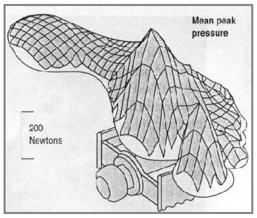
Bikefit guidelines

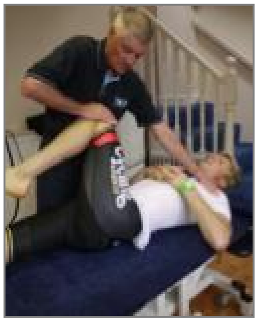


Extensively researched

NJD Sports Injury Clinic has extensively researched into cycling biomechanics and how lower-limb / foot biomechanics can impact on cycling performance. These findings, combined with our own published research, enable us to optimise our **Bikefit**. To keep abreast of new research and technology, we frequently work with, and liaise with, various Universities in cycling related matters.

All adjustments are explained and justified

We provide friendly advice throughout the process. All adjustments are clearly explained and when applicable, justified with supporting evidence. Our **Bikefit** uses a logical systematic approach, commencing with the all too frequently neglected, undervalued, or misunderstood biomechanical screening of the rider.

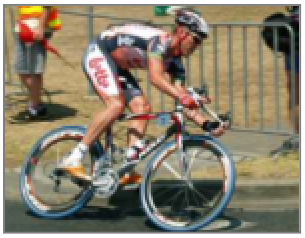


Effective Bikefit relies on effective screening

Our **Bikefit** relies very heavily on the findings and observations gathered from our unique and well publised **Biomechanical Pre-Bike Screening Protocol.** We identify problems which are likely to disturb pedalling symmetry. Problems are then addressed as part of our simple, but effective, Bikefit process. Our Bikefit may include fitting **Wedges** to correct biomechanical pedalling alignment and a personalised **Musculoskeletal Rehabilitation plan** to restore any musculoskeletal weaknesses or imbalances.

We welcome all our customers

All our customers are made welcome, from recreational to international cyclists. This includes cyclists of all ages, capabilities and disciplines i.e.; road, time-trial, MTB and triathletes.

Our Bikefit considers the key areas

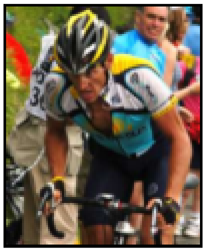
Our **Bikefit** takes approximately 1 to 1 ½ hours. We employ a logical, sequential process to examine all the key areas, starting at the **Foot/Pedal interface,** arguably the *cornerstone* to effective Bikefit.

Checking footwear

- **Footwear**
- **Foot/pedal interface**
  (foot, pedal system, cleat position)
- **Crank length**
- **Frame geometry & size**
- **Saddle position**
- **Handlebar position**

Checking saddle position

We aim to optimise the three point contact



From the conception of the bicycle in the 19th century through to the modern-day competitive race cycle, cycling has been a marriage between an adaptable human body and an adaptable machine. The rider makes contact with the cycle at three points; handlebars saddle and pedals. Optimum settings at these three points will help optimise pedalling efficiency, power output, and comfort with less injury. In general, cyclists should seek a weight balance of 40-45%: 60-55% between front and rear wheels respectively. Mountain Bikers will tend to shift weight distribution more towards the rear wheel, whereas Time Trialists will tend to shift their weight distribution more towards the front wheel.

Foot / Pedal interface

The **foot/pedal interface** is considered the *cornerstone* of all good Bikefits. As such the foot/pedal interface should be addressed first employing a routine sequential approach. This is the consensus of the vast majority of experienced professional Bike fitters, including Paul Swift of www.Bikefit.com. The foot/pedal interface includes the anatomic structure of the foot, subsequent foot and leg alignment, pedal system, five potential cleat positions and shoe design. There are many reasons for this approach. Below, we attempt to provide sound rationale behind this approach

Foot misalignment rationale

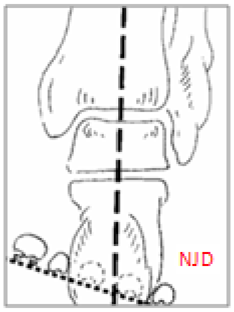


Figure 1a

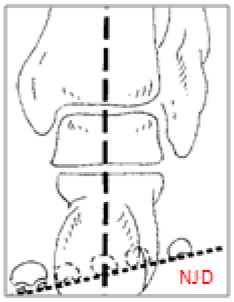


Figure 1b

The *foot/pedal* interface is the mechanical link between the leg and the cycle, and the point at which pedalling asymmetry most often arises. The structure and function of the foot dictate how effectively pedal forces are transmitted down to the cranks, and potentially, how deleterious forces are transmitted up the kinetic-chain – impacting on the knee, hip, pelvis, lower back and neck. Research demonstrates that less than 10% of cyclists have a neutral foot (1-3). According to Garbalosa et al (4), of which most Bikefit organsations now refer to; findings suggest that 87% of cyclists have forefoot varus tilt (fig. 1a), 9% forefoot valgus tilt (fig. 1b), and 4% have a neutral forefoot-rearfoot relationship. In a later study on foot/pedal positions, Millslagle et al (5) reported that conventional pedal systems are designed for the cyclist to connect to the pedal flat-footed.

Therefore **all** conventional pedal systems are only ideally suited to the 4% of the cycling population who do not have forefoot misalignment. The smallest amount of misalignment at the foot / pedal interface, via connection of rider to bicycle by conventional pedal systems - results in pedalling asymmetry, power loss, discomfort and pain. Hence, the need and justification to use wedges to correct forefoot tilt misalignment.

Modern technology increases misalignment rationale

Modern cycling technology and rider strength has made rapid advancements over the last couple of decades. Rigid carbon-fiber frames allied with carbon wheels have improved stiffness and power transfer. Research studies have demonstrated modern carbon-fiber soled shoes 42% stiffer in longitudinal bending and 550% stiffer in three-point bending compared with plastic shoes (6). While these improvements in technology and rider strength provide

more efficient power transfer / output, they have come at the expense of increased forefoot pressures. Past studies have shown that increasing power outputs lead to higher peak forefoot pressures, (causing the foot to collapse), which in turn, leads to further increases in forefoot tilt and misalignment.

Why wedge to correct misalignment?

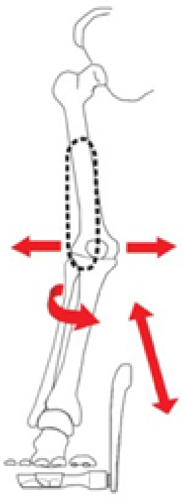


Figure 2a

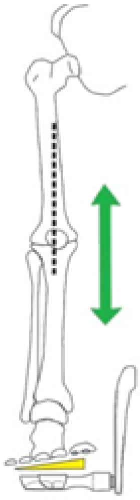


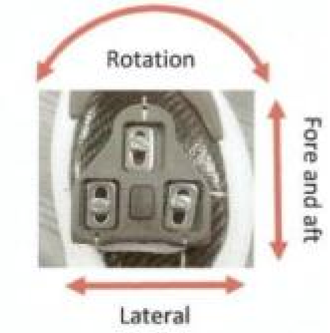
Figure 2b

Forces applied to the pedal during the downstroke reach their maximum at approx 90° of crank angle (7,8). Studies show that as forces increase so does the amount of misalignment (tilt) in the direction that allows the forefoot to become parallel with the pedal (9,10). Inward tilting of the forefoot causes the knee to move inwards towards the top-tube – depicted by red arrows in (fig. 2a). The dotted-oval trace (fig.2a) represents knee motion during a pedal revolution. Varus wedges support the forefoot in cyclists with forefoot tilt (fig. 2b). Studies have demonstrated increased power output when using wedges compared without wedges (11,12). Our very own unique research (12), recently undertaken at Manchester Metropolitan University demonstrated an average increase in power output of 3.8% in favour of using wedges compared without wedges. Even more interesting, cyclists with the highest levels of forefoot varus tilt demonstrated improvements of up to 10%.

Cleat Position

Often ignored, cleat position is vital to pedalling efficiency, comfortable and injury free cycling. Many race cyclists train to a periodised training program, use training aids like heart rate monitors and power meters - yet fail to appreciate the implications of correct cleat position. For optimum Bikefit, critical adjustments to cleat position should precede the obvious saddle, handlebar and stem adjustments. There are five basic variables to consider with respect to cleat position:

1. **Fore and Aft (front to back)**
2. **Cant (varus / valgus tilt)**
3. **Rotational angle (toe-in and toe-out)**
4. **Lateral position (side-to-side)**
5. **Whether to shim (leg-length difference)**



1. Fore and Aft position

A foot in a modern carbon-fibred soled cycling shoe functions as a lever. The efficiency of that level depends on its length from the fulcrum. The lever length is determined by the distance between the fulcrum (ankle joint) and the centre of the cleat when engaged in the pedal system. Although there is limited robust research on ideal cleat position, generally what does exist concludes that fore and aft cleat position has little impact on the ability to deliver power. A recent study in 2007 tested trained cyclists at 90% of VO2 max with three different cleat positions: (1) under the 1st

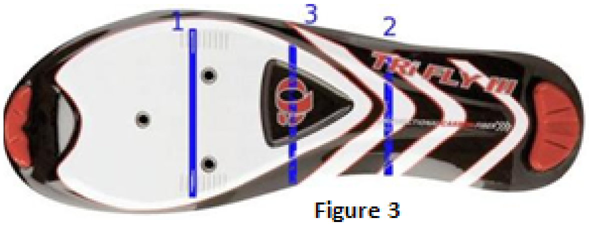


Figure 3

Metatarsophalangeal head (ball of big toe), (2) midway between the rear of the heel bone and the 1st metatarsal head, and (3) midway between positions 1 and 2 as shown in (Figure 3). The results found no difference in efficiency in favour of any of the cleat positions (14). However, while there are variations, the time honoured, and by the far most common cleat position, used by the majority of professionals, is with the centre of the 1st Metatarsophalangeal joint (ball of big toe joint) positioned over the centre of the pedal spindle (Figure 4).

Figure 4

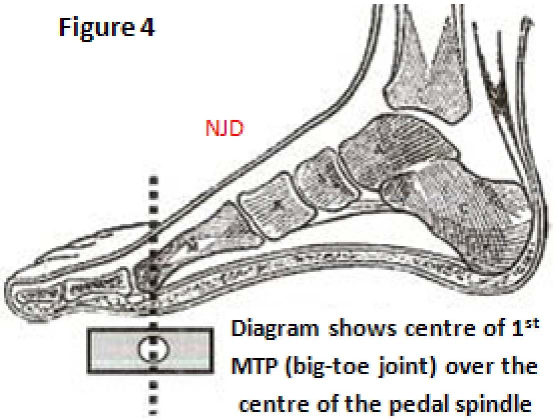
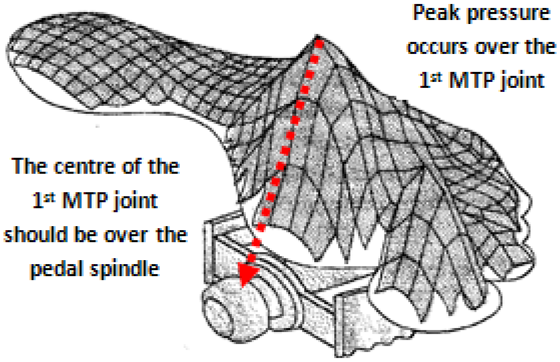


Diagram shows centre of 1st MTP (big-toe joint) over the centre of the pedal spindle

Studies have shown that peak pressures pass through the 1st Metatarsophalangeal head or in close vicinity, as shown in Figure 5. These findings provide a logical rationale in support of positioning 1st Metatarsophalangeal joint over the centre of the pedal spindle. In some cases, especially larger riders with large feet, the cleat should be moved backwards slightly towards the heel, thus reducing the length of the lever arm. Incidentally, when checking the fore and aft position, the crank-arm should be horizontal at 3 o'clock and the foot/shoe should also be horizontal. The further forward the cleat, towards the toes, the harder the calf muscles have to work to control and stabilise the foot owing to the lengthening lever arm. Moreover, this forward cleat position places more stress on the Achilles tendon with increased risk of overuse injury. Conversely, if the cleat is too far back towards the heel bone the length of the lever arm reduces and this limits the rider's ability to sprint or climb while out of the saddle. According to Hogg (15), generally speaking the shorter and more extreme the effort, the further forward the ideal cleat placement. The longer the effort required particularly ultra-distance endurance events, then the further back the cleat ought to be positioned towards the heel bone. A small number of riders including professionals and elite triathletes use a mid-foot cleat position represented as positions 1 & 2 in (Figure 3). This unusual cleat position offers both advantages and disadvantages. Although only anecdotal, mid-foot cleat positions may offer advantages for some cyclists involved in ultra-distance endurance events.

Figure 5



Peak pressure occurs over the 1st MTP joint

The centre of the 1st MTP joint should be over the pedal spindle

(Sanderson & Cavanaugh, 1987) NJD

2. Cant

Ideally any *cant* (forefoot tilt) issues should be addressed before adjusting the cleat for lateral (side-to-side) and rotational position (toe-in and toe-out). The reason being; cant corrections are likely to impact on other subsequent cleat positions. Cant is the angle (tilt) that the forefoot makes when presented to the pedal which is called either *varus* tilt (with the big toe elevated as shown in (Figure 6a) or *valgus* tilt (with the big-toe on the pedal and the little toe elevated as shown in Figure 6b). The consequences of foot and/or forefoot tilt are clearly explained above under the heading **Foot misalignment rationale.** In brief, as pedal forces increase so does the amount of misalignment (tilt) in the direction that allows the forefoot to become parallel with the pedal. Research suggests that approximately 85% of cyclists have forefoot *varus* (tilt) as shown in Figure 6a. Our unique **biomechanical Pre-Bikefit Screening protocol** is designed to identify foot and limb misalignment problems – enabling them to be addressed later in our Bikefit.

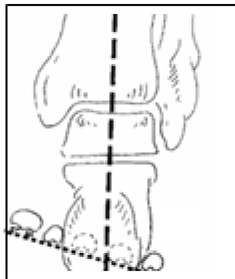


Figure 6a

NJD

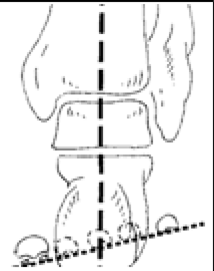


Figure 6b

One very effective solution is to fit cant *wedges* which are becoming more and more common in cycling. Competitive riders realise the potential power output and stability benefits wedges can offer. The concept behind cant wedges is to accommodate for misalignment of the lower-limb and foot, which results in forefoot tilt (varus or valgus) – common amongst cyclists. Essentially, there are two different types of wedge; the *In-The-Shoe Wedge* (ITS) shown in Figure 7a, and the *Cleat Wedge* shown in Figure 7b. Both wedge types are made from stiff plastic and can be used to address either varus or valgus tilts simply by reversing the wedge. The use of wedges and associated benefits are explained above under the heading **Why wedge to correct misalignment?** Cant or forefoot tilt results in the motion known as pronation or supination. Forefoot tilt is more apparent when the foot is subjected to high loads experienced during the downstroke of intense pedalling. Pronation is a tri-plane motion consisting of simultaneous movements; *abduction*, *dorsiflexion* and *eversion* and can occur at the subtalar joint or mid foot.

Figure 7a; In-The-Shoe Wedges

Figure 7b; Cleat Wedges fitted

How does this affect cycling? Apart from the obvious inward tilting of the forefoot which causes the knee to 'wobble' and deviate inwards towards the top-tube with resultant power loss – the foot also tends to abduct (move outwards). This motion increases the amount of toe-out as depicted by the red arrow in Figure 8. As such, pedal systems with limited rotational float may not offer sufficient float to accommodate increasing toe-out positions during the downstroke of a cyclists with excessive forefoot tilt. This means the foot remains locked in a position with inadequate rotation to dissipate harmful stresses; these harmful stresses get transferred upwards through the kinetic-chain. Additionally, cleats may get adjusted unnecessarily rather than controlling the effect of cant. Cleats are often moved inwards (side-to-side) and/or a spacer washer placed between the crank-arm and pedal to prevent the heel from brushing either the crank-arm or chainstay.

NJD

Figure 8

When cant has been correctly addressed, the foot, knee and hip remain in the same sagittal plane (tracking up and down in a near vertical motion). Power output improves, the foot no longer abducts (moves outwards) on the downstroke – the need for extra float and/or side-to-side cleat adjustment is often negated. Limited float pedal systems can actually be better for many riders, but they require much closer attention to proper cleat alignment and the need to address any cant is crucial to minimise unnecessary foot abduction (toe-out).

3. Rotation angle (toe-in or toe-out)

The vast majority of competitive cyclists require some degree of rotational float, nowadays provided by modern pedal/cleat systems. If the cyclist's leg and foot do not have a natural linear motion (travel up and down in a straight line), then constraining the foot (lack of pedal float) will produce an additional constraint at the foot/pedal interface (16). Pedal / cleat systems with rotational float are designed to accommodate lower-limb and foot misalignment, thereby dissipate any harmful stresses. This is important, because overuse injury occurs when harmful stresses exceed the body tissue capabilities. Moreover, every single cyclist has an injury threshold. The product of limb / foot misalignment combined with high training loads is often the catalyst for lower-limb overuse injury, particularly knee related. Generally, the greater the degree of misalignment, then lower the injury threshold. When insufficient rotational float (toe-in and toe-out) exists, the foot is locked in a position at less than an ideal rotational angle. Consequently, these harmful stresses fail to dissipate at the foot/pedal interface and travel up the limb exploiting the weakest link within the kinetic-chain. Hence, overuse injury results in e.g. Achilles, knee, trochanter, hip, pelvic or low-back region.

Lower-limb / foot misalignment is highly prevalent amongst cyclist, and there are many contributing factors for this phenomenon, e.g. degenerative hip joint, abnormal femoral neck angle and alignment, musculoskeletal imbalances of the hip and pelvic region, leg-length differences, tibial varum (bow-legged), tibial torsion (twisting of shin bone) and forefoot tilt (varus and valgus).

Some of these contributing factors require correcting by manual therapy techniques and/or rehabilitation strategies designed to restore any musculoskeletal weaknesses or imbalances. Forefoot tilt requires installation of wedges to prevent the foot from abducting (excessive toe-out) during the downstroke. Only thereafter, should the pedal system and cleat position be checked and corrected to ensure sufficient rotational float exists to accommodate any remaining misalignment. Generally, the greater the degree of misalignment the greater the amount of float required. Conversely, a small minority of cyclists gifted with ideal lower-limb biomechanics (ideal leg and foot alignment) can successfully tolerate, and often prefer, pedal systems with less float.

Studies have demonstrated that modern float pedal systems have the potential to reduce undesirable knee loads related to overuse injury by achieving a more linear motion of the knee, importantly, *without* compromising power output (17,18). Below is a brief summary on the evolution of clipless pedals and float pedal systems.

In 1984, **Look** the French-based ski binding manufacturer first tested a *rigid float-less* clipless pedal with the help of professional cyclist Bernard Hinault. This clipless system was introduced to the market in 1986. However, this rigid float-less system placed undesirable stress on the knees and increased the incidence of knee injuries. In 1987, Jean Beyl invented the Time pedal system, known as *Bioperformance*, which allowed free rotational float and some lateral motion of the foot. At first the Bioperformance system received much criticism from competing pedal manufactures, alleged claims of power loss due to float were proved incorrect after research studies demonstrated otherwise. Professional cyclist quickly adopted the system, and subsequently most manufactures modified their pedal systems to include varying degrees of rotational float. Within 18 months, the incidence of knee injuries reduced significantly.

Most modern-day clipless pedal systems (e.g. Shimano, Time, and Look) use spring loaded devices which employ a self-centering mechanism which allows varying degrees of rotational motion (typically 4° to 8°) against increasing resistance, this brings the shoe back to the preset neutral alignment. Once cant has been addressed, these pedals systems are suitable for the majority riders. However, in a minority of cases where riders present with greater biomechanical problems, such as tibial torsion, a greater degree of rotation is often needed to accommodate misalignment. The *Speedplay* pedal offers 0° to 15° of free float rotational motion. Compared with its competitors, the Speedplay offers two benefits; increased but adjustable float, and free float – meaning the foot does not have to work against spring loaded resistance.

self-centering pedal systems

Speedplay offers 15° free float

4. Lateral position (side-to-side)

Ideally, the knee should track straight up and down in an almost vertical line throughout the pedal revolution. Simultaneously the knee should remain directly over the second toe throughout the pedal revolution. Cyclists with wider hips require their feet further apart than cyclists with narrow hips. We often see riders whose knees stick out, or flick out over top dead centre of the pedal stroke. In situations like this we generally move the cleats inwards which effectively move the feet further apart. However, it is important to anatomically and biomechanically screen the cyclist for other conditions likely to cause such problems. For example musculoskeletal and degenerative conditions of the hip joint(s) are conditions which can cause the knee to deviate outwards. Past trauma, especially lower limb fractures or joint replacements can alter limb alignment. Excessive external tibial torsion (twisting of shin bone) tends to increase toe-out position which often necessitates both lateral and rotation cleat adjustments. Unfortunately, many pedal systems do not offer adequate lateral cleat adjustment because rotational angle and lateral adjustments are combined.

To our knowledge, Speedplay are the only manufactures that provide separate rotational angle and lateral adjustments. Otherwise, lateral adjustment can be increased by carefully filing the cleat slots wider, or placing a spacer washer between the crank-arm and pedal. In extreme cases, some manufactures offer spacers, known as 'knee-savers' which are 25 or 30mm, as shown in figure 9.

Figure 9

5. Whether to shim or not (leg-length differences)

Packing shims can be used to correct or compensate for leg-length differences (LLD) which are highly prevalent. However, fitting shims can be controversial and potentially harmful if installed incorrectly. Great care is required when assessing and diagnosing LLD. Ideally LLD assessment should be carried out by a trained, qualified Sports Medicine Clinician (19). Alternatively, there should be appropriate input by a Clinician working within the Bikefit team. There are several reasons for this;

1. **Accurately measuring LLD is difficult**
2. **Differentiating between ‘anatomical’ and ‘functional’ LLD is essential**

Shims should only be used for anatomical LLD - we strongly believe that packing shims should only be fitted when a true *anatomical* LLD has been reliably diagnosed. A true *anatomical* LLD is when a true bone length difference (tibia or femur) exists. A *functional* LLD is when an apparent shortening of one leg has occurred (but no bone length difference), usually due to pelvic dysfunction, muscle weakness, muscle imbalance or unilateral foot pronation. Pelvic dysfunction and muscle imbalances can usually be corrected by manual therapy and rehabilitation strategies.

Incorrect diagnosis - anatomic LLDs are often mistaken for *functional* LLDs, as such, inadvertently compensatory packing shims are fitted to the cycling shoe. Over recent years we have encountered cyclist who have had such packing shims incorrectly fitted by Bikefit sources. On careful examination, the cyclists have been found to have *functional* LLD rather than *anatomical* LLD. This approach is potentially harmful and can exacerbate the problem.


Checking for LLD

How do we diagnose LLD? – The only definitive method of establishing true anatomical LLD is by X-ray or similar scanning devices. However, well trained, qualified clinicians using a battery of simple differential diagnostic tests can usually arrive at a sound clinical judgment (19-24. Details can be found in our well publised **Biomechanical Pre-Bikefit Screening Protocol**. *The prevalence of anatomic LLD is high;* studies show that anatomic LLD affects approximately 90% of the population. Although prevalent, the mean LLD is small, and considered unlikely to be significant in a clinical setting (25, 26). However, in a competitive cycling arena, these small mean LLDs may prove to be significant.

Arch supports: Are they necessary in Cycling?

Longitudinal arch support

Studies have demonstrated that simple longitudinal arch supports are not adequate, as stand only, to support the foot when high pedal forces move forwards directly over the forefoot during the pedal downsroke, as during intense efforts (9,10). However, when ankling between 10 and 2 o’clock of pedal revolution, the ankle is in a dorsiflexed position, the foot is more susceptible to pronation, and therefore the longitudinal arch may collapse slightly, inwardly. Therefore, the use of a firm longitudinal arch support to complement varus wedges can be justified and likely to prove beneficial, especially for short intense cycling events. The problem with many commercial off-the-shelf cycling insoles is that the longitudinal arch support is insufficiently firm and often incapable of providing support under high loads. Some of customised foot beds are good. However, they can be expensive, and the effectiveness can depend on how the mold is taken. At ***NJD Sports Injury Clinic***, we recommend using a reasonably firm longitudinal arch placed slightly proximal (nearer) to the heel rather than distally (away). The reason for this is to prevent the arch from encroaching, and thus, interfering with the 1st Metatarsophalangeal joint.

Transverse arch support


Transverse arch


Metatarsalgia

The transverse arch, sometimes known as the metatarsal arch, stretches from the big-toe across to the little-toe. This arch can be subjected to extreme plantar pressures (forefoot pressures) during intense cycling efforts. If the arch collapses, the cyclists will suffer from a condition commonly known amongst cyclists as *hot-foot*. The medical term is metatarsalgia and is often described as a *burning* or aching sensation under the metatarsophalangeal joints (balls of your toes) shown as red in image. The above symptoms may be accompanied by shooting pains, tingling or numbness in the toes. Conventional treatment of this condition usually involves fitting a metatarsal pad / button to support the transverse arch. However, the primary reason why the transverse arch collapses is due to excessive pronation (forefoot tilt). First and foremost, the foot should be supported by appropriate wedges and a longitudinal arch support, and then if necessary, a metatarsal pad. This approach assumes the problem is not down to tight cycling shoes.

Saddle Position

Saddle height


Knee angle 25° to 35°

Saddle height is arguably the most important and fundamental adjustment of all, for optimal performance. Adjustments in saddle height serve to enable the muscles to work optimally in the longitudinal reach; and crucially there is only one optimum saddle height for each of us. For years there have been many unsubstantiated theories and methods on how to arrive at the most favourable saddle height. While a definitive method has remained elusive, a consensus within the research literature clearly demonstrates that saddle height is critical for *optimal performance* (27-30) and *injury prevention* (31-37). Failing to get the saddle height correct, or near correct can be prove to be disastrous.

The most common problem is riding with the saddle too low, or too far forward. These positions result in excessive flexion of the knee, leading to excessive pressure across the patellofemoral joint (PFJ). Optimal saddle height has been estimated on the basis of power output, caloric expenditure, and oxygen consumption. Muscle activity patterns, joint forces, movement patterns, and pedalling effectiveness (biomechanically) have all been linked to optimal saddle heights. Optimum saddle height allows the extensor muscles to contract through a range of lengths at which the force they can produce is near maximal. Conversely, a low saddle leads to a more flexed knee, which leads to a larger and less efficient length knee extensor muscles. Saddles that are too high can result in posterior knee pain (hamstring tendon problems) or increased risk of iliotibial band syndrome (ITBS) which is arguably the second most frequent of knee injuries in cycling.

Differences in body morphology make it difficult

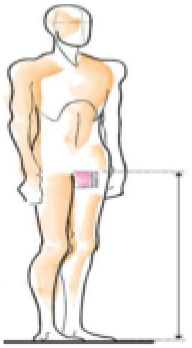
Differences in body morphology (e.g., foot, tibia and femur lengths) varies greatly from cyclist to cyclist that it makes it almost impossible to single out a saddle height formula appropriate for all cyclists (38). This theory has been recently validated by a number of robust studies by Professor

Peveler and colleagues (39-42). These are arguably the most robust and reliable findings to date on optimal saddle height, and certainly the most recent. We will discuss Professor Peveler's findings and explain their implications shortly, in addition to the plethora of other less substantiated methods and theories of determining saddle height.

Different saddle height methods

As highlighted above, multiple saddle height methods exist primarily developed to fit the road cyclist. The four listed below appear to be the most common.

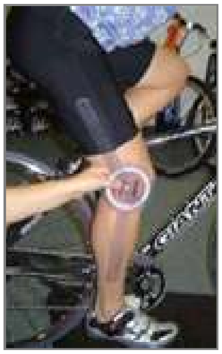
- **Hamley and Thomas, (1976) - 109% of inseam method** (for combined saddle height and crank length)
- **Lemond method - v**alue of **0.884 of inseam** (for saddle height measured from the bottom bracket centre)
- **Heel method** (heel placed on pedal at bottom of stroke with leg straight)
- **Holmes method (25° to 35° knee angle)**



Hamley & Thomas
(109% of inseam**)**

Lemond method
(0.884 of inseam**)**

Heel method



Holmes method
(25-35° knee angle)

Comparison between these methods

In 2005, Peveler *et al* (39) compared the accuracy of the four methods listed above with respect to knee angle falling within the universally recognised 25° to 30° range. Their study examined accuracy and reliability between the various methods. The authors recommended the *Holmes* method in favour of the others. Although not reported, the *Holmes* method would appear more accommodating for differences in body morphology.

What does the latest research say?

The latest peer-reviewed findings clearly favour a saddle height set at 25° knee angle compared to a 35° knee angle and the Hamley and Thomas 1967 method of 109% of inseam with respect to both cycling performance and injury prevention (40-42). The main reason for these differences is that the Hamley 109% inseam method is less reliable, less consistent. Many of the inseam methods are reliant on formulae which fail to take into account variables likely to create differences in the functional knee angle e.g., shoe sole thickness, pedal stack height, differences in foot lengths and saddle design. Furthermore, different pedalling styles (e.g. ankle joint angle) can significantly influence saddle height calculated from formulae when passing through bottom dead centre of the pedalling cycle. Peveler *et al* (39) found that the Hamley method only puts a cyclist's knee within the Holmes method (25° to 35° knee angle range) 45% of the time. Below follows a summary of each of these recent studies.

In 2007, Peveler *et al* (40) compared the effects of saddle height on Anaerobic Power output between two saddle height methods; (i) 25° to 35° knee angle, and (ii) 109% inseam, using a 30 second Wingate protocol. The results demonstrated that a 25° knee angle produced significantly higher mean power out compared with 109% inseam, in those cyclists that fell outside the recognised 25° to 35° knee angle range.

In 2008, Peveler (41) once again examined the effects between two different saddle height methods. While the previous study compared anaerobic power, this particular study compared *aerobic power* and *economy* in cycling. Subjects rode for 15 minutes at 70% VO_2 max on a cycle ergometer. While there was no significant differences in heart rate of rate of perceived effort (RPE), VO_2 was found to be significantly lower at a saddle height of 25° knee angle when compared with a 35° knee angle and the 109% inseam method.

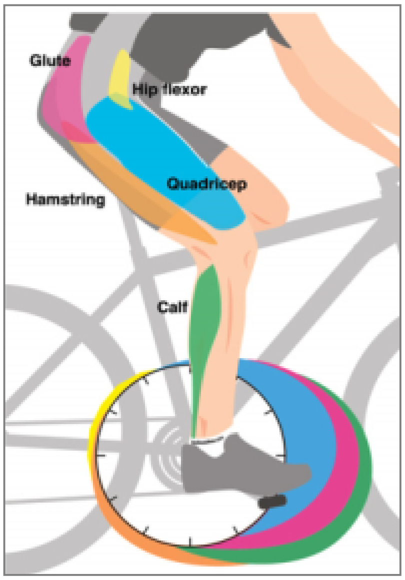
Most recently in 2011, Peveler and Green (42) yet again examined the effects of saddle height. Here, they measured both aerobic economy and anaerobic power in well-trained cyclists. Results once again clearly favoured a 25° knee angle when compared with 35° knee angle and 109% of inseam. VO_2 was significantly lower at 25° in comparison to 35° knee angle and the 109% of inseam method. Both peak and mean anaerobic power output was higher for 25° knee angle in comparison to the other two methods. Similar to their previous study, the 109% of inseam fell outside the recommended 25-35° knee angle range on 73% of the time, further highlighting the inconsistency of inseam methods.

Conclusion of different saddle height methods

A saddle height of 25° to 30° of knee angle would appear to be the ideal range for cycling performance and injury prevention. A knee angle closer to 25° would appear to be the optimum for both anaerobic power output and aerobic economy. The inconsistency and somewhat poor reliability of inseam methods that rely on formulae to calculate saddle height have been clearly exposed. Direct dynamic methods of measuring knee angle appear superior to methods that rely on formulae. Many of the inseam methods reliant on formulae fail to take in account variables which are likely to influence the functional knee angle. For example, these include; shoe sole thickness, pedal stack height, angle of ankle joint, differences in foot lengths and saddle design.

Muscle recruitment activity during cycling

During the pedal cycle, the knee goes through approximately 75° of motion. The knee begins the downstroke (power-phase) at top dead centre (TDC) of the pedal cycle while flexed at about 110-120° and extends to about 25-35° of flexion at the bottom dead centre (BDC) of pedal cycle (43). The hip, knee and ankle joints extend simultaneously during the pushing action of the downstroke. The quadriceps muscles and gluteals are the main muscle groups to generate forces on the downstroke. The hip and knee flexors (rectus femoris, psoas and hamstring group respectively) work to drive the pedal rearward near BDC, and then to lift the pedal during a large part of the recovery phase (44). The ankle plantar flexors (gastrocnemius and soleus) and ankle dorsiflexor (tibialis anterior) stabilize the ankle and foot throughout the pedalling cycle, in addition to being minor force generators at various stages of the pedal cycle. Changes in saddle height alter the range of joint motion and muscle length, subsequently affecting both muscle activity and cycling performance(44,45).



The pedal stroke

Pedalling in a simple circle is a complex thing, but mastering it can save energy, according to Todd Carver, biomechanist at Colorado's Centre for Sports Medicine (46).There are different phases, or zones, throughout the 360° of the pedal cycle. These zones or phases can be referred to as times on a clock face. In its simplest form, mostly applicable to most recreational cyclists, there are two phases, namely; the *power-phase* (downstroke) from 12 to 6 o'clock and the recovery-phase (upstroke) from 6 o'clock back to the top at 12 o'clock. For maximum pedalling efficiency, foot forces should be directed perpendicular to the crank throughout the entire pedal revolution. There are two main *dead-spots* i.e., going over top dead centre (TDC) and going round bottom dead centre (BDC). Modern clipless pedals allow competitive cyclist to drive throughout the 360°. Thus, clipless pedals enable competitive cyclists to employ *four* different phases within the 360° pedal stroke, to assist with overcoming *dead-spots*. From about 5 o'clock of the *power-phase*, the cyclist should plantar-flex the ankle by approximately 20° (toes pointing downward) and draw the pedal backwards around BDC. Then, coming to the end of the *recovery-stroke,* from about 11 o'clock through to 2 o'clock, the rider should dorsiflex the ankle to approximately 10° (drop the heel) while pushing the pedal over TDC. Please note, the above zones and ankle joint ranges should only be considered as typical – our intention is to deliver the concept.

Saddle Fore and Aft position

K*nee* ***O****ver* ***P****edal* ***S****pindle* **(KOPS)** *method*

Although there is no scientific evidence to support the (**K**OPS) method, consensus within the literature clearly recommends its use. KOPS has no real biomechanical basis but does seem to work quite well, and remains popular with the vast majority of Bikefit organisations, especially when working with road cyclists on road geometry frames. By starting from the neutral KOPS position the rider can tweak the seat position forward or back depending on riding style. Generally, the neutral KOPS position serves as a good starting point for most road cyclists; however there are slight variations for other cycling disciplines. Long distance (stage) racers and Mountain Bikers often move the saddle back approximately 1 to 2 cm from the neutral KOPS position, whereas Sprinters, Time Trialists and Triathletes often move the saddle forward from neutral KOPS.

Finding KOPS

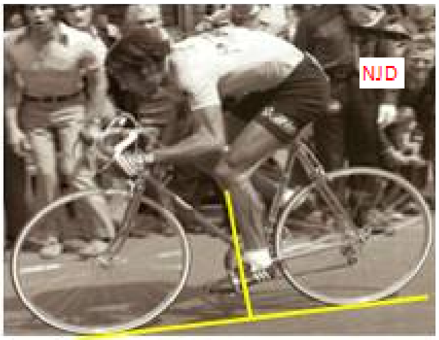
Using a turbo-trainer or similar device positioned on a level horizontal surface, a plumb line or laser should generate a straight (vertical) line from the tibial tuberosity over the center of the pedal spindle. The leading crank-arm should be horizontal (3 o'clock) as should the cyclist's foot/shoe. The tibial tuberosity represents the bony lump about 2 cm below the bottom of the kneecap.

Effects of variation on KOPS

According to some authors, the neutral KOPS position tends to greatly reduce the strain on the patellar tendon during the downstroke, specifically when the most force is being generated, on typical road geometry frames. Riding with the saddle *too far forward* or too low (31-33) results in excessive flexion of the knee, leading to excessive pressure across the PFJ, with a more perpendicular vector force across the joint (29) – which can lead to knee problems. Any changes to the Fore & Aft saddle position will ultimately alter the saddle height. This will necessitate a compensatory saddle height re-adjustment.

KOPS and Tour de France

Although not definitive, the images below (17 Tour de France wins) tend to support the neutral KOPS position as a good starting point with respect to Fore & Aft saddle position.



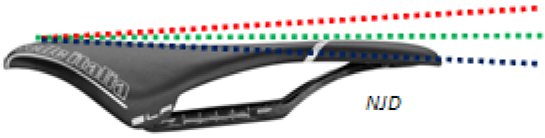
Eddy Merckz – 5 times Tour winner
Not too far from neutral KOPS position

Bernard Hinault – 5 times winner
Not too far from neutral KOPS position

Armstrong – 7 times Tour winner
Not too far from neutral KOPS position

Saddle tilt

Generally, the saddle should be set level (green dotted-line), or with a slight backward tilt for road racing and mountain biking (red dotted-line). The level of the saddle can be checked by placing a spirit-level along the longitudinal axis. Some women prefer the front of the saddle tilted sligthly downwards (blue dotted-line) to reduce pressure on the perineal area. Some Time Trial and Triathlon riders riding in a forward aero-position will also prefer the front of the saddle tilted slightly downwards.



The role of Core & Pelvic stability in cycling

Core stability has received considerable attention over the recent with regards to functional training in sports, and there is no single universally accepted definition of core stability (47). Balance and strength in the core and pelvic muscles is a must for efficient performance in road, track, triathlon or mountain biking (48). Specific to cycling, core and pelvic stability provides the foundation from which power is generated in cycling (32). The core muscles maintain the neutral pelvic position on the bike when the anterior and posterior muscle components are equally balanced. On the basis of orientation and attachment of the psoas muscle on the lumbar spine, pelvic stabilization and resistance to fatigue are critical to maintain the natural curve of the spine as well as provide the leverage from which the psoas and gluteal muscles contract when a greater power output is required (49). Despite of all the *hype* that has been written in magazines and on the web, little cycling specific research has been done on how core and pelvic stability affects cycling performance.

Latest research suggests that a weakened core affects cycling mechanics

In 2007, Apt et al (50) carried out a study to determine the relationship between cycling mechanics and core stability. They found that core fatigue resulted in altered cycling mechanics that might increase the risk of injury because the knee joint is potentially exposed to greater stress. This means that core stability contributes to lower limb cycling mechanics. Subsequently, improvements in core strength could promote greater torso stability and maintain lower limb (knee) alignment to apply greater force transmission to the pedals. Conversely, prolonged cycling with altered lower limb mechanics as a result of a fatigued core might increase the risk of overuse injury from malalignment.

Conclusion

Strengthening the core musculature could enhance the stability of the foundational leverage from which the cyclist generates power. Thus, improved core stability and endurance could promote greater alignment of the lower extremity when riding for extended durations as the core is more resistant to fatigue (50).

The foot can affect core and pelvic stability

While much *hype* has been written about exercise programs for core and pelvic development, plentiful available in magazines and on-line, little attention is ever given to the role of the foot in core and pelvic matters. The literature clearly demonstrates that good posture during *gait* is dependent on foot stability during mid-stance (51-53). Studies have demonstrated that both unilateral and bilateral foot pronation displaces the body's line of gravity forward through forward pelvic rotation (54) and levels of forefoot varus >7° cause pelvic and core instability (55,56). Although no cycling specific research has been carried to substantiate that the foot can cause core and pelvic instability, extrapolation of *gait* findings across to cycling is both logical and reasonable.

Conclusion

Control of excessive foot pronation for both *gait* and *cycling* activities is likely to help maintain core and pelvic stability. This approach is likely to enhance the effectiveness of core and pelvic stability exercise programs in cyclists presenting with excessive foot pronation and/or forefoot varus.

Handlebar position

Handlebar and stem length settings represent the final adjustment of the 3 body point contacts for optimal position. Handlebar position, in all forms of cycling is a compromise between efficiency (power output and aerodynamics), safety and comfort.

Aerodynamics

At cycling velocities exceeding 20mph, approximately 80% of the total resistive forces on a cyclist and bike combined are to due to aerodynamic drag. Traditional road racing bikes are responsible for approximately 35% of the total aerodynamic drag; the remaining 65% is attributed to the cyclist's body. Using modern aerodynamic Time Trial and Triathlon cycles may reduce aerodynamic drag to approximately 20% of the total (Broker, 2003).

Aerodynamics is the study of how a solid body (cyclist) moves through the air. Effective aerodynamics is how a rider and cycle overcome air resistance created by forward motion and the prevailing wind. The speed that can be achieved on the bike is determined by two factors; i) how much power you are able to produce, ii) and wind resistance, commonly referred to as "drag". The force on an object that resists its motion through air is called ***drag***. Aerodynamic drag consists of two forces: air pressure drag and direct friction (also known as surface friction or skin friction). A blunt, irregular object disturbs the air flowing around it, forcing the air to separate from the object's surface. Low pressure regions from behind the object result in a pressure drag against the object. With high pressure in the front, and low pressure behind, the cyclist is literally being pulled backwards. Streamlined designs help the air close more smoothly around these bodies and reduce pressure drag. Direct friction occurs when wind comes into contact with the outer surface of the rider and the bicycle.

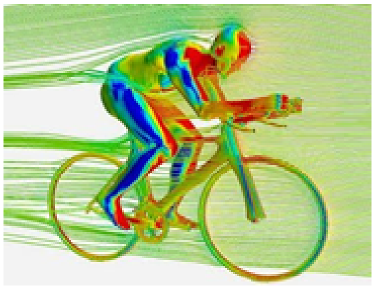


Diagram showing high pressure in front and low pressure behind

References

1. Whitney, K.A. (2003). Foot deformities Part II. *Journal of Clinics in Podiatric Medicine & Surgery, 20*(3), 511-526.
2. Cornwall, M.W. (2000). Common pathomechanics of the foot. *Journal of Athletic Therapy Today. 5*,10-16.
3. Agosta, J. (2001). *Biomechanics of common sporting injuries.* In P. Brukner & K. Khan (Eds.). *Clinical sports medicine* (2nd ed. pp. 43-83). Sydney: McGraw-Hill Companies.
4. Garbalosa, J.C., McClure, M.H., Catlin, P.A., Wooden, M. (1994). The frontal plane relationship of the forefoot to the rearfoot in an asymptomatic population. *Journal of Orthopaedic and Sports Physical Therapy, 20,* 200-206.
5. Millslagle, D., Rubbelke, S., Mullin, T., Keener, J., & Swetkovich, R. (2004). Effects of foot-pedal positions by inexperienced cyclists at the highest aerobic level. *Perceptual and Motor Skills, 98,* 1074-1080.
6. Jarboe, N.E., & Quesada, P.M. (2003). The effects of cycling shoe stiffness on forefoot pressure. *Foot Ankle Int., 24*(7), 784-788.
7. Davies, R.R., & Hull, M.L. (1981). Measurement of pedal loading in bicycling: II. Analysis and results. *Journal of Biomechanics, 14*, 857-872.
8. Farrell, K.C., Reisinger, K.D., & Tillman, M.D. (2003). Force and repetition in cycling: possible implications for Iliotibial band friction syndrome. *The Knee, 10,* 103-109.
9. Hannaford, D.P.M., Moran, G.T., & Hlavac, A.M. (1986). Video analysis and treatment of overuse knee injury in cycling: a limited clinical study. *Clinics in Podiatric Medicine and Surgery, 3*, 671-678.
10. Hennig, E.M., & Sanderson, D.J. (1995). In-shoe pressure distributions for cycling with two types of footwear at different mechanical loads. *Journal of Applied Biomechanics, 11,* 68-80.
11. Moran, G.T., & McGlinn, G.H. (1995). The effect of variations in the foot pedal interface on the efficiency of cycling as measured by aerobic energy cost and anaerobic power. *Biomechanics in Sport, 12,* 105-109.
12. Dinsdale, N.J., & Williams, A. G. (2010). Can forefoot varus wedges enhance anaerobic cycling performance in untrained males with forefoot varus? *Journal of Sport Scientific and Practical Aspects, 7*(2), 5-10.
13. Sanderson, D.J., Cavanaugh P.R. (1987). An investigation of the in-shoe pressure distribution during cycling in conventional cycling shoes. In Jonsson (Ed) Biomechanics XB, 903-907. USA, Champaign; Human Kinetics.
14. Van Sickle, J.R. & Hull, M.L. (2007). Is economy of competitive cyclists affected by the anterior–posterior foot position on the pedal? *Journal of Biomechanics, 40*, 1262–1267.
15. Hogg, S. (2008). *Footloose*. In: Bicycling Australia, 2008, Sept – Oct. http://bicyclingaustralia.com/node/77
16. Ruby, P., Hull, M.L., Kirby, K.A., & Jenkins, D.W. (1992). The effect of lower-limb anatomy on knee loads during seated cycling. *Journal of Biomechanics, 17*(2), 1195-1207.
17. Wheeler, J.B., Gregor, R.J., & Broker, J.P. (1995). The effect of clipless float design on shoe/pedal interface kinetics and overuse knee injuries during cycling. *Journal of Applied Biomechanics, 11,* 119-141.
18. Gregory, R.J., & Wheeler, J.B. (1994). Biomechanical factors associated with shoe/pedal interfaces. *Sports Medicine, 17*(2), 117-131.
19. Dinsdale, N.J (Mr.) & N.J. Dinsdale (Miss), (2011). The benefits of anatomical and biomechanical screening of competitive cyclists. *sportEX dynamics, 28*, 17-20.
20. Brady, R.J., Dean, J.B., Skinner, T. M., & Gross, M.T. (2003). Limb length inequality: Clinical implications for assessment and intervention. *Journal of Orthopaedic & Sports Physical Therapy, 33*, 221-234.
21. Cooperstein, R., Haneline, M., & Young, M. (2007). Mathematical modelling of the so called Allis test: a field study in orthopedic confusion. *Chiropractic & Osteopathy, 15*:3 doi: 10.1186/1746-1340-15-3.
22. Krawiec, C.J., Denegar, C.R., Hertel, J., Salvaterra, G., & Buckley, W.E. (2003). Static innominate asymmetry and leg length discrepancy in asymptomatic athletes. *Manual Therapy, 8*(4), 207-213.

23. Caselli, M. & Rzonca, E.C. (2002). Detecting and treating Leg-Length Discrepancies. *Podiatry Today, 15*(12), 65-68.
24. Juhl, J. (2004). Prevalence of frontal plane pelvic postural asymmetry. *J Am Acad Osteopath Assoc, 104*(10), 411-21.
25. Knutson, G. A. (2005). Anatomic and functional leg-length inequality: A review (Part 1*). Chiropractic & Osteopathy, 13*(11): http://www.biomedcentral.com/content/pdf/1746-1340-13-11.pdf
26. Knutson, G.A. (2005). Anatomic and functional leg-length inequality: A review and recommendation for clinical decision-making. Part 2, the functional or unloaded leg length asymmetry. *Chiropractic & Osteopathy, 13*;12 http://www.chiroandosteo.com/content/13/1/11
27. Hamley, E. J., & Thomas, V. (1967). Physiological and postural factors in the calibration of the bicycle ergometer. *Journal of Physiology*, *191*(2), 55P-56P.
28. Nordeen-Snyder, K. (1977). The effect of bicycle seat height variation upon oxygen consumption and lower limb kinematics. *Medicine and Science in Sports, 9,* 113-117.
29. Wanich, T., Hodgkins, C., Columbier, J.A., Muraski, E., & Kennedy, J.G. (2007). Cycling injuries of the lower extremity. *Journal of the American Academy of Orthopaedic Surgeons, 15*, 748-756.
30. Wozniak Timmer, C.A. (1991). Cycling biomechanics: A literature review. *Journal of Orthopeadic & Sports Physical Therapy, 14*(3), 106-113.
31. Holmes, J.C., Pruitt, A. L., & Whalen, N.J. (1994). Lower extremity overuse in bicycling. *Clinics in Sports Medicine, 13*(1), 187-203.
32. Mellion, M.B. (1991). Common cycling injuries: Management and prevention. *Sports Medicine, 11*(1), 52-70.
33. O'Brien, T. (1991). Lower extremity cycling biomechanics: a review and theoretical discussion. *Journal of American Podiatric Medical Association, 81*(11), 585-592.
34. Burke, E.R., & Pruitt, A.L. (2003). Body position for cycling. In E.R. Burke (Ed.), *High-Tech cycling* (2nd ed., pp. 69-92). Champaign, IL: Human Kinetics.
35. Fletcher, S. & Hutson, W. (2001) Saddle up: Fit body to bike. *sportEX health, 9,* 25-28.
36. Moore, F. (2008). Correct bicycle set-up to minimise the risk of injury. *sportEX medicine, 37,* 6-9.
37. Brown, G. (2001). Breaking the cycle of injury. *sportEX health 9,, 29*-33.
38. Sanner, W.H., & O'Halloran, W.D. (2000). The biomechanics, etiology, and treatment of cycling injuries. *Journal of American Podiatric Medical Association, 90*(7), 354-376.
39. Peveler, W.W., Bishop, P., Smith, J., Richardsson, M. & Whitehorn, E. (2005). Comparing methods for setting saddle height in trained cyclist. *Journal of Exercise Physiology-online, 8*(1), 51-55.
40. Peveler, W.W., Pounders, J., & Bishop, P. (2007). Effects of saddle height on Anaerobic Power production in cycling. *Journal of Strength & Conditioning Research, 21*(4), 1023-1027.
41. Peveler, W.W. (2008). Effects of saddle height on economy in cycling. *Journal of Strength & Conditioning Research, 22*(4), 1355-1359.
42. Peveler, W.W. & Green, J.M. (2011). Effects of saddle height on economy and anaerobic power in well-trained cyclists. *Journal of Strength & Conditioning Research,* 25(3), 629-633.
43. Asplund, M.D., & St Pierre, P. (2004). Knee pain and bicycling. *The Physician and Sports Medicine, 32*, 23-30.
44. So, R.C., Ng, J., Ng, G. (2005). Muscle recruitment patterns in cycling; a review. *Physical Therapy in Sport, 6,* 89-96.
45. Koning, J., & van Soest, K. (2002). Biomechanics. In A. E. Jeukendrup (Ed.), *High-Performance cycling* (pp. 129-138). Champaign, IL: Human Kinetics.
46. Mooney, L. The perfect pedal stroke: How to get the most energy from each crank revolution. Bicycling Mag. http://www.bicycling.com/training-nutrition/training-fitness/perfect-pedal-stroke
47. Kibler, W.B., Press, J., & Sciascia, A. (2006). The role of core stability in athletic function. *Sports Medicine – (Auckland), 36,* 189-198.
48. Hinds, S. (2005). A balancing act for cyclists. *sportEX dynamics, 6*, 6-9.
49. Juker, D., McGill, S., Krope, P., & Steffen, T. (1998). Quantitative intramuscular myoelectric activity of lumbar portions of psoas and the abdominal wall during a wide variety of tasks. *Med. Science Sports Exercise,* 30:301–310.
50. Apt, J.P., Smoliga, J.M., Brick, M.J., Jolly, J.T., Lephart, S.M., & Fu, F.H. (2007). Relationship between cycling mechanics and core stability. *Journal of Strength and Conditioning Research, 21*(4), 1300-1304.
51. Cote, K.P., Brunet, M.E., Gansnedert, B.M., & Shultzs, S.J. (2005). Effects of pronated and supinated foot postures on static and dynamic postural stability*. Journal of Athletic Training, 40*(1), 41-46.
52. Tsai, L.C., Yu, B., Mercer, V.S., & Gross, M.T. (2006). Comparison of different structural foot types for measures of standing postural control. *Journal Orthopaedic & Sports Physical Therapy, 36*(12), 942-953.
53. Cibulka, M.T. (1999). Low back pain and its relation to the hip and foot. *Journal Orthop Sports Phys Therapy, 10,* 595-601.
54. Rothbart, B.A. (2006). Relationship of functional leg-length discrepancy to abnormal pronation. *Journal of American Podiatric Association, 96*(6), 499-507.

55. Cobb, S.C, Tis, L.L., Johnson, B.J., & Higbie, E.J. (2004). The effect of forefoot varus on postural stability. *Journal of Orthopaedic & Sports Physical Therapy, 34*, 79-85
56. Cobb, S.C, Tis, L.L., Johnson, J.T. (2006). The effect of 6 weeks of custom-molded foot orthosis intervention on postural stability in participants with ≥ 7 degrees of forefoot varus. *Clinical Journal of Sports Medicine, 16,* 316-322.

Bibliography

Astrom, M., & Arvidson, T. (1995). Alignment and joint motion in the normal foot. *Journal of Orthopaedic and Sports Physical Therapy, 22,* 216-222.

Bini, R.R., & Diefenthaeler, (2009). Mechanical work and coordination pattern of cycling: literature review. *Journal of Kinesiology, 41*(1), 25-39.

Boone, D., Azen, S., Lin, C., Spence, C. et al (1978). Reliability of goniometric measurements. *Physical Therapy, 58*(11), 1355-1360.

Broker, J. (2003). Aerodynamics. In E.R. Burke (Ed.), *High-Tech cycling* (2nd ed., p.155). Champaign, IL: Human Kinetics.

Elveru, R., Rothstein, J., & Lamb, R. (1988). Goniometric reliability in a clinical setting: subtalar and ankle joint measurements. *Physical Therapy, 68*(5), 672-677.

Faria, E.W., Parker, D.L., & Faria, I.E. (2005). The science of cycling: Physiology and training - Part 1. *Sports Medicine, 35,* 285-312.

Gajdosik, R. L., & Bohannon, R. W. (1987). Clinical measurement of range of motion: Review of goniometry emphasizing reliability and validity. *Physical Therapy, 67*(12), 1867-1872.

Morgan, N. (2008). Technique: How to get your saddle height right. Online: http://www.bikeradar.com/road/fitness/article/technique-how-to-get-your-seat-height-right-14608

Pierrynowski, M. R., & Smith, S. B. (1997). Effect of patient position on the consistency of placing the rearfoot at subtalar neutral. *Journal of the American Podiatric Medical Association, 87*(9), 399-406.

Plastaras, C.T., Rittenberg, J.D., Rittenberg,K.E., Press, J., & Akuthota, V. (2005). Comprehensive functional evaluation of the injured runner. *Phys Med Rehabil Clin N Am., 16*, 623-649.

Somers, D., Hanson, J., Kedzierski, C., Nestor, K., & Quinlivan, K. (1997). The influence of experience on the reliability of goniometric and visual measurement of forefoot position. *Journal of Orthopaedic and Sports Physical Therapy, 25*(3), 192-202.

Stefanyshyn, D.J. & Nigg, B.M. (2001). In:Plastaras et al (2005). Comprehensive functional evaluation of the injured runner. *Phys Med Rehabil Clin N Am., 16*, 623-649.

Nick

AUTHORS

Nick Dinsdale BSc (Hons), MSc, MSST

Nicola Dinsdale BSc (Hons), MSST

Graduate Sports Therapists Nick and Nicola Dinsdale, father and daughter team, run ***NJD Sports Injury Clinic*** in Clitheroe, Lancs. UK. The family clinic is recognised for its strong *evidence-based* approach to the management of sports related musculoskeletal injuries and its keen interest in working with competitive cyclists. Patients include professional cyclists, in addition to British Cycling officials.

Nicola