.

The function of the patellofemoral retinaculum is to provide stability to the patellofemoral joint. However, an inflexible lateral retinaculum can cause a lateral

drift of the patella and patellofemoral pain^{70 71}. In recent studies, a high concentration of nerve endings has been observed in the lateral retinaculum. These nerve endings are thought to play a role in the proprioception of the knee joint and, if injured, could be a possible source of pain²⁶.

Inflexibility of the rectus femoris muscle will inhibit full flexion of the patella and this can potentially increase the patellofemoral joint reaction force (PFJRF). Inflexibility of the iliotibial band can result in a lateral force vector on the patella during knee flexion⁷⁸. Inflexible hamstring muscles can cause an increase in the amount of dorsiflexion that is required at the ankle joint. If maximum dorsiflexion has already occurred at the talocrural joint, further dorsiflexion can only occur at the subtalar joint, which will then increase subtalar joint pronation. Increased subtalar joint pronation causes internal rotation of the tibia resulting in increases in the dynamic Q angle, therefore the valgus vector force on the patella also increases. Inflexible hamstring muscles also cause greater flexion of the knee thus increasing the PFJRF in stance¹¹⁰. Similarly an inflexible gastrocnemius muscle also results in a compensatory subtalar joint pronation because dorsiflexion of the talocrural joint is reduced⁸⁹.

As with other lower limb biomechanical variables, inflexibility as a factor altering patellar tracking has only been studied in long distance runners. There are no data available on the relationship between inflexibility and abnormal tracking in cyclists.

Excessive medio-lateral deviation of the knee during cycling

A marked medio-lateral deviation of the knee during the downstroke of cycling has been observed in cyclists with chronic knee pain^{68 45 75 106}. In one of the first pilot studies, using video analysis of eight cyclists with knee pain, excessive medio-lateral deviation was noted in five subjects⁴⁵. An attempt was made to correct the transverse movement by means of shoe inserts, pedal inserts or cleat modifications. A decrease in knee pain was reported in three of the four symptomatic cyclists.

More recently, a case control study was conducted to establish whether excessive medio-lateral deviation was associated with patellofemoral knee pain in cyclists⁷⁵. In this study, cyclists with knee pain were compared with cyclist with no knee pain, and maximum medio-lateral deviation of the knee during the downstroke of cycling was documented in the injured knees when compared with the non-injured group. Two characteristic patterns of deviation in the knee pain group were observed: (a) a Figure of 8, and (b) an Oval pattern. An important finding of this study was that 20 of the 24 cyclists with no medio-lateral knee pain had a linear pattern of downstroke with no deviation. It was concluded that a predisposition to knee pain in cyclists might be related to increased maximum medio-lateral deviation in the downstroke of cycling⁷⁵.

Extrinsic factors affecting patellar tracking

Extrinsic factors that affect patellofemoral tracking are factors outside the patellofemoral joint. Extrinsic factors include equipment, training methods, training surfaces and external trauma to the patellofemoral joint. In cycling these extrinsic factors are related to incorrect equipment, incorrect settings of equipment and training errors.

The incorrect setting of equipment is a common error, especially amongst novice cyclists. Settings include saddle height, cleat type, and cleat position. Incorrect equipment is mainly the type of cycling shoe. Training errors may also affect the biomechanics of the patellofemoral joint. Common training errors that have been associated with patellofemoral pain in cyclists include using high gears, excessive hill training, and excessive training volume^{29 44 68}. It is thought that the mechanism whereby injury is caused during hill training and pushing at a low cadence is related to an increase in patellofemoral joint reaction forces (PFJRF)^{8 23 49 65}.

a) Incorrect settings of the bicycle

A saddle that is set too high can result in increased knee and hip extension at the end of the downstroke of cycling and can increase the tension in the iliotibial band⁴⁹. As previously mentioned, increased tension in the iliotibial band can alter the

patellar tracking by exerting a lateral force on the patella.

b) Cleats

Cleat positioning is of the utmost importance in regard to the angle of force at the foot-pedal interface^{8 23 23 49}.

Medial or lateral rotation of the cleat can affect tibial rotation and thus patellar tracking^{2 49}. In one study, transducers were used to measure power at the foot-pedal interface. A 100% increase in reaction force through the ankle joint was measured when changing from the posterior to the anterior foot position on the cleat during cycling. It was assumed that force at the foot pedal interface is directly related to the patellofemoral joint. Therefore, incorrect cleat positioning may result in abnormal patellar tracking¹⁵.

The introduction of the rigid cleat system in the mid-1980s resulted in an increase in patellofemoral pain syndrome in cyclists²⁴, possibly by restricting the normal tibial rotation, and therefore increasing patellofemoral torsion forces. More recently the effect of "floating" pedal systems on knee pain and performance has been investigated. This system allows for a small degree of movement between the shoe, and the cleat. It has been reported that in some instances the use of a "floating pedal system" resulted in reducing patellofemoral torsion forces, and decreasing patellofemoral pain^{43 44 91}.

c) Cycling shoes

It has been suggested that the type of cycle shoe may alter patellar tracking. A more rigid cycle shoe may be effective in maintaining the functional arch of the foot³⁴. A markedly flexible or worn cycle shoe may allow for excessive subtalar pronation. Excessive subtalar pronation can lead to an increase in internal tibial rotation, which in turn will force the patellar tendon medially. Medial patellar displacement will alter patellar tracking. A more rigid shoe will support the arch of the foot, especially during prolonged cycling, where muscle fatigue becomes a factor.

d) Training errors

It has been observed that, in an effort to decrease wind resistance, a cyclist may bring his or her knees toward the crossbar of the bicycle frame. This may place a valgus stress on the medial knee structures²³. A valgus stress on the knee might alter patellar tracking, as bringing the knee to the cross bar would require internal rotation and adduction of the hip, which would lead to an increase in patellofemoral torsion forces, and potentially result in patellofemoral pain.

Summary: Patellar tracking

Patellar tracking is an important element of patellofemoral joint function. Several studies have investigated the intrinsic dynamic and static factors that affect patellar tracking. These studies were mostly conducted in the general population or among

long distance runners. A few studies investigated the Q angle, leg length discrepancy, forefoot, and rearfoot alignment as static constraints in cyclists with patellofemoral pain. However, most studies were conducted on the extrinsic factors: the settings of the bicycle, cleats, cycling shoes and training errors. The only intrinsic factors that was associated with patellar tracking in cyclists, was forefoot varus¹⁰⁶, and rearfoot valgus⁶⁸. Saddle height^{106 23}, saddle position⁴⁴, and cleat position²⁸ was extrinsic factors associated with patellar tracking in cyclists.

Patellofemoral Joint Reaction Force (PFJRF)

PFJRF is the force between the ventral surface of the patella and the femoral condyles. It can be defined as a force that is equal in magnitude but in the opposite direction to the resultant forces of the quadriceps contractile force and the patellar tendon tension. The PFJRF is therefore a product of the muscle contraction around the patellofemoral joint, and the angle of knee flexion at which this action is taking place. The magnitude of the PFJRF depends on tension in the quadriceps muscle, the angle of knee flexion, and tension in the patellar tendon⁸⁷.

In closed chain movement of the knee, an increase in knee flexion would lead to an increase in the quadriceps torque that is required to resist the momentum of the body. As the angle between the quadriceps and the patellar tendon decreases, the resultant force increases. A two-dimensional model of PFJRF assumes that the

resultant force directed posteriorly on the patella is evenly distributed against both femoral condyles, and that it is only influenced by the flexion/extension motions of the knee^{14 32}.

Inflexibility of the quadriceps muscle increases the passive tensile force in the knee extensor mechanism and this may result in an increase in PFJRF. An excessive, or prolonged, increase in PFJRF may then lead to injuries of the ventral surface of the patella^{65 49 52 70}.

During cycling, the angle of knee flexion for a complete revolution can be considered as follows. By convention, the onset of the movement is taken when the pedal is at the top (top dead centre; TDC), at which point the knee is flexed at $\pm 120^\circ$. There is progressive knee extension until the pedal is at its lowest point (bottom dead centre; BDC) at which point the knee is flexed at $\pm 40^\circ$. Progressive knee flexion would then occur until the knee reaches the TDC position (120° flexion).

Factors that can affect the knee flexion angle are saddle height and the forward or backward movement of the saddle^{12 42}. Quadriceps contraction is maximal between 90° and 110° of the downstroke in cycling. Because quadriceps contractile force is directly related to PFJRF, the maximal PFJRF would be applied between 90° and 110° of knee flexion¹⁵.

The effect of changes in saddle height on electromyographic (EMG) patterns in the muscles that are involved in cycling has been the focus of considerable attention. It is well documented that the leg muscle EMG activity (mainly in the quadriceps and the hamstring muscles) increases as the seat height decreases. It can therefore be postulated that increasing the saddle height will decrease the quadriceps contractile force and therefore the PFJRF^{28 51}. A saddle that is set too low will increase knee flexion at top dead centre of the cycling motion. Increased knee flexion could lead to an increase in the PFJRF, hence potential injury to the patellofemoral joint^{23 77}. A saddle positioned too far forward, or too far back, could also potentially affect the angle of knee flexion and therefore the PFJRF⁴⁴.

In one study, the power at the foot-pedal interface using transducers was measured in cyclists. It was assumed that force at the foot-pedal interface was directly translated to the patellofemoral joint, therefore forceful knee extension (quadriceps contraction) would occur as the knee is extended from TDC position to BDC position (recorded peak pedal load between 90° and 110° of the pedalling cycle). In this study, it was documented that because quadriceps contraction is related to the PFJRF, the maximal PFJRF in cycling is applied between 90° and 110° of the downstroke in cycling¹⁵.

In a study to evaluate the use of foot orthotics in the treatment of patellofemoral pain, it was suggested that PFJRF is influenced by rotation of the tibia and femur. Malalignment of the lower extremity was associated with unequal transmission of the

resultant PFJRF to the femoral condyles, and an increased load to the overlying patellar facet ²⁶.

It is commonly hypothesised that training errors can contribute to patellofemoral pain ^{34 8 65}. High workloads, hill training, and high-gear ratio are all elements that may be associated with an increase in PFJRF and could result in patellofemoral pain. An increase in PFJRF by using high gears at a low cadence ^{8 23 65}, excessive hill training ^{49 65}, as well as a sudden increase in training volume, may all result in the development of patellofemoral pain ^{65 49 52 68}. However, it should be noted that in one study the overall training volume itself was not related to the development of symptoms ¹⁰⁸. All the studies on training volume was prospective, the population of the study conducted by Weiss et al ¹⁰⁸ was that of amateur long distance cyclists, but the average training volume compared well with that of the other studies. No case control studies has been conducted in this area.

Patellofemoral contact area

The patellofemoral contact area is the area on the ventral surface of the patella that is in contact with the femoral condyles during knee flexion. It is the area over which the patellofemoral joint reaction force is applied during knee movement. At full knee extension there is no contact of the patella on the femur. The first contact occurs between 10° and 20° of knee flexion along the inferior pole of the patella. Further flexion results in contact across the medial and lateral facets. With further flexion,

the area of contact moves superiorly and increases in magnitude. At 90° of knee flexion, contact is made at the large area of the superior pole of the patella. At no stage between 10° and 90° knee flexion is there contact with the odd facet. The medial margin only comes into contact with the femur when the knee is flexed at approximately 135°, when there is also contact between the lateral and odd facet. The overall patellofemoral contact area increases with the degree of flexion from 2.0 cm² at 30° flexion, to 5.0 cm² at 90° degrees flexion. This increase is almost linear⁵³.

The areas of the patella that are in contact with the femoral condyles between 90° and 110° during the downstroke of cycling are the middle of the superior pole, the lateral facet and the odd facet (medial). During cycling, patellofemoral contact stress would therefore be high in these areas^{68 105}. These findings have been confirmed in clinical studies in cyclists, where it has been shown that the superior- and supero-medial poles are the most frequent sites of patellar tenderness^{65 68 108}. It has already been mentioned that the position of the saddle (height, forward or backward position) would affect the angle of knee flexion and therefore the patellofemoral contact area. It has been suggested but not confirmed that adjustments to these parameters may be effective measures to decrease patellofemoral pain in cyclists⁸⁶.

Patellofemoral contact stress

Stress can be defined as the force per unit area. Patellofemoral contact stress therefore refers to the unit load (kg) applied over the contact area (cm²) of the

ventral surface of the patella during knee movements. A large force that is applied over a small surface area could overload the tissue and cause injury.

It should be noted that, with the greater angle of knee flexion, the PFJRF and the contact surface area increase during knee flexion (closed chain activity). In open chain activities the PFJRF is maximal at full extension precisely at a position where there is a small patellar contact area. Open chain activities are therefore associated with a much larger patellofemoral contact stress than closed chain activities at the same PFJRF. This is relevant in cycling, as closed chain activity and the contact surface between the patella and the femoral condyles therefore both increase with progressive knee flexion.

Patellofemoral contact stress has been calculated as 0.5 times body weight (BW) during level walking, 3.3 BW during stair climbing, 2.6 BW on maximum isometric knee extension, and 7 BW on squatting²¹. Although patellofemoral contact stress has never been measured in cycling, transducers to measure pedal reaction forces were used to measure the power output of varying foot positions during cycling⁴⁴. The aim of this study was to analyse foot positions and to explore the best technique riders should employ to impart force to the bicycle. On the basis of the results suggestions were made with regard to optimal seat height, optimal crank length, foot-pedal interface and pedal force patterns.

Pathophysiology of pain in the patellofemoral pain syndrome

The origin of the pain in the patellofemoral pain syndrome is not clear. However, there are a number of hypotheses. It has been suggested that the pain be due to any of the following mechanisms.

- A degeneration in the mid and deep layers of cartilage (basal degeneration) which then causes changes in the energy absorption resulting in increased intra-osseous pressure of subchondral bone ⁵.
- Basal degeneration of hyaline cartilage which progresses to the superficial layer of cartilage and then transfers excessive loads to the richly innervated subchondral bone ⁵.
- By-products of articular degeneration which irritate the synovium causing synovitis and pain ⁴¹.

More recently, there is evidence that patellofemoral pain may originate from the well-innervated lateral retinaculum. Biopsies of the lateral retinaculum have shown that small nerves in this area can be injured as a result of malalignment of the patellofemoral joint ²⁶. This can result in articular damage because of increased local stresses and decreased normal loading ⁷⁰.

Clinical diagnosis of the patellofemoral pain syndrome

The diagnosis of patellofemoral pain syndrome is made on the basis of symptoms, clinical examination of the knee joint and, less frequently special investigations are

required to confirm the diagnosis. A flow chart suggesting a diagnostic and management algorithm for cyclists with PFP has been constructed by the author of this paper. The purpose of this flow chart is to assist the clinician in formulating a systematic approach to the diagnosis and management of patellofemoral pain in cyclists is depicted in Fig 1.

In cyclists, the presentation of patellofemoral pain can range from minor discomfort that causes a brief interruption in training, to pain that is completely debilitating and disruptive to the professional cyclist^{30 44 45 68}.

Characteristics of patellofemoral pain

Pain is the most common symptom of patellofemoral pain syndrome. It presents as anterior knee pain, which generally has an insidious onset. The pain is characterised by a diffuse ache in the vicinity of the patella, and occasionally it is described as a vague knee pain "underneath the knee cap". Climbing stairs, or sitting for prolonged periods can exacerbate patellofemoral pain. This is also known as "movie go'ers knee". Other symptoms of patellofemoral pain are crepitus, "giving way", swelling, and a locking or "catching" sensation^{6 11 70}.

The site of the patellofemoral pain in cyclists is reported more frequently in the superior, superio-medial, and retro-patellar areas of the patella^{11 34 70 68 108}. The

onset of pain varies with the severity of this condition. It can present as pain only after cycling (Grade I), pain during cycling (Grade II and III), and less frequently, severe pain that prevents the cyclist from training (Grade IV) ⁶⁸.

The duration of pain can vary from a few minutes after cycling training, to pain that starts during training and lasts for several hours after training ceases. In some cases, the pain can last several days after the training session ^{68 49}.

Factors that either increase patellofemoral joint reaction force or factors that cause malalignment of the patella during tracking often aggravate patellofemoral pain in cyclists. The precise mechanism to why an increased PFJRF, or malalignment of the patella causes knee pain in cyclists is not exactly clear. With the limited understanding we have of the pathophysiology of patellofemoral pain syndrome it can be assumed that an increase PFJRF would cause abnormal contact pressure in the patellofemoral joint, in the long run this could lead to irritation, and eventually damage of the underlying structures. Malalignment of the patella during the down stroke could cause irritation to the pain sensitive lateral retinaculum, as well as causing an abnormal strain to the underlying structures. The intrinsic and extrinsic factors that can alter patellar tracking have already been reviewed.

Clinical signs of patellofemoral pain

The purpose of the clinical examination in cyclists presenting with suspected

patellofemoral pain is to confirm the anatomical-pathological diagnosis, and to make a functional diagnosis. Firstly, it is important to confirm the anatomical (patella) and the pathological (microscopic injury to ventral surface of the patella) diagnosis. Secondly, it is essential that the underlying functional abnormalities that are associated with patellofemoral pain are identified (functional diagnosis). Failure to identify functional abnormalities will result in incomplete management of this condition.

The most important clinical sign in the diagnosis of patellofemoral pain is patellar tenderness. During palpation the patella in cyclists with patellofemoral pain is mostly tender in the superior, or superio-medial aspect of the patella. Compression of the patella often results in pain on the ventral aspect of the patella^{70 68}.

Other less common clinical signs of patellofemoral pain include retropatellar crepitus, atrophy of the VMO, and a small effusion. Often the clinical signs may not be prominent and the clinician may not find signs of an effusion, or may not be able to elicit pain on any active or passive tests. The clue to the successful diagnosis, and treatment of patellofemoral pain, lies in the correct interpretation of a complete injury history, and taking into account all the relevant biomechanical factors^{70 38 11 6}. The differential diagnosis of patellofemoral pain is listed in Table 1.

Special investigations of patellofemoral pain

Special investigations to assist the clinician in confirming the anatomical-pathological diagnosis are imaging techniques such as radiography, magnetic resonance imaging (MRI), triple phase technetium bone scans. A full lower limb biomechanical assessment of the knee during cycling is essential to confirm functional abnormalities that may predispose to the development of patellofemoral pain (functional diagnosis).

Lateral, and skyline radiographs are valuable in eliciting joint space narrowing and osteophytes in patients with suspected osteoarthritis (OA) of the patellofemoral joint. In one study, skyline views of the patella were found to be more reproducible than lateral views for the diagnosis of OA of the patellofemoral joint³. Radiographs are also useful for detecting biomechanical abnormalities of the patellofemoral joint such as patellar tilt, patella alta, or patella baja. Fractures of the patella can be excluded if the patient had a history of acute trauma. However, bone stress injury of the patella can not be diagnosed using radiography as radiography is not sensitive enough¹⁹.

Magnetic resonance imaging (MRI) has proven to be an excellent technique to evaluate patients with PFP. It has been shown that MRI can identify abnormalities of menisci, ligaments, patellofemoral joints and other soft tissue and osseous structures of the knee that can mimic the clinical signs of patellofemoral pain. In a recent study, 41 patients with suspected internal derangement of the knee were examined with a T1-weighted FS 3D FLASH sequence and subsequently underwent

arthroscopy. The results show that for the detection of abnormal articular cartilage of the patellofemoral joint with the FS 3D FLASH sequence, sensitivity was 81%, specificity was 97%, and accuracy was 97%. This study concluded that T1-weighted FS 3D FLASH imaging is accurate for the detection and grading of articular cartilage abnormalities of the patellofemoral joint⁸⁶. Motion-triggered Cine MRI has shown to be a reliable tool in assessing the effectiveness of patellar realignment surgery¹⁰. Active movement loaded kinematic magnetic resonance (MR) imaging was used in a study to assess the effect of using a patellar realignment brace in 19 patients with patellar subluxation. In 16/19 patellofemoral joints (76%) a qualitative correction of or improvement in patellar subluxation after application of the brace could be demonstrated⁹⁶. The main advantage of the MRI is that it is a non-invasive method and is sensitive enough to obtain an accurate diagnosis⁹⁶.

Computerised tomography (CT) may identify patellar alignment, assess the degree of tilting or subluxation, and reveal pathology of the patellar cartilage. The newer "ultra fast" MRI and CT can assess the true dynamic state of patellofemoral articulation with virtual, or "real-time", imaging^{20 46}.

The triple phase technetium-99 bone scan is very valuable for establishing the presence of bone stress injuries, hairline fractures, and avulsion fractures⁷. Bone scans can also be of value if reflex sympathetic dystrophy (RSD) of the knee joint is suspected³⁹. In RSD, the bone scan will show increased peri-articular uptake which is thought to be a result of an increased blood flow to the bone secondary to

hyperaemia and increased bone metabolism.

Lower limb biomechanics during cycling using kinematic analysis of the knee has been used to evaluate cyclists with patellofemoral pain for the presence of abnormal knee movement^{34 45 75 68 106}. In a recent study, more than 80% of cyclists presenting with patellofemoral pain, an abnormal medio-lateral deviation of the knee during the downstroke of cycling was demonstrated⁷⁵. In a control group of cyclists with no PFP most had a linear pattern of downstroke. The intra-test repeatability for this type of kinematic analysis during the downstroke of cycling was good ($r=0.934$, with 97% of the differences falling within the two standard deviations of the mean)⁷⁵.

Management of patellofemoral pain

The management of patellofemoral pain is always conservative in the first instance (Fig 1). Conservative management can be divided into Phase I (symptomatic treatment), Phase II (correction of the underlying cause), and Phase III (maintenance and return to full activity). As an exception, and only once conservative management of patellofemoral pain has failed (at least 4 months of treatment) should surgical options be explored.

Conservative management of patellofemoral pain in cyclists

Phase I: Symptomatic treatment

The objectives of symptomatic treatment are to decrease pain and swelling.

Symptomatic treatment of patellofemoral pain consists of active rest, application of ice, local ultrasound and the judicious use of non-steroidal anti-inflammatory drugs (NSAIDS). There are no published double blind placebo controlled clinical trials that have evaluated the different modalities of symptomatic treatment of patellofemoral pain in general, and in cyclists specifically. In one study, conservative management of patellofemoral pain consisting of symptomatic treatment (rest, ice) and rehabilitation of the VMO, it was claimed that 82% of patients were treated successfully ²².

It seems that in most instances conservative treatment that does not attempt to improve patellofemoral biomechanics only decreases symptoms temporarily. There are no clinical studies on the effect of symptomatic treatment on patellofemoral pain in cyclist.

McConnel et al ⁷⁰ claims to have a long term solution to patellofemoral pain by altering patellar alignment through taping, and supporting this with rehabilitation of VMO function. This author brought with her work a new approach, and 'hope' to the problem of patellofemoral pain. In a study to investigate the 'McConnel approach, Gerrard et al ⁴⁰ found that after a 12 month period, only 30% of patients remained symptom free.

It has been suggested that the main reason for poor long term results of symptomatic treatment only are because underlying biomechanical abnormalities have not been identified and treated^{70 40}.

Phase II: Correcting biomechanical abnormalities

The purpose of correcting the underlying biomechanical abnormalities is to restore joint mobility, muscle power, and ultimately function of the patellofemoral joint. It is most important to identify and correct the factors (intrinsic and extrinsic) that lead to abnormal patellofemoral biomechanics. Correction of the underlying biomechanical abnormalities is essential to prevent the reoccurrence of patellofemoral pain.

The aim of treating the biomechanical abnormalities in patellofemoral pain is to restore normal patellar tracking, decrease excessive patellofemoral joint reaction forces, increase the patellofemoral contact area, and decrease the patellofemoral contact stress. These principles are all relevant in the management of patellofemoral pain in cyclists.

It is important to identify the appropriate biomechanical factor in the rehabilitation of patellofemoral pain syndrome. Here follows a list of the most frequent corrections of biomechanical abnormalities:

- Rehabilitation of the vastus medialis obliquus muscle (VMO)
- Decreasing the lateral force on the patella

- Correcting forefoot, and rearfoot abnormalities
- Restoring lower limb alignment
- Correcting equipment
- Correcting training errors

Each of these areas will now be discussed.

a) Rehabilitation of the VMO

Rehabilitation of the VMO has two components: i) Decreasing VMO inhibition, by realigning the patella, stretching tight lateral structures and inhibition of an overactive vastus lateralis. ii) VMO strengthening, which consists of exercises to improve the eccentric control of the VMO, and biofeedback to improve the timing of the VMO to vastus lateralis (VL) contraction (VMO:VL ratio).

i) Decreasing VMO inhibition

Patellar taping procedures have been proposed to correct abnormal patellar postures, and therefore decrease abnormal patellar tracking. Studies using patellar taping techniques have been reported in the general population, and in long distance runners⁷⁰. Taping should only be applied after careful evaluation of patellar position. Taping can correct abnormal tilt, glide and rotation of the patella, thereby temporarily facilitating normal patellar tracking and allowing for training and rehabilitation in a pain-free manner. It has been reported that taping facilitates the

increase of effective quadriceps strength by decreasing pain and VMO inhibition⁷⁰
^{88 94}. The VMO:VL ratio, as measured by biofeedback, was reported to improve with
patellar taping. Specific taping techniques have also been developed to decrease
symptoms after patellectomy and in patients with patellar tendinopathy. In one case
series, a 96% success rate with patellar taping was reported over a twelve-month
period. However, as this was a case series, there were no control subjects^{70 71}.
There are no well-controlled clinical trials on the effect of taping on patellofemoral
pain athletes in general, and in cyclists in particular. This area needs further
investigation.

ii) *VMO strengthening*

Eccentric muscle strengthening exercises has been recommended in the
rehabilitation of the VMO⁴⁰. It is to be performed in a weightbearing and functional
position (closed chain). Eccentric exercises in the rehabilitation of the VMO have
been shown to be less painful in subjects with patellofemoral pain, create greater
tension within the muscle, and enable a greater positive effect in a shorter time
period. The VMO can be rehabilitated by stimulation through touch, electrical
stimulation, and biofeedback¹¹¹.

Models for treatment of patellofemoral pain (PFP) initially suggested exercises,
which are designed to minimise PFJRF. These included open-chain exercises in the
last few degrees of knee extension. However, open chain exercise training is non-
weight bearing, and therefore is not a functional exercise. Furthermore, open chain

exercises take place in the last degrees of knee extension, where the patellofemoral contact surface is minimal, and the potential for excessive patellofemoral contact stress is at its greatest. It has been suggested that correcting patellofemoral alignment allows for early rehabilitation^{4 13 14 70 97}.

b) Decreasing the lateral force on the patella

There is anecdotal evidence that techniques to decrease the lateral force of inflexible structures such as the lateral retinaculum, and the iliotibial band can successfully alter patellar tracking, and decrease patellofemoral pain^{70 95}. It has been proposed that in a pain free knee the VMO: VL ratio should be 1:1. In patients suffering from patellofemoral pain that ratio is often disturbed by a stronger VL and delayed activity in the muscle fibres of the VMO. It has been suggested that specific rehabilitation and strengthening of the VMO, and taping techniques can inhibit an overactive vastus lateralis muscle (VL). It has been suggested by some investigators that biofeedback is useful in the rehabilitation of the VMO, and in detecting an overactive vastus lateralis^{71 88 94 95}. Once again, there are no controlled clinical trials to show that stretching the lateral retinaculum or inhibiting the vastus lateralis decreases patellofemoral pain in athletes in general, and in cyclists specifically.

c) Correction of forefoot and rearfoot abnormalities

Increased or prolonged subtalar pronation has been associated with patellofemoral pain in the general population and long distance runners^{18 26 58}. There is substantial anecdotal evidence that the use of in-shoe orthotics control excessive and/or prolonged subtalar pronation in long distance runners²⁶. There is good evidence from a controlled laboratory study that a medial forefoot wedge can decrease excessive medio-lateral deviation of the knee during the downstroke of cycling¹⁰⁶. In an A-B-A clinical trial design, the use of medial forefoot wedges to correct medio-lateral deviation of the knee was recently shown to substantially decrease patellofemoral pain during cycling¹⁰⁶.

d) Restoring dynamic lower limb alignment

i) Pelvic control

Exercises to improve the control of the pelvic stabilisers and the hip rotators has been suggested as an important factor in correcting the alignment of the lower limb, and in the treatment of patellofemoral pain^{13 70 94 95}. However, these suggestions, even though they may be derived from a sound theoretical model, are based on anecdotal evidence and there are no controlled clinical studies to substantiate these hypotheses.

There is no evidence to suggest that abnormal pelvic control is related to patellofemoral pain in cyclists. All that is known at this stage is that cycling has a weight-bearing component, and that femoral anteversion may reduce hip internal or external rotation. This could result in abnormal patellar tracking. It is once again an area that requires further investigation.

ii) Correcting medio-lateral deviation during the downstroke of cycling

There is strong evidence that abnormal medio-lateral deviation of the knee during the downstroke of cycling is associated with patellofemoral pain. In a recent study, more than 80% of cyclists presenting with patellofemoral pain demonstrated an abnormal medio-lateral deviation of the knee during the downstroke of cycling⁷⁵. In a control group of cyclists with no PFP most had a linear pattern of downstroke.

Recently, two studies were conducted to determine whether correcting lower limb kinematics decreases patellofemoral pain in cyclists. In the first study medio-lateral deviation during the downstroke of cycling as measured by two dimensional video analysis⁷⁵, was reduced significantly by a medial forefoot wedge, and by raising the saddle height¹⁰⁶.

We suggest that the following mechanism could explain why a medial forefoot wedge could reduce patellofemoral pain in cyclists. As has already been mentioned, a medial forefoot wedge would correct forefoot varus, thereby decreasing subtalar joint pronation during the downstroke of cycling. A reduction in subtalar joint

pronation would decrease internal tibial rotation and this would restore patellar tracking.

Similarly, an increase in saddle height is associated with reduced quadriceps EMG activity and a reduction in knee flexion angle. Reduced quadriceps EMG activity as well as a reduced knee flexion angle both reduce patellofemoral joint reaction force and thereby decrease the patellofemoral contact stress during the downstroke of cycling.

These findings were recently tested in a second study. In a controlled clinical trial, a laboratory and a field test were conducted to determine the effect of a reduced medio-lateral deviation on patellofemoral pain in cyclists¹⁰⁶. A significant decrease in total pain in a 30-min laboratory cycle test and during a field test was reported when medio-lateral deviation was corrected in the cyclists. This study concluded that cyclists with patellofemoral pain exhibiting excessive medio-lateral deviation in the downstroke of cycling can be corrected to a more linear pattern using minor biomechanical modification, and that once corrected, patellofemoral pain during cycling decreases¹⁰⁶.

e) Correction of equipment

It is important to assess and correct the abnormal use of equipment. Corrections that have to be considered are correcting the saddle height and the cleat position²

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As has already been discussed, a change in saddle height can alter knee range of movement during cycling^{8 49}. It has also been mentioned that in a clinical trial it has been shown that by raising the saddle height, medio-lateral deviation of the knee during the downstroke of cycling can be corrected and that this resulted in a decrease in patellofemoral pain during cycling¹⁰⁶.

There is anecdotal evidence to suggest that “floating” as opposed to rigid cleats can reduce high torsional forces during cycling^{24 28}. A “floating” type of cleat theoretically allows for some movement of the foot thereby preventing excess translation of torsional force to the knee, and the patellofemoral joint. There are no controlled studies to verify this hypothesis.

f) Correction of training errors

It has been suggested that training errors should be identified and corrected in cyclists with patellofemoral pain. Modifications to training may include active rest, reducing training mileage and avoiding hill training and the use of high gear ratio's until the patellofemoral pain has resolved^{49 65}. Active rest includes a reduction in overall cycling training, as well as supplementing training with other forms of exercise. Exercise should maintain cardiovascular, endurance and power, as well as excluding activities that could cause an excessive PFJRF, like hill training and high

gears. Open chain strengthening exercises should also be avoided for example knee extensions in sitting, against resistance.

Cycling with high gear ratio's can be corrected by the teaching of "spinning" techniques. Spinning involves a high cadence, and lower gear ratio, and both of these manoeuvres will decrease PFJRF.

Phase III: Maintenance

It is important to change biomechanical factors that have been identified in a step-wise fashion, starting with the most severe or likely factor. The effects of management in Phase II should be re-evaluated after 2-6 weeks. The evaluation consists of subjective feedback from the patient on the symptoms of the patellofemoral pain, as well as an objective clinical evaluation of the signs of the condition. During Phase II other forms of cardiovascular exercise can be incorporated in the treatment programme, to maintain general cardio-respiratory conditioning. The cycling training distance and intensity can be increased gradually, once patellofemoral pain subsides. Cycling techniques to decrease patellofemoral joint reaction forces can be taught. These include spinning, avoiding hill training and using low rather than high gears.

Summary: Conservative management of patellofemoral pain in cyclists

Although there are no published controlled prospective studies, it is our experience

that conservative treatment of patellofemoral pain appears to be successful, provided the management is aimed at identifying and treating the underlying causes. Surgical options have to be considered after failed conservative management for patellofemoral pain syndrome.

Surgical management of patellofemoral pain in cyclists

Surgical procedures to treat patellofemoral pain can be divided into those restoring the static or dynamic structures of the patella and patella resurfacing or decompression procedures. The basis of surgical procedures is to restore the mechanical abnormality rather than relying on the dynamic alteration of the patellar tracking by rehabilitation of muscle groups. Common surgical procedures are:

- lateral retinacular release
- distal realignment
- dynamic realignment
- patellar shaving
- patellectomy

A lateral retinacular release involves the cutting of all the lateral structures from the patellar tendon to within the muscle fibres of the vastus lateralis during an arthroscopy. Good results have been reported in case series when the strict selection criteria of the excessive lateral static pull were applied⁹⁸. It is important to note that in most cases the post operative rehabilitation programme was considered

an important element in the success of this procedure ⁴⁷.

Subluxation and dislocation of the patella are mainly treated surgically by moving the tibial tubercle medially and changing the Q angle. Possible complications of this procedure are an increase in patellofemoral reaction forces, and an increase in patellar rotation and compressive forces ^{40 47}.

Dynamic realignment involves the transfer of muscles or tendons to counteract the lateral tracking of the patella, thereby increasing the effect of the medial pull of the vastus medialis obliquus (VMO) muscle. The main disadvantage of this procedure is that it interferes with an already weakened muscle, and the progress of post-operative care is much slower than that of the other procedures that have been described ⁹⁸.

Patellar shaving has been shown to produce variable and often only temporary improvement of pain. Arthroscopic lavage by itself often settles a painful joint, as it removes small articular particles that might produce synovitis, and may lead to the formation of loose bodies ⁹⁸.

Patellectomy, has been performed, but has severe detrimental effects on the biomechanics of the knee joint ⁹⁸.

To conclude, the following surgical procedures are the most frequently reported in

the management of patellofemoral pain: Patellar lateral release is still a common surgical option for the denervation of a painful retinaculum, correction of a mild malalignment, or the reduction of a tilted patella^{36 95}. Patellar realignment, is a more extensive procedure, and recommended if the patient has a recurrent subluxed or dislocated patella, with considerable patellar tilting³⁸. Tibial tubercle transfer is a more drastic intervention, recommended in cases of severe patellar instability, prominent lateral tracing, excessive Q angle, and failed lateral release³⁸. The surgical management of patellofemoral pain was mostly reported as case series, conducted on the general population, with very few investigations in the long-term outcome. There are no scientific data available on the surgical management of patellofemoral pain in cyclists.

It is important to note that individuals show a wide range of anatomical variation and a 'perfect model', or formula cannot be applied broadly to all cyclists. The success in treating patellofemoral pain in cyclists will depend on a diligent evaluation of all the contributing biomechanical factors involved. The clinical reasoning should be communicated to the cyclist, with the necessary motivation and goal setting.

Summary

Patellofemoral pain is the most common overuse injury in cyclists. This condition has proven to be a challenge to clinicians, as traditional conservative approaches to

management rarely improved the condition in the long-term. There is little scientifically evidence linking biomechanical factors to patellofemoral pain in cyclists.

Patellar tracking, patellofemoral joint reaction forces, patellar contact areas and patellar contact pressure, are elements that play an important role in the biomechanics of patellofemoral pain. Static intrinsic factors affecting patellar tracking in cyclists are rearfoot valgus and forefoot varus. An important dynamic intrinsic factor that has recently been identified is excessive medio-lateral deviation during the down-stroke of cycling.

More information is available on the extrinsic factors that may contribute to patellofemoral pain in cyclists. These include the incorrect settings of equipment such as saddle height, cleat position, cleat mobility, cycling shoes, and training errors.

Sound clinical reasoning is vital in the successful management of patellofemoral pain in cyclists. It is clear that the cyclist and the bicycle should be assessed as a unit, and contributing factors for each individual identified. Specific factors are abnormal lower limb alignment, incorrect settings of the bicycle, and incorrect training methods. Once a treatment plan is implemented, it should be carefully evaluated at regular intervals. Cycling training should gradually be increased once the patellofemoral pain is resolved.

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Table 1: The differential diagnosis of Patellofemoral Pain. (Brukner and Kahn 1992; McConnel 1986)

Common

- Meniscal lesions
- Hoffa fat pad syndrome
- Retropatellar tendon bursitis
- Ligamentous lesions (medial collateral; lateral collateral)
- Quadriceps tendinopathy
- Patellar tendinopathy
- Growth plate injury eg Siding Larsen Johannson syndrome
- Synovial plica syndrome
- Osgood-Schlatter's disease
- Osteochondral lesions of the femur
- Chronic quadriceps muscle tear
- OA of the patellofemoral joint
- OA of the Tibiofemoral joint

Less common

- Prepatellar bursitis
- Pes insurance bursitis
- Proximal tibial bone stress
- Systemic synovitis
- Femoral condylar bone "bruises"
- Bone stress injury of the patella
- Osteochondral lesions of the patella
- Bone tumors
- Retinaculitis

Table 2a: Intrinsic factors affecting the patellofemoral joint^{29 49 68}*Static*

- Rearfoot valgus (abnormal tracking, rotational stress)
- Forefoot varus (abnormal tracking, rotational stress)
- Increased Q angle (abnormal tracking)
- Leglength discrepancy (abnormal tracking)
- Abnormalities of the patella (abnormal tracking, abnormal stress)
- Abnormalities of the femoral condyles (abnormal tracking, abnormal stress)
- Genu valgus (abnormal tracking)

Dynamic

- Excessive tibial rotation (abnormal tracking, rotational stress)
- Excessive media-lateral deviation of the down stroke movement
- Femoral anteversion (abnormal tracking, rotational stress)
- Vastus medialis insufficiency (abnormal tracking)
- Muscle tightness (abnormal tracking, abnormal stress)
- Poor pelvic and hip control (abnormal tracking)

Table 2b: Extrinsic factors affecting the patellofemoral joint.*BICYCLE*

- Incorrect saddle heights
- Incorrect cleat position
- Rigid cleats
- Type of cycling shoes

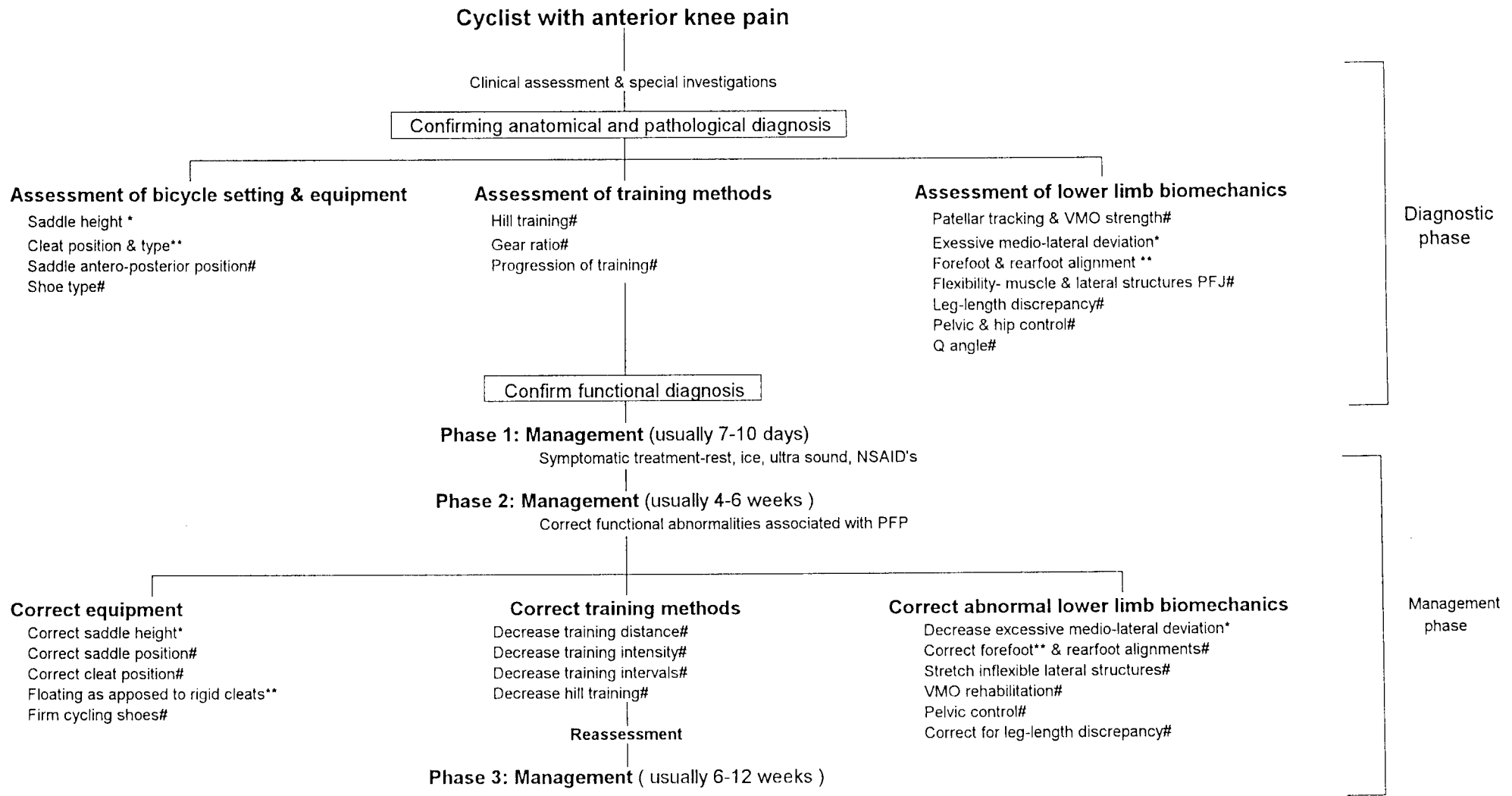
TRAINING ERRORS

- High work loads
- Hill training
- High gear ratios
- Speed training

Table 3: Epidemiology of chronic knee pain in cyclists

Type of study	Type of event	No of cyclist	Distance (miles)	Knee Pain %	Site
questionnaire ¹¹¹	cycle tour	132	500 miles (8 days)	34.4	peri-patellar latt/med
quest / interviews ⁶⁵	cycle tour	89	4500 miles (80 days)	65	peri-patellar
questionnaire ¹⁰⁹	recreational	518	-	41.7	-
questionnaire ⁶³	off-road	-	-	30	-
log book ⁶²	triathlon	155	100.2/w (8 weeks)	19	-

Fig 1: A diagnostic and management algorithm for cyclists with PFP



1 *: Factors well documented in controlled clinical trails

2 **: Factors documented with limited clinical scientific evidence (case control studies)

3 #: Postulated factors for which there is no clinical evidence (case series, anecdotal reports)

Chapter 3

Research paper

**Title: CORRECTING LOWER LIMB KINEMATICS DECREASES
PATELLOFEMORAL PAIN (PFP) IN CYCLISTS**

Submitted for publication in: The American Journal of Sports Medicine

**CORRECTING LOWER LIMB KINEMATICS DECREASES
PATELLOFEMORAL PAIN (PFP) IN CYCLISTS**

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Abstract

A longitudinal study was conducted to investigate 1) techniques of correcting medio-lateral deviation of the knee during the downstroke in cycling (Phase I), and 2) to assess the effect of a reducing medio-lateral deviation on patellofemoral pain during cycling (Phase II). In Phase I, 15 cyclists (32 ± 9 years, mean \pm SD) with patellofemoral pain, and abnormal patterns of knee movement [oval (O) or figure-of-8 (F)] resulting in medio-lateral deviation >3 mm confirmed in 21 knees, were subjected to kinematic 2 dimensional video analysis. Five methods of correction were tested: internal and external foot rotation (5 degrees respectively), medial and lateral forefoot wedges (5 mm respectively), and raising the saddle height to 110% of the distance between the greater trochanter, and the medial malleolus. A significant reduction in medio-lateral deviation (mean \pm SD) was achieved with the medial forefoot wedge, and raising the saddle height. In 16 knees, medio-lateral deviation (mm) was reduced from 38.9 ± 13.4 to 20.4 ± 7.8 ($p=0.0001$) when corrected with a medial forefoot wedge. In 12 knees medio-lateral deviation (mm) was reduced from 41.4 ± 13 to 22.3 ± 7.8 ($p=0.0005$) when corrected by raising the saddle height. In Phase II, an A-B-A type clinical trial using the best method of correction of the knee medio-lateral deviation was conducted over three training periods (Time 1: training four weeks with no correction, Time 2: training four weeks with correction, and Time 3: training four weeks with the correction removed). Measures of outcome were 1) a laboratory test (30 minute cycle recording pain on a visual analogue scale (VAS) (1-10) every minute, 2) a field test (recording pain during training on a VAS), and 3) a log book of pain experienced during cycling. A significant reduction in patellofemoral pain (pain units 0-10; mean \pm SD) was shown when the deviation was corrected. The laboratory test show that Total pain for Time 1 was 42.2 ± 38.9 , Time 2 was $19.5 \pm 23.7^*$, and

Time 3 was 33.8 ± 42 (*:p=0.0004). The field test showed that maximum pain for Time 1 was 3.0 ± 1.7 , for Time 2 was $1.4 \pm 1.2^*$, and for Time 3 was 2.2 ± 1.5 (*:p=0.002). In conclusion, cyclists exhibiting excessive medio-lateral deviation of the downstroke of cycling can be corrected to a more linear pattern using biomechanical modification and, once corrected, patellofemoral pain during cycling decreases.

Introduction

Cycling for recreation and as a sport has steadily increased in popularity since the 1980's. It is generally regarded as an activity with great potential for fitness and rehabilitation because it is regarded as safer than activities that are associated with repetitive joint impact^{18 34}. Although cycling is associated with less repetitive impact force to weight bearing joints, studies have shown that there is still a risk for the development of acute accidental^{6 23 30 31} as well as overuse injuries^{18 7}.

Only limited research is available on the epidemiology of overuse injuries in cyclists^{18 23 7 34 35}. Knee pain, and specifically the patellofemoral pain (PFP) syndrome, is the most common overuse injury in cyclists. Patellofemoral pain syndrome alone can account for about 25% of reported overuse injuries in cyclists².

The biomechanics of the patellofemoral joint complex and the nature of the forces that cycling imposes on this joint is the key to understanding the mechanism of patellofemoral pain in cyclists. The optimal pedalling rate during cycling training is 80–100 revolutions per minute¹³. It is conceivable that if minor abnormality in patellar tracking is repeated at this rate, damage to the patellofemoral joint can occur. The pathomechanics of the knee during the propulsion phase, also known as the downstroke phase, has been well investigated^{17 28 32}. It has been shown that cyclists with knee pain and a poor pedalling technique exhibit a marked medio-lateral deviation of the knee during the downstroke of cycling^{10 15 17 25 28}.

In pilot studies, the use of in-shoe orthotics appears to have reduced the amount of

medio-lateral deviation during the downstroke in cycling¹⁷. There is also anecdotal evidence to suggest that the reduction of medio-lateral deviation decreases patellofemoral pain. However, small numbers of subjects and the lack of a control group, limit interpretation of the findings of these studies^{13 17 33}.

The aim of this study was firstly to determine whether excessive medio-lateral deviation during the down-stroke in cycling could be corrected to a more linear pattern, and secondly whether the reduced medio-lateral deviation decreases patellofemoral pain and therefore increases the distance cycled without pain.

Methodology

Subject recruitment

The aim of subject recruitment was to identify cyclists with patellofemoral pain who also displayed an associated medio-lateral deviation of the knee during the downstroke of cycling. Cyclists with chronic (>3 months) anterior knee pain were recruited through advertising in local newspapers and a national cycling magazine. Fifty-eight cyclists responded to the advertisement. Specific criteria were used to identify subjects that should be asked to report for an assessment (Table 1). Twenty-six cyclists had symptoms that did not fit the criteria for patellofemoral pain, or were living too far from Cape Town to participate in the study. Thirty-two subjects were therefore requested to report to the laboratory for a clinical assessment.

Physical examination of the subjects

The physical examination to confirm clinical diagnosis of patellofemoral pain and the kinematic analysis were all conducted by the principle researcher. The 32 subjects underwent a physical examination to clinically confirm the diagnosis of patellofemoral pain. Patellofemoral pain was defined as tenderness on the ventral aspect of the patella with pain on flexion/extension of the knee joint. At least four of the seven inclusion criteria listed in Table 2 were required to confirm the diagnosis^{1 3 14 26 28}. Twenty-four out of the 32 cyclists that were examined fitted the clinical criteria for the diagnosis of patellofemoral pain. This sub-group was then screened for the presence of significant medio-lateral deviation of the knee during the downstroke of cycling (greater than 3mm) using kinematic analysis.

Kinematic analysis

Kinematic analysis of the cycling motion of the knee was conducted to establish whether patellofemoral knee pain in subjects is associated with medio-lateral deviation. The cyclists brought their own bicycles to the laboratory. The bicycles were fitted on a Kingcycle air braked cycle ergometer (Kingcycle Ltd., High Wycombe, Bucks, U.K). This system allows cyclists to ride their own bikes in the laboratory. After the removal of the front wheel, the bicycle was attached to the ergometry system by the front fork and supported by the adjustable pillar under the bottom bracket. The bottom bracket support could be adjusted to alter the rolling resistance of the rear tyre an the air-braked flywheel. The Kingcycle computer (Kingcycle Ltd., High Wycombe, Bucks, U.K) was then attached to the bicycle to

ensure that each subject cycled at a predetermined cadence of between 85 and 95 revolutions per minute. The Kingcycle ergometer was calibrated according to the operating manual (published by Kingcycle Ltd, High Wycombe, Bucks, U.K.) before each test to ensure repeatability for the test.

Spherical reflective markers were placed on the most prominent part of the tibial tuberosity on each knee. This site was chosen as the marker for the knee as the overlying skin does not move significantly during the knee flexion and extension of the cycling motion^{17 28}.

A video camera (Sharp. Model: VL-C7950) was placed 3 metres away from the front end of the Kingcycle rollers. The settings for camera placement were marked with tape on the floor of the testing laboratory and remained the same for the duration of the trial. The video camera was placed on a tripod, 75 cm above the floor surface, and in line with the reflective marker on the tibial tubercle of the knee. The height of the camera was set to correspond to the point exactly half way between TDC (top dead centre), and BDC (bottom dead centre) of the knee. In this position, the knee was required to be in the centre of the video camera frame of 34mm wide-angle lens. The camera was set on auto-focus with a lens aperture of f.8. These settings remained constant throughout the duration of the trial. The movement of each knee was recorded separately. A ruler (in mm) was placed next to the knee, to correct the measurement for any magnification that the camera lens might have introduced.

Prior to testing, the cyclist was required to warm up by cycling for two minutes. This was considered necessary to familiarise the cyclist with the equipment, and specifically, to familiarise the cyclist with the cadence of 85-95 revolutions per

minute which was required during filming. After the warm up period, the cyclist was required to cycle at the predetermined cadence of 85-95 revolutions per minute, for 30 seconds whilst filming took place. This short period of filming was deemed necessary to limit the possible onset of knee pain, which might affect knee movement during cycling²⁸.

Analysis of the downstroke movement was conducted by digitising the movement of the reflective marker. The videotape was played back frame by frame on a 57cm Philips CM8833 monitor. The movement of the reflective marker on the tibial tuberosity was plotted directly on to a transparency that covered the screen. The medio-lateral deviation was measured and the known measurement of the ruler next to the knee (during filming) was used to correct for any magnification. The medio-lateral deviation was measured in millimetres. The inter-tester repeatability of this measurement technique has previously been established with 97% of the differences falling within 2 standard deviations of the mean²⁸.

The pattern of knee movement during the downstroke/upstroke sequence was classified as an oval pattern (O), a pattern resembling a figure of eight (F), or a linear pattern of knee movement^{17 28}.

Using this measurement technique, subjects that exhibited a medio-lateral deviation during the downstroke of >3 millimetres were identified. After the screening process, 20 of the 24 cyclists (83%) with patellofemoral pain in 27 knees were diagnosed with significant (>3mm) medio-lateral deviation.

During the course of the study, four cyclists were involved in accidents with motor vehicles, and one was unable to complete the study due to illness. The final group of subjects therefore consisted of 15 cyclists (14 males, 1 female) who suffered from patellofemoral pain and had associated significant medio-lateral deviation of the knee during the downstroke of cycling. Six subjects had bilateral patellofemoral pain, and therefore the total number of injured knees that were studied was 21.

All the cyclists signed informed consent, and completed questionnaires, which included elements of training history, such as frequency, distance, and hill training. In addition, an injury history questionnaire on the characteristics of the knee pain was completed together with a response to previous treatment, if any.

Phase I: Correcting medio-lateral deviation during the downstroke of cycling

The aim of Phase I of the study was to identify whether excessive medio-lateral deviation during the downstroke of cycling could be corrected to a more linear pattern using five different techniques. Four of these techniques altered the position of the foot pedal interface, namely internal and external rotation of the cleats, and the insertion of a medial, and a lateral forefoot wedge. Raising the saddle was the fifth method of correction. These methods of correction were chosen, as they all potentially affect patellar tracking. The methods were implemented to correct abnormal static lower limb biomechanical parameters in cyclists, and thereby reduce medio-lateral deviation of the knee during the downstroke of cycling.

In the first instance, a static lower limb clinical biomechanical assessment, and a

static assessment of the bicycle was conducted. This was followed by a kinematic analysis, during which five separate methods of correcting medio-lateral deviation of the knee during downstroke was tested^{13 25 26}.

Static biomechanical assessment of the cyclist

The same investigator conducted all the static lower limb biomechanical assessments to reduce inter-tester variability¹⁹. The following static lower limb biomechanical variables were assessed: leg-length discrepancy, quadriceps angle, forefoot alignment, rearfoot alignment, flexibility of the iliotibial band (ITB) and hip abductors^{11 13 16 25}.

Leg-length discrepancy was defined as a difference in leg length of 1cm or more. The measurement was taken in the supine position, using a rigid tape measure, as the distance from the anterior superior iliac spine (ASIS) to the medial malleolus¹⁶.

The quadriceps femoris angle (Q-angle) was measured in the erect position with a clinical goniometer (Biomet, Medical distributors, Cape Town). The Q angle was defined as the angle between 1) a line drawn from the ASIS to the mid line of the superior pole of the patella and 2) a line drawn from the middle of the inferior pole of the patella to the tibial tubercle. The reported average Q angle is 15.8 ± 4.5 degrees for females, and 11.2 ± 3.0 degrees for males^{20 27}.

Forefoot alignment (varus/valgus) was measured with the cyclist in the prone position. This is the angle between a line perpendicular to the long axis of the

calcaneus and a line parallel to the metatarsal heads, whilst the subtalar joint is in a neutral position ²⁷.

Rearfoot alignment (varus/valgus) was determined in the erect position with the feet together, and measured as the angle between a line connecting the midpoint of the popliteal crease proximally to the insertion of the Achilles tendon distally, and a line bisecting the calcaneus ²⁷.

Inflexibility in the iliotibial band (ITB) and other hip abductors was measured using Ober's test. The cyclist is positioned in a side lying position, with the hip in full extension and with the knee flexed at 90°. The hip was kept in full extension and then adducted. If the ITB is inflexible, knee extension occurred with adduction, and the muscle was classified as 'inflexible'. If the knee remained flexed during the manoeuvre, the ITB was classified as 'flexible' ²⁹.

Static assessment of the bicycle

All assessments including the static assessment of the bicycle, shoes, and cyclists position on the bicycle were conducted by the principle researcher. A number of characteristics of the bicycles of each cyclist were measured. These included the frame size, distance from pedal axis to seat and the crank length. The ratios of each of these variables to the leg length of the cyclist (measured as the distance from floor to crotch in standing) were then determined ⁴.

The type of shoes, soft or rigid, and the type of pedals, cleated or not, and whether

they allowed for foot rotation during the downstroke of the pedal revolution, was noted. Maximum knee flexion (MKF) and maximum knee extension (MKE) was measured once the cyclists had mounted their bicycles - with the knee angles at top dead centre (TDC), at 90° and bottom dead centre (BDC) at 270°. These measurements were made using a standard clinical goniometer¹⁰.

Kinematic analysis of the knee during cycling

The technique that was used to measure the medio-lateral deviation of the knee during cycling has already been described. Two-dimensional video analysis of the up-stroke/down-stroke pattern of the knee whilst cycling was measured during each of the following interventions.

- Cleats in a neutral position, and no corrective forefoot wedge (N)
- Cleats fixed in 5° internal foot rotation, and no corrective forefoot wedge (IR)
- Cleats fixed in 5° external foot rotation, and no corrective forefoot wedge (ER)
- Cleats in a neutral position, and a 5mm lateral forefoot wedge (LFFW)
- Cleats in a neutral position, and a 5mm-medial forefoot wedge (MFFW)
- Cleats in a neutral position, no corrective forefoot wedge, but with increased saddle height of 110% (SH)

Measurements with the increased saddle height were determined as a percentage (110%) of the distance between the ischial tuberosity and the medial malleolus on each subject. The saddle height was measured as the greatest distance from the saddle surface to the centre of the upper pedal surface in a straight line along

saddle pillar and crank^{10 15}.

The medio-lateral deviation of the knee during the downstroke of cycling was measured for each of these interventions, and this was compared with the baseline. When a method of correction was able to reduce the deviation by more than 20% it was defined as successful. The intervention that best corrected the medio-lateral deviation of the knee was then prescribed, and used in Phase II of the study.

Phase II: The effect of correcting medio-lateral deviation on patellofemoral pain during cycling

The effect of correcting excessive medio-lateral deviation on patellofemoral pain was studied in Phase II. This phase of the study was conducted in the form of an A-B-A type clinical trial. This type of trial was chosen due to the difficulty in applying some form of placebo intervention in a control group. The aim of the second phase of the study was to determine the effect of correcting an excessive medio-lateral deviation to a more linear pattern during the downstroke of cycling, on patellofemoral pain, and cycling performance.

A laboratory and field test was performed to assess whether knee pain is reduced once the medio-lateral deviation during the downstroke of cycling was restored to a more linear pattern.

Subject recruitment (Phase II)

The 15 cyclists, and 21 knees, that were recruited and studied in Phase I of the study were also recruited as subjects for Phase II of the study.

Laboratory test

All the subjects were studied over three time periods lasting 4 weeks each. During the first time period (Time 1), none of the subjects implemented the intervention (cleat change, forefoot wedge, or increased saddle height) that was shown in Phase I to maximally reduce the medio-lateral deviation of the knee during cycling. During second time period (Time 2), all the subjects implemented the intervention technique that reduced their medio-lateral deviation. In the third time period (Time 3) this technique was once again removed. At the end of each time period a laboratory test was conducted. There was no cycling training prior to testing on the day the laboratory test was performed. During the laboratory test, the subject cycled on stationary rollers connected to a Kingcycle air braked cycle ergometer (Kingcycle Ltd., High Wycombe, Bucks, U.K). The Kingcycle ergometer was calibrated before each test. This ensured that the exact setting could be reproduced throughout the study for every test. Before the cyclist mounted the bicycle, he or she had to score their knee pain on a visual analogue scale (VAS) of 0-10 (0=no pain, and 10=unbearable pain). This scale was in the form of a vertical line with numbers, from 0 at the bottom to 10 at the top ²².

The subject warmed up for 2 min, cycling at a cadence of 85-95 prior to the start of the laboratory test. The subject then cycled continuously for 30 minutes at a

predetermined cadence of 85-95 revolutions per minute. At the end of every minute, the subject was asked to score their knee pain using the VAS. The pain grading which was reported every minute was plotted against time (min) for each subject. At the end of the 30-min test period the total pain score was calculated, as the total of pain for the duration of the test. This 30-min laboratory test is based on the model of the functional treadmill running test. This test has previously been shown to be a sensitive indicator of therapeutic outcome in clinical trials²².

The workload was increased from 120 watt during the first 10 minutes, to 180 watt during the second 10 minutes, and 200 watt during the last 10 minutes. These conditions were identical for tests conducted at the end of the three time periods, as described on page 17 and 18. The aim of the laboratory test was to record an accurate total pain score (pain units 0-10), which would be the total score of pain recorded at every minute for the duration of the 30-min test. The parameter that was calculated as the area under the pain vs time curve for that test, [pain (0-10) vs time (min) graph] was Total Pain.

Field testing

The field testing was also conducted over the three 4 week time periods. Each cyclist was requested to complete a logbook during the twelve weeks of the study. The recordings covered aspects of the subjects training, and details of knee pain during training. The cyclists were asked to record their knee pain using the same visual analogue scale (0-10) that was used during the laboratory tests. The worst knee pain experienced during cycling training for every ride was recorded. Average

pain (0-10) for every week of cycling training was then calculated.

The cyclists were asked to record the number of km that they cycled free of knee pain during training per week. The amount of km cycled per week (distance) with knee pain, whether it was affecting the quality of training or not was, recorded, and also the amount of training distance lost due to knee pain.

Each cyclist was encouraged to cycle a minimum of 80-150km per week. This distance was affected by the degree of patellofemoral pain the cyclist was experiencing, and the fitness of the cyclist. It was stipulated that a specific route of about 30km should be cycled once a week. This route consisted of a combination of flat riding, speed work, and hill training, and had to be finished in a set time of about 1 hour.

Time periods

Time 1 (0 - 4 weeks)

During this period subjects trained with no correction to the medio-lateral deviation of the downstroke during cycling, this is as they were cycling with knee pain prior to phase 1. Subjects kept to their normal training regime, and were encouraged to cycle a minimum of 3 training rides per week, covering a distance of a minimum of 80–150 km per week.

At the end of Time 1, the first laboratory test was conducted. The subject cycled on his or her own bicycle for 30 minutes on stationary rollers connected to a pre-

calibrated Kingcycle monitor. Knee pain was recorded on a visual analogue pain scale of 0-10 every minute, for the 30-min cycle ride. The degree of pain was then plotted against time. Data of the first 4 weeks of training was collected from the subject's logbook, and processed.

Time 2 (4 - 8 weeks)

After the first laboratory test, subjects were fitted with the correction that was shown during Phase I to most reduce their medio-lateral deviation. Subjects then cycled for a further 4 week period, using the same regime as during Time1, and recording data in the log book as before.

At the end of Time 2 a second laboratory test was conducted, with the bicycle set up to exactly the same parameters, and calibrated as for the test conducted during Time 1. Data from the logbook for weeks 4 - 8 were collected, and processed.

Time 3 (8 - 12 weeks)

At the end of Time 2, after the laboratory test, the corrections to the medio-lateral deviation were removed, or reversed, so that the subject cycled in the same uncorrected position as during Time 1. The subject then continued training for a further 4 weeks, recording the parameters in the logbook as before.

At the end of Time 3 a third laboratory test was conducted, with settings identical to

the tests during Time 1 and Time 2. Data from the log book for weeks 8-12 were collected and processed. Data from the laboratory tests for the 3 time periods were collected and compared, as well as data from the field tests.

Statistical analysis

Statistical analysis of data was conducted by the Biostatistics Division of the Centre of Epidemiological Research of the Medical Research Council of South Africa in Parow, Cape Town. The system used for doing the analysis was the Statistical Analysis System (SAS) (SAS Institute Inc. Cary, NC, USA).

The following statistical tests were conducted: The Wilcoxon Rank Sum Test, a non parametric test, was used to compare the two pattern groups {Figure of 8 (n=9), and the Oval pattern (n=12)} for all of the continuous variables concerned with the biomechanics of a subject. This test was preferred, as the data from comparing these two groups was not normally distributed.

The Wilcoxon Signed Rank Test is also a test that can be conducted when data are not normally distributed, but in this study it was used for paired observations. Apart from testing whether the average difference between two measurements (pre and post) differed significantly from zero, it was also used to test whether the change in total pain (pre and post) was significantly different from zero.

The Chi-square Test was used to compare two categorical variables with each other. The Fisher's Exact Test was used where the sample sizes were too small

and/or the cell frequencies too low. The Fisher's Exact Test is an analogue to the Chi-square Test. In all cases, statistical significance were where $p < 0.05$ and marginal significance were where $0.1 < p < 0.05$.

Results

Phase I

Fourteen males and one female cyclist completed the study. The age of the cyclists (mean \pm SD) was 31.6 \pm 8.9 years, their weight (mean \pm SD) was 76.9 \pm 9.8 kilograms, and their height (mean \pm SD) was 178.6 \pm 9.7 centimetres.

The cyclists completed a training history questionnaire, which documented their level of experience, elements of cycling training and other aspects of training such as stretching and weight training (Table 3).

The time (months; mean \pm SD) cyclists had suffered with knee pain prior to the study was 20.8 \pm 18.5 months, and the cycling distance (mean \pm SD) covered before the onset of knee pain was 31.4 \pm 23.4 kilometres. The duration of knee pain (mean \pm SD) after the cessation of training, in this group of cyclists was 27.4 \pm 24.3 hours, and the amount of training days lost (mean \pm SD) due to knee pain was 1.7 \pm 1.1 days.

The static lower limb biomechanical assessments of the subjects (n=15) showed that 4 subjects (26.7%) had no significant leg length discrepancy, 10 subjects (66.7%) had a leg length difference of 1-2 cm, and 1 subject (6.7%) had a leg length difference of > 2 cm. The quadriceps (Q) angle (mean \pm SD) as 17.7 \pm 3.0 degrees on

the left leg, and 19.1 ± 2.8 degrees on the right leg. Measurements of the rearfoot alignment (mean \pm SD) (n=21), showed a rear-foot valgus of 3.3 ± 14.2 degrees. Measurements of the forefoot alignment (mean \pm SD) (n=21), showed a varus alignment of 7.1 ± 1.9 degrees.

The results of the biomechanical measurements of the bicycle (n=15) were as follows. The mean saddle height (mean \pm SD), measured from the saddle surface to the centre of the upper pedal surface in a straight line along the saddle pillar and crank was 79.2 ± 6.6 cm. The maximum knee flexion (mean \pm SD) was 110.7 ± 4.2 degrees, and maximum knee extension was 30.2 ± 9.4 degrees.

Cyclists reported that the most likely factor aggravating patellofemoral pain (in 21 knees) was hill training (90.5%), followed by the use of high gears (66.7%), excessive training distance (42.9%), and speed training (9.5%).

The abnormal patterns of medio-lateral deviation of the knee during the downstroke movement of cycling. in this group of cyclists was as follows. The Figure of 8 pattern was identified in 9 knees (43%), with a deviation (mean \pm SD) of 42.3 ± 13.6 mm, and an oval pattern was identified in 12 knees (57%), with a deviation (mean \pm SD) of 35.2 ± 11.3 mm.

The results of the methods of correcting medio-lateral deviation of the downstroke during cycling are shown in Table 4. The method of correction that resulted in the greatest reduction of a deviation was chosen for the clinical trail (Phase II).

The oval pattern of deviation was corrected with a medial forefoot wedge in 10/12 (83%) of knees. This resulted in a reduction (mean \pm SD) in the medio-lateral deviation from 33.9 \pm 11.0mm to 19.4 \pm 8.2mm (14.4 \pm 6.4mm) ($p=0.002$). The Figure of 8 pattern of deviation was corrected with a medial forefoot wedge in 6/9 (67%) of knees, resulting in a reduction from 47.3 \pm 13.5mm to 22.0 \pm 7.5mm (25.3 \pm 7.0mm) ($p=0.0313$). The total reduction of deviation achieved with a medial wedge ($n=16$) was from 38.9 \pm 13.4 to 20.4 \pm 7.8 (18.5 \pm 8.4mm) ($p=0.0001$).

In none of the knees, in the cyclists displaying the oval pattern, did a lateral forefoot wedge correct the deviation. Cyclists with knees that displayed a Figure of 8 pattern of deviation could be corrected with a lateral forefoot in 3/9 (33%) of knees resulting in a non-significant ($p=0.25$) reduction of the deviation (mean \pm SD) from 32.3 \pm 7.5mm to 21.0 \pm 6.6mm (11.3 \pm 8.1mm).

In none of the knees, in the cyclists displaying the Figure of 8 pattern, could the deviation be corrected by a 5° medial rotation of the cleat. Cyclists with knees that displayed an oval pattern of deviation could be corrected with 5° medial rotation of the cleat in 4/12 (33%) of knees. However, the reduction (mean \pm SD) was from 35.5 \pm 11.5mm to 24.0 \pm 8.6mm (11.5 \pm 3.4mm) and was not statistically significant ($p=0.125$).

The Oval pattern of deviation was corrected by increasing saddle height in 6/12 (50%) of knees. The reduction of deviation (mean \pm SD) was from 38.0 \pm 13.6mm to 23.3 \pm 9.6mm (14.67 \pm 7.01mm) ($p=0.0313$). The Figure of 8 pattern of deviation was corrected by increasing the saddle height in 6/9 (67%). The reduction of deviation

was from 44.8 ± 12.7 mm to 21.2 ± 6.2 mm (23.7 ± 7.8 mm) ($p=0.0313$) (Table 4). The total reduction of deviation (mean \pm SD) achieved with raising the saddle height ($n=12$) was from 41.4 ± 13.0 to 22.3 ± 7.8 (19.17 ± 8.51 mm) ($p=0.0005$).

In summary, the deviation prior to correction (mean \pm SD) for the Figure of 8 pattern ($n=9$) was 42.3 ± 13.6 mm and after correction was 20.6 ± 6.8 mm. The total reduction in deviation (all methods of correction) was 21.7 ± 6.8 mm ($p=0.0039$). The deviation prior to correction (mean \pm SD) for the oval pattern ($n=12$) was 35.2 ± 11.3 mm and after correction was 14.4 ± 2.5 mm. The total reduction of deviation (all methods of correction) was 20.8 ± 8.8 mm ($p=0.0005$). The overall reduction of the medio-lateral deviation of the downstroke movement during cycling was significant. The deviation ($n=21$) prior to correction (mean \pm SD) was 38.2 ± 12.5 mm. After the appropriate correction was applied the deviation (mean \pm SD) was 21.2 ± 7.8 mm ($p=0.0001$).

Phase II

Laboratory test

The mean total pain (mean \pm SD) (scored on a visual analogue scale of 0-10 for every minute) during the 30 min test conducted at the end of Time 1 was 42.24 ± 38.94 , for Time 2 was 19.48 ± 23.69 , and for Time 3 was 33.81 ± 42.04 . The difference between the mean total pain between Time 1 and 2 (mean \pm SD) was -22.76 ± 31.44 ($p=0.0004$)*, and between Time 2 and 3 (mean \pm SD) was 14.33 ± 24.58 ($p=0.0032$)*. There was no significant difference between the mean total pain during the 30 minute cycle at the end of Time 1 and Time 3 (mean \pm SD), -8.43 ± 35.40 ($p=0.1924$) (Table 5).

The mean total pain experienced by the cyclists displaying the different patterns of deviation (Oval pattern = 12, Figure of 8 = 9) over the time periods was as follows. The difference (mean \pm SD) in mean total pain (0-300) between Time 1 and 2 for the Oval pattern was -18.3 ± 22.7 ($p=0.0186$)*, and for the Figure of 8 pattern was -28.7 ± 41.1 ($p=0.0156$)*. The difference (mean \pm SD) between Time 1 and 3 for the oval pattern was 0.6 ± 34.7 ($p=0.8311$), and for the Figure of eight pattern was -20.4 ± 34.5 ($p=0.0781$). The difference between (mean \pm SD) Time 2 and 3 for the Oval pattern was 18.9 ± 30.1 ($p=0.0195$), and for the Figure of 8 pattern was 8.2 ± 13.9 ($p=0.1641$).

Field Test

The mean total pain (mean \pm SD) recorded ($n=21$) during cycling training for the 4 weeks of Time 1 was 3.0 ± 1.7 . The mean total pain recorded for Time 2, was 1.4 ± 1.2 , and the mean total pain for Time 3 was 2.2 ± 1.5 . There were significant differences in the mean total pain (mean \pm SD) recorded between Time 1 and Time 2 ($p=0.0020$)*, between Time 2 and 3 ($p=0.0020$)*, and between Time 1 and Time 3 ($p=0.0078$)*.

The mean total pain (mean \pm SD) recorded during Time1 for the Oval pattern ($n=12$) was 3.1 ± 1.6 , for Time 2 it was 1.4 ± 1.2 , and for Time 3 it was 2.0 ± 1.5 . The mean total pain (mean \pm SD) recorded during Time 1 for the Figure of 8 pattern ($n=9$) was 2.9 ± 1.7 , for Time 2 it was 1.4 ± 1.2 , and for Time 3 it was 2.0 ± 1.5 .

The mean total pain (mean \pm SD) that cyclists experienced during the 3 time periods, for each week within the time periods was also compared (n=21). The mean total pain (mean \pm SD) in the first week of each of the three time periods, was 3.2 \pm 1.4 during Time 1, 1.2 \pm 1.1 during Time 2, and 2.3 \pm 1.5 during Time 3 (Table 13). There was only a significant difference in the mean total pain during the first week between Time 2 and 3 (p=0.0156*) but not between Time 1 and 2 (p=0.0781), or between Time 1 and 3 (p=1.0).

In week 2, the mean total pain (mean \pm SD) that cyclists experienced during Time 1 was 3.1 \pm 1.9, Time 2 was 1.4 \pm 1.0, and Time 3 was 1.9 \pm 1.4. The difference in mean total pain between Time 1 and 2 was significant (p=0.0039*), as well as between Time 1 and 3 (p=0.0156*). The difference between Times 2 and 3 was not significant (p= 0.0635).

In week 3, the mean total pain (mean \pm SD) that cyclists experienced during Time 1 was 3.0 \pm 1.7, Time 2 was 1.4 \pm 1.1, and Time 3 was 2.1 \pm 1.6. The difference in mean total pain between Time 1 and 2 was significant (p=0.0039*), between Time 1 and 3 (p=0.0938), and between 2 and 3 was not significant (p=0.0039).

In week 4, the mean total pain (mean \pm SD) that cyclists experienced during Time 1 was 2.7 \pm 1.6, Time 2 was 1.6 \pm 1.4, and Time 3 was 2.4 \pm 1.6. There was a significant difference between mean total pain Time 2 and 3 only (p=0.0313) (Table 6)

Cycling Distance (km)

The distance cycled per training week (km) for every week in each of the three time periods (n=15) is depicted in Table 8. During week 1, the distance cycled (mean±SD) during Time 1 was 104.8±57.5 km, during Time 2 was 88.2±37.4 km, and during Time 3 was 94.9±34.7 km. The difference in distance cycled between Time 1 and 2 was p=0.2188, between Time 1 and 3 was p=0.4961, and between Time 2 and 3 was p=0.5449.

During week 2, the distance cycled (mean±SD) during Time 1 was 104.6±71.5 km, during Time 2 was 110.5±36.2 km, and during Time 3 was 90.1±33.7 km. The difference in distance cycled between Time 1 and 2 was p=0.0195*, between Time 1 and 3 was p=0.1270, and between Time 2 and 3 was p=0.0742.

During week 3, the distance cycled (mean±SD) during Time 1 was 101.5±29.8 km, during Time 2 was 94.3±51.1 km, during Time 3 was 96.4±28.2 km. The difference in distance cycled between Time 1 and 2 was p=0.6816, between Time 1 and 3 was p=0.4707, and between Time 2 and 3 was p=1.000.

During week 4, the distance cycled (mean±SD) during Time 1 was 85.1±24.7 km, during Time 2 was 93.9±33.6 km, during Time 3 was 91.2±34.0 km. There was a significant difference in distance cycled between Time 1 and 2 (p=0.0218), but not between Time 1 and 3 (p=0.9570), or between Time 2 and 3 (p=0.0684).

Discussion

The aim of this study was firstly to determine whether excessive medio-lateral deviation during the down-stroke in cycling could be corrected to a more linear pattern. In this study a significant reduction in deviation was achieved by either increasing the saddle height, or inserting a medial forefoot wedge.

The second aim of this study was to determine whether the reduced medio-lateral deviation might result in decreasing patellofemoral pain. The results of a laboratory and field tests conducted over three time periods showed clearly that patellofemoral pain decreases during the time period where the method of correction was used.

The third aim of the study was to investigate whether a decrease in medio-lateral deviation might lead to an increase in the weekly distance cycled without patellofemoral pain. The results in this study, did not clearly show a significant increase in weekly cycling distance. The possible reasons for this would be discussed.

Static and dynamic biomechanical variables of the knee and lower limb in cyclist with patellofemoral pain were examined in this study. The static biomechanics of the bicycle and various training factors that can affect the biomechanics of the knee were also assessed. During the first phase of the study a kinematic analysis was conducted to assess whether it was possible to reduce the medio-lateral deviation that is associated with the downstroke of cycling in cyclists with patellofemoral pain. The second phase of the study was conducted to ascertain whether a decrease in medio-lateral deviation resulted in less patellofemoral pain suffered by cyclists, and whether the decreased in deviation increases the distance cycled during training.

Most of the cyclists participating in this study have been suffering with patellofemoral pain for more than two years, and reported that conventional conservative management failed^{14 26}.

A significant finding of the kinematic analysis during Phase I was that 83.3% of the cyclists with patellofemoral pain had a marked medio-lateral deviation during the downstroke of cycling. This supports the findings of Milligan (1994)²⁸ and Hannaford (1986)¹⁷. Two characteristic patterns of deviation during the down stroke of cycling was noted in this study, namely a Figure of 8 pattern and an Oval pattern this correlates with previous findings²⁸. In this study 9 subjects show a Figure of 8 pattern whilst 12 subjects showed an Oval pattern of deviation.

Five different methods of correction were investigated in Phase I of this study. A method of correction was considered successful if it reduced the medio-lateral deviation by 20% or more. *Therefore, it was found that more than one method of correction could reduce the deviation. however, only the method resulting in the greatest reduction was chosen in Phase II for the clinical trail.*

Eighty-three per cent of cyclists with the Oval pattern and 67% with the figure of 8 pattern could be corrected with the medial forefoot wedge. The success of this method of correction might be explained by the significant degree of forefoot varus that was prevalent in this study group. Previous studies in long distance runners have shown that forefoot varus can be corrected with a medial forefoot wedge⁸. A possible explanation to the reductuin is that during cycling force transmission takes place at the forefoot. Forefoot varus would lead to an increased force transmission, a subsequent increased subtalar pronation, increased medial rotation of the tibia,

which then results in medio-lateral deviation. The insertion of a medial forefoot wedge, would decrease the force transmission, and therefore lead to a decrease in subtalar pronation, a decrease in medial rotation of the tibia, and a decrease in medio-lateral deviation. The candidate wish to clearly state that this is only speculation, and that further investigation is needed.

Raising the saddle height also reduced medio-lateral deviation significantly during the down stroke of cycling in 50% of cyclists with an oval pattern and 67% with a figure of 8 pattern. The reduction of medio-lateral deviation by documented the saddle height is a unique finding, as is has not been investigated in any other research. This study was not designed to investigate the mechanisms of such an intervention and the reason for the deviation is not clear. Raising the saddle height would decrease hip, and knee flexion, therefore muscles in the lower limb would operate at different lengths. Further EMG studies during cycling is required to investigate the mechanism of the MLD.

Thirty three per cent of cyclists with a figure of 8 pattern of deviation were corrected with a lateral forefoot wedge. Thirty three per cent of cyclists with an oval pattern were corrected with medial rotation of the cleat. The reduction in deviation using the lateral forefoot wedge, and medial rotation the cleat was smaller in comparison to the reduction provided by using the medial forefoot wedge. All the methods that corrected medio-lateral deviation >20% were reported, but the most effective methods were applied in Phase two.

It is interesting that only the Figure 8 pattern had a reduction of deviation with the insert of a lateral wedge, and only the Oval pattern had a reduction of deviation by

medially rotating the cleat. As previously stated, this study was not design to investigate the effect of these methods of correction on lower limb biomechanics, and no other study could explain these findings. This needs further investigation.

The saddle height in this study was measured as an average for the whole group therefore any individual increases and decreases may have been masked in the group average. However, the measurement of maximum knee extension, and maximum knee flexion also reflect the ideal cyclist/bicycle relationship. The optimum ranges of Maximum knee extension (MKE), and Maximum knee flexion (MKF) are 65 to 70 degrees of flexion, and 140 to 145 degrees knee extension ²⁵. The cyclists in this study had an average measurement for the MKF that corresponded well with values previously reported (69.3 ± 4.2 degrees), but the MKE measurement was slightly higher than the values previously reported at 149.8 ± 9.4 degrees. A slightly higher MKE means that the overall population of this study cycled with a slightly higher average saddle height setting than the cyclists in the study referenced in this paragraph. A possible explanation is a difference in population, i.e. recreational cyclists, and mountain bikers tend to cycle with lower settings of the saddle, whereas more experienced and elite cyclists tend to cycle with higher settings. The population studied in this research were all experienced cyclists.

The assessment of the static biomechanics of the cyclists showed that 73% of cyclists had a leg length difference of 1cm or more. Leg length discrepancies have been described as a factor that could be associated with patellofemoral pain and iliotibial band friction syndrome in cyclists. This could be explained that the fact that

only one side would be correctly adjusted for the leg length. The other side would then compensate in either a varus-type position, or a position requiring excessive hip and knee extension at the bottom of the pedalling stroke ¹⁸.

Forefoot varus was found to be common in all the subjects, with an average of 7 ± 2 degrees. In the weight-bearing position, forefoot varus can lead to rearfoot valgus. Rearfoot valgus will increase internal tibial rotation during the downstroke of cycling ^{13 17}. This increased internal tibial rotation could result in increased medio-lateral deviation of the knee. Increased medio-lateral deviation of the knee could then result in abnormal tracking of the patella, and potential injury to the patellofemoral complex ^{21 32}.

Cyclists reported in an injury questionnaire certain components of cycling training that are more likely to cause patellofemoral pain (appendix A). These were hill training, and pedalling at a high gear ratio ^{18 24 2}. Hill training and high gears are training factors that may increase patellofemoral compression forces that could lead to overuse injury to the ventral aspect of the patella ⁹.

In Phase II patellofemoral pain was measured during a laboratory test, as well as during a field test. The most significant finding was that there was a decrease in patellofemoral pain from Time 1 to Time 2 in the laboratory as well as the field test. Time 2 was the period during which the method of correction was applied to reduce the medio-lateral deviation. Once the correction was removed (Time 3) patellofemoral pain increased again. In Phase II the method of correction that reduced medio-lateral deviation the most effectively was applied during Time 2,

therefore the cyclist was training and tested whilst cycling with a more linear pattern of down-stroke. The subsequent reduction of patellofemoral pain during that period could be ascribed to the correction of the abnormal pattern to a more linear pattern, with a possible increase in patellofemoral contact area, and a decrease in patellofemoral contact stress. A decrease in medio-lateral deviation could also lead to a decrease in valgus strain, and abnormal patellar tracking, or a better alignment of the patella with a subsequent decrease in the irritation of pain sensitive structures such as the lateral retinaculum. Milligan (1996) observed that a medio-lateral deviation was common in cyclist with knee pain if compared with cyclists with no knee pain. Very significant to the above findings was that 20 of the 24 cyclists with no knee pain had a linear pattern of downstroke with no deviation.

These findings support the findings reported by Hannaford in a pilot study, where the number of subjects was small and the methods of correction not controlled.

During the laboratory test there was a significant difference in total pain for both Figure of 8 and the Oval pattern from Time 1 to Time 2, however at the end of Time 3 (during which the cyclists trained with the method of correction removed) it was only the cyclists exhibiting an Oval pattern of deviation that had a significant increase in patellofemoral pain. The effect of decreasing the medio-lateral deviation during Time 2 seemed to have had a longer lasting effect on cyclists exhibiting a Figure of 8. The reasons for this result are not clear. Again, the key to understanding the results of this investigation seems to lie in the analysis of the biomechanical factors that cause these abnormal patterns in the first place.

Furthermore it would have been interesting to perform video analysis at the end of Time 3 for the Figure of 8 pattern, to ascertain whether the medio-lateral deviation

differs from that in Time 1. The same study conducted with greater numbers over a longer period might give more insight to these findings.

Mean total pain (logbook) during cycling training decreased significantly after the method of correction was applied (Time 2), and increased significantly after it was removed (Time 3) for both the Figure of 8 and Oval patterns. The log book results also showed that mean total pain for Time 3 (both patterns) was significantly less than for Time 1. From these results it can be assumed that during training in this study, patellofemoral pain was similar in both the oval pattern and the Figure of 8 pattern for all three time periods. Furthermore although mean total pain increased significantly after the correction was removed in Time 3, it was still significantly less than in Time 1.

Mean total pain (logbook) was compared on a weekly basis for all four weeks of the three time periods. There was a significant decrease in mean total pain from Time 1 to Time 2 for weeks 2, and 3, but not for week 1 and 4. There was a small but not significant decrease in mean total pain during the first week. This could be due to the fact that was the first week that the cyclists cycled with the corrections, and that it was too early for a significant reduction in pain. The small, but not significant reduction in mean total pain from Time 1 to Time 2 for week 4 can not be explained satisfactorily. A greater number of subjects might give more insight to these findings.

The reason for the lack of increased weekly cycling distance by the group after correction is not clear. It could be that it took a longer time for the cyclist to feel confident to increase training distance.

The laboratory test was found to be a useful clinical tool in this study, so was the kinematic analysis (two dimensional video analysis), the use of which can be recommended in the assessment of patellofemoral pain in cyclist.

Limitations of this study were that it was in the format of an A-B-A trail, and had no control group. This format was chosen, as it was difficult to apply placebo corrections in a control group. This study only covered a relative short time period. It would have been important to observe the effect of the correction had over longer training periods. It should be stated that this study investigate only a limited number of static biomechanical factors that may influence patellofemoral tracking. Correction of the downstroke pattern is important, but by no means the only method of altering patellar tracking. Taping of the patella and the rehabilitation of vatus medialis obliquus control in cyclists are other factors that should be investigated.

Conclusion

This study showed that medio-lateral deviation during the downstroke of cycling is common in cyclists with patellofemoral pain. A medial forefoot wedge and raising the saddle height are effective methods to reduce the medio-lateral deviation.

Laboratory and field testing show that by reducing medio-lateral deviation, a decrease in patellofemoral pain in cyclists can be achieved. Kinematic analysis (two dimensional video analysis) during cycling has great potential as a clinical tool, to investigate cyclists with chronic patellofemoral pain.

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Table 1: The screening criteria that were used to identify which subjects should report for a clinical assessment

1. Knee pain during cycling for longer than 12 weeks.
2. Knee pain that is severe enough to interfere with cycling training or prevent cycling.
3. No history of direct trauma to the knee joint in the last 2 years, which is associated with the current knee pain.
4. No treatment for knee pain in the four weeks prior to the trial period.

Table 2: The clinical criteria that were used for the diagnosis of patellofemoral pain

a. Inclusion criteria

1. Retro-patellar or peri-patellar pain on palpation of the patella
2. Pseudo locking of the patella
3. Clicking, grating or "catching" of the patella
4. Pain on walking upstairs or downstairs
5. Pain or stiffness with prolonged sitting
6. Pain on squatting or rising from the squatting position
7. Pain on jumping or on landing

Subjects were excluded from the study if there was any clinical evidence of associated knee pathology such as; degenerative changes in the patellofemoral and/or tibio-femoral joints, as clinically diagnosed on X ray, ligamentous instability and meniscal injury or loose bodies on clinical examination

Table 3: The training history of the cyclists with knee pain (n=15) (values are mean±SD).

Years of cycling (yr.)	6.1±3.8
Number of rides/week (n)	4.5±0.9
Average distance cycled/week (km)	231±102
Hill training (sessions/week)	2.8±1.1
Speed training (sessions/week)	1.2±1.0
Distance training (sessions/week)	1.8±1.5
Weight training (sessions/week)	0.2±0.4
Stretching (sessions of 10 min or more/week)	1.7±2.4

Table 4: The effect of corrections on medio-lateral deviation during the downstroke of cycling (values are mean±SD).

	Method of correction	Before correction	After correction	'P' Value
All patterns	MFFW n=16	38.9±13.4	20.4±7.8	p=0.0001*
	LFFW n=6	32.3±7.5	21.0±6.6	p=0.25
	IR n=4	35.5±11.4	24±8.6	p=0.125
	ER	-	-	-
	SH n=12	41.4±13.0	22.3±7.8	p=0.0005*
Oval pattern	MFFW n=6	33.8±11.0	19.4±8.2	p=0.002*
	LFFW	-	-	-
	IR n=4	35.5±11.4	24.0±8.6	p=0.125
	ER	-	-	-
	SH n=6	38±13.56	23.3±9.61	p=0.0313*
Fig 8 pattern	MFFW n=6	47.3±13.5	22.0±7.5	p=0.0313*
	LFFW n=6	32.3±7.5	21.0±6.6	p=0.25
	IR	-	-	-
	ER	-	-	-
	SH n=6	44.8±12.7	21.2±6.2	p=0.0313*

*: Indicates a significant reduction of medio-lateral deviation ($p < 0.05$)

Table 5: The total pain (pain units per min) recorded by cyclists during a 30-min laboratory test for each of the three time periods (values are mean \pm SD).

	Time 1	Time 2	Time 3
All patterns (n=21)	42.2 \pm 38.9*	19.5 \pm 23.7	33.8 \pm 42*
Oval (n=12)	37.25 \pm 32.5*	18.9 \pm 28.9	37.8 \pm 54*
Fig 8 (n=9)	48.9 \pm 47.5*	20.2 \pm 16	28.4 \pm 18.6

*: Indicates a significant difference from Time 2 ($p < 0.05$)

Table 6: The mean total pain (0-10) recorded during cycling training (logbook) for each of the time period (values are mean \pm SD).

	Time 1	Time 2	Time 3
All patterns (n=21)	3.0 \pm 1.7	1.4 \pm 1.2*	2.2 \pm 1.5
Oval (n=12)	3.1 \pm 1.6	2.9 \pm 1.7	2.0 \pm 1.5
Fig 8 (n=9)	2.9 \pm 1.7	1.4 \pm 1.2	2.3 \pm 1.5

*: Indicates a significant difference from Time 2 ($p < 0.05$)

Table 7: The mean total pain (0-10) recorded by cyclists for every week in the three time periods (values are mean \pm SD).

	Week 1	Week 2	Week 3	Week 4
Time 1	3.2 \pm 1.4	3.1 \pm 1.9*	3.0 \pm 1.7*	2.7 \pm 1.6
Time 2	1.2 \pm 1.1	1.4 \pm 1.0	1.4 \pm 1.1	1.6 \pm 1.4
Time 3	2.3 \pm 1.5*	1.9 \pm 1.4#	2.0 \pm 1.6*	2.4 \pm 1.6*

*: Indicates a significant difference from Time 2 ($p < 0.05$)

#: Indicates a significant difference from Time 1 and Time 3 ($p < 0.05$)

Table 8: The weekly distance cycled (km) for all 4 weeks during Time 1,2, and 3 (values are mean±SD).

	Week 1	Week 2	Week 3	Week 4
Time 1	82.3±18.2	83.4±16.8*	92.8±32.2	84.1±22.0
Time 2	93.0±40.1	115.3±27.6	100.5±42.2	98.3±27.6
Time 3	85±10.9	90.8±16.7	98.8±12.9	85.8±13.4

*: Indicates a significant difference from Time 2 ($p < 0.05$)

Appendix A

INJURY HISTORY QUESTIONNAIRE

1. Name: _____
2. Age : _____
3. Sex : _____
4. Diagnosis: _____
5. Injury :
 - (a) Left Side_____ Right Side_____ Both sides_____
 - (b) Symptoms : I) Pain V) Weakness
 II) Pain sitting VI) Giving way
 III) Pain stairs VII) Locking
 IV) Swelling
 - (c) Time of Onset: _____ (Weeks / Months)
 - (d) Current Injuries: _____
 - (e) Previous Injuries: _____
6. Treatment:
 - (a) Medication : _____
 - (b) Physiotherapy : _____
 - (c) Other : _____
7. Training :
 - (a) Distance before onset of pain during training: _____(km)
 - (b) Duration of pain after the cessation of training: _____(hrs)
 - (c) Aggravating factors: Hill training _____
(Tic) High gear ratio's _____
Speed training _____
Distance training _____
Other _____
 - (d) Training days lost per week: _____
 - (e) Other sports participation; Type _____
hrs /week _____

Appendix B

TRAINING HISTORY QUESTIONNAIRE

1. Name : _____
2. Age : _____
3. Sex : _____
4. Number of years of cycling training _____
5. Distance cycling training per week _____
6. Number of training rides per week _____
7. Number of times per week when the following elements are included in cycling training:
 - a) Hill training
 - b) Long distance training
 - c) Speed training
8. Any additional training (times per week)
 - a) Weight training
 - b) Other
9. Warm-up (Times per week)
 - a) Stretching _____
 - b) Other _____

Appendix C

CLINICAL EVALUATION SHEET

1. Name: _____
2. Age: _____
3. Sex: _____
4. Injury: Diagnosis _____
 Side _____
5. Height: _____
6. Weight: _____

BIOMECHANICAL EVALUATION

1. Leg Length: ASIS to MM _____(L)_____(R)
 TT to MM _____(L)_____(R)
2. Q Angle _____(L)_____(R)
3. Rear foot Varus/Valgus _____(L)_____(R)
4. Forefoot Varus/valgus _____(L)_____(R)

BICYCLE PARAMETERS

1. Saddle Height (Saddle to crank) _____
2. Maximum knee flexion _____(L)_____(R)
3. Maximum knee extension _____(L)_____(R)

Appendix D

LOG BOOK

Subject Detail

1. Name: _____
2. Age: _____
3. Sex: _____
4. Injury: Diagnosis _____
 Side _____
5. Height: _____
6. Weight: _____

7. Degree of pain (Gr I-IV) _____
8. Deviation an assessment _____
9. Adjustment/Correction _____
10. Deviation after correction _____

INFORMATION IN THE LOG BOOK AFTER EVERY RIDE

1. Distance cycled per ride (km) _____
2. Intensity/type of training _____
3. Average speed of ride (km/hr) _____
4. Distance cycled before onset of pain _____
5. Elements of training that elicit pain _____
6. Average pain for the ride (0-10) _____

Log book : Time _____ Week _____

DATE	TRAINING				PAIN		
	Distance/ride (km)	Intensity/type of training	Average speed of ride (km/hr)	Distance before onset of pain (km)	Elements of training that elicit pain	Average pain for ride (0-10)	
MONDAY							
TUESDAY							
WEDNESDAY							
THURSDAY							
FRIDAY							
SATURDAY							
SUNDAY							
COMMENTS							