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CLINICAL COMMENTARY

THE ROLE OF A BIKE FIT IN CYCLISTS WITH HIP PAIN. A CLINICAL COMMENTARY

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ABSTRACT

Hip pathology is common amongst athletes and the general population. The mechanics of cycling have the potential to exacerbate symptomatic hip pathology and progress articular pathology in patients with morphologic risk factors such as femoroacetabular impingement. A professional fit of the bicycle to the individual which aims to optimize hip joint function can allow patients with hip pathology to exercise in comfort when alternative high impact exercise such as running may not be possible. Conversely improper fit of the bicycle can lead to hip symptoms in otherwise healthy individuals who present with risk factors for hip pain. Accordingly a bike fit can form part of the overall management strategy in a cyclist with hip symptoms. The purpose of this clinical commentary is to discuss hip pathomechanics with respect to cycling, bicycle fitting methodology and the options available to a physical therapist to optimize hip mechanics during the pedaling action.

Key Words: bicycling, femoroacetabular impingement syndrome, hip, movement system, myofascial trigger points, osteoarthritis.

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INTRODUCTION

Cycling is a popular sport. In Australia approximately 15% of people ride a bicycle for recreation or transport per week.[1] The incidence of hip pain and pathology in cyclists is not clear and has received little attention in the literature. Previous reports suggest an incidence of unspecified groin or buttock pain occurring in between 34% and 72% of amateur cyclists participating in week long recreational road cycling events,[2,3] and an incidence of 18% of unspecified causes of hip or groin pain in club level cyclists averaging ten hours per week of training.[4] In the general population the incidence of hip pain is better understood. There is a high lifetime incidence of hip pathology, with the prevalence of symptomatic hip osteoarthritis in people who live to age 85 being approximately twenty-five percent.[5] This incidence appears to be higher (up to 60%) in former athletes.[6] Clinical experience indicates that the development of hip pain is a common reason for cyclists to seek professional health care. One of the aims of clinical care in such athletes is to address both the intrinsic and extrinsic factors contributing to the cyclists' hip complaint. The purpose of this clinical commentary is to discuss hip pathomechanics with respect to cycling, bicycle fitting methodology and the options available to a physical therapist to optimize hip mechanics during the pedaling action. Poor positioning, which is the major extrinsic risk factor for overuse injuries of the hip in cyclists, has the potential to alter biomechanics and neuromotor control in a manner which places excessive load on the athletes' hip relative to their functional capability. A physical therapist who is trained in pathology and analysis of human motion is in a unique position to offer a professional bike fit for cyclists seeking to improve performance or address pain that is related to poor positioning on their bicycle.

HIP PAIN AND PATHOLOGY IN CYCLISTS

When assessing cycling-related atraumatic hip pain, consideration is given to both intra-articular and extra-articular sources of pain. The range of diagnoses related to hip pain is broad and includes bursitis, myofascial pain and dysfunction arising from trigger points, tendinopathy, hernia, referred spinal pathology and articular hip pain from ligamentum teres tears, synovitis or chrondrolabral disorders.[7] Both intra-articular and myofascial pain are common in cyclists. Myofascial pain may arise from the posterior hip musculature such as the gluteus maximus, deep hip rotators, gluteus medius, gluteus minimus or upper hamstrings.[8] The posterior hip muscles, particularly the gluteus maximus, are prime movers in the pedaling action[9] and are thought to become overloaded via repetitive training loads or poor position on the bicycle leading to the development of painful myofascial trigger points. In contrast to the high incidence of muscular pain around the hip in cyclists, tendon pathology and atraumatic bursitis are relatively less common in this population.

When evaluating intra-articular hip pathology, joint specific risk factors require consideration. For the hip joint these factors are thought to include abnormalities in joint morphology, biomechanical overload, abnormal function of the peri-articular muscles, and a past history of joint injury.[10] A combination of these factors may be present in the cyclist who complains of cycling-related hip pain, with repetitive loading associated with cycling combined with extrinsic risk factors such as poor positioning, and any intrinsic risk factors such as abnormal joint morphology, acting together to produce a painful hip. The most common intra-articular pathologies of the hip are osteoarthritis (OA) and femoroacetabular impingement syndrome (FAIS).[11]

In younger active patients, FAIS is recognized as a cause of intra-articular hip pain and may be a precursor to the development of hip OA.[11] In FAIS, abnormalities in the morphology of the hip joint predispose the individual to mechanical impingement, causing abnormal shear forces that may initiate degenerative change in the hip joint.[12] The morphologic abnormalities in FAIS include two broad categories, being cam (femoral) and pincer (acetabular) impingement. These may occur alone or in combination.[13] In cam impingement, the morphologic abnormality is a thickened aspherical femoral head-neck junction (Figure 1A). In pincer impingement the acetabulum is deepened with acetabular over-coverage of the femoral head (Figure 1B). Both morphological types of FAIS cause abutment of the femoral neck and acetabulum in hip flexion, compressing the labrum and creating a horizontal shear force at the acetabular articular cartilage, considered instrumental in the pathogenesis of OA. This

Osteoarthritis of the hip is well recognized and may present with variable features, ranging from significant pain in the early phases of the condition or conversely may remain largely asymptomatic until advanced joint changes have occurred.[18] In the early pathogenesis of hip OA, biomechanical load patterns have been implicated.[10] In particular, repetitive shear stress at the hyaline cartilage to bone interface and injury of the labro-chondral junction appears likely to initiate the cellular processes associated with degenerative change.[19] This mechanism is identical to that described for FAIS and is a reason why some authors consider that FAIS may lead to OA.[15]

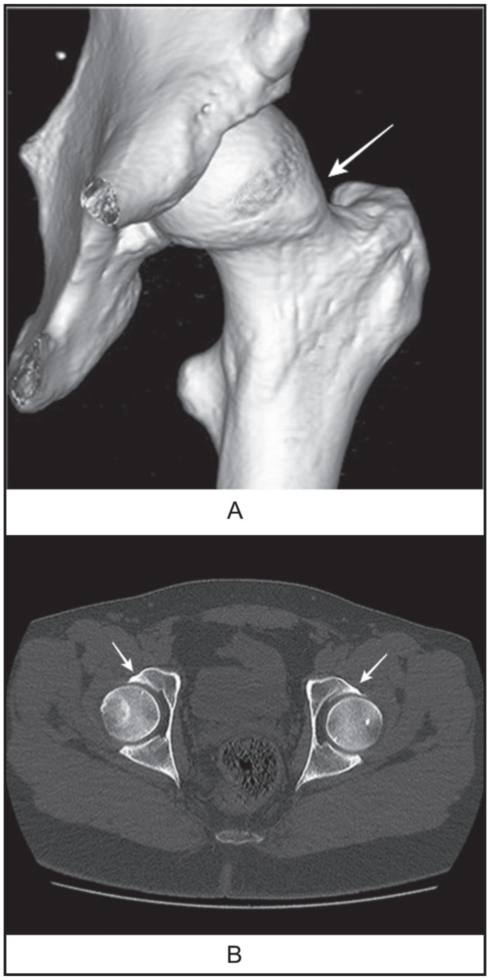


Figure 1. *Cam and Pincer Impingement. (A) Cam impingement: Three dimensional CT reconstruction demonstrating cam lesion on femoral neck (arrow) with thickening and irregular sphericity of the head-neck junction. (B) Pincer impingement: Axial CT image demonstrating bilateral pincer type femoracetabular impingement (arrows) secondary to relative acetabular retroversion. In these situations, pelvic radiographs often demonstrate a characteristic "cross-over" sign.*

premature bony abutment limits hip flexion and internal rotation in symptomatic patients.[14] The repeated abutment is thought to cause degenerative tearing of the labrum, delamination and erosion of the articular cartilage which progresses to OA over time.[15] In cycling, repeated hip flexion[16] at the top of the pedal stroke is a potential mechanism for repetitive impingement in those patients whose joint morphology predisposes them to FAIS. It should be noted that morphological abnormalities are a risk factor for hip pain and are frequently present in asymptomatic persons, and that not all people with abnormal morphology will develop symptoms.[17]

DIAGNOSIS OF HIP PATHOLOGY IN CYCLISTS

Patients with intra-articular hip pathology typically present with insidious onset groin pain that is activity related, although approximately one in three to four patients may describe a specific incident that initiated their symptoms.[20] Most patients with intra-articular pathology (83%) report groin pain,[14] although overlapping pain at other sites is common including the lateral hip, buttock, low back, thigh and knee. Pain may be aggravated by common physical activities such as walking, running or cycling, and by prolonged sitting.[14] Triathletes often report increased symptoms relating to the transition between cycling and running. Cyclists with intra-articular hip pain present with groin pain of gradual onset that may be related to increases in cycling volume, or a change in cycling position which requires greater hip flexion such as lowering the handlebars, fitting longer cranks or commencing cycling on a time trial bike. The clinical examination findings in cyclists with hip pain are the same as that reported for other athletes and the general population as noted below.

Differential diagnosis of hip pain can present a clinical challenge. Diagnosis relies on pattern recognition of a cluster of symptoms and signs that are consistent with a particular condition, supplemented by diagnostic imaging when required. For example, a recent consensus statement[11] recommends that the diagnosis of FAIS is based on symptoms of activity- or position- related pain in the groin or hip; signs including a positive FADIR test and limitation of internal rotation in the 90° flexed hip;

and imaging findings consistent with cam or pincer impingement. In hip OA, diagnosis relies on recognizing a pattern that includes symptoms of groin or hip pain related to weight bearing or to activity with or without morning stiffness lasting less than one hour; signs including limited passive hip joint range of greater than 15° in at least two of its six directions when compared to the non-affected side; and imaging findings consistent with degenerative joint disease such as joint space narrowing and osteophytes.[21] When evaluating a patient with hip pain, it is useful to consider that both intra- and extra- articular causes of hip pain may be present.

Physical examination to implicate intra-articular hip pathology typically includes acetabular rim provocation tests (also termed a quadrant test, FADIR or impingement test), which are considered to have high sensitivity and low specificity for conditions such as FAIS and OA.[22] A positive test is reproduction of groin pain or the patients pain. Some cyclists may experience pain in the buttock muscles when they are stretched in these tests, which suggests the need to examine the posterior structures for symptomatic myofascial trigger points or other extra-articular causes of pain. The high sensitivity of the hip pain provocation tests can assist in excluding intra-articular pain from the differential diagnosis; however the clinical utility of such tests has been questioned since data regarding sensitivity and specificity has only been confirmed in patient populations strongly suspected of having intra-articular pathology.[23] Other clinical tests include assessment of passive range of motion, with limited hip flexion range (typically 90-100°) and limited hip internal rotation range (typically 5-20°) with the hip flexed to 90° being commonly reported in patients with intra-articular pathology.[14,20] Loss of internal rotation range in the 90° flexed hip is often considered a sign of FAIS in patients with non-arthritic hip joints, with recent research suggesting that limitation of both hip flexion and internal rotation in flexion are more severe in men than women.[24] Nepple and co-workers[24] reported mean flexion ranges of 97° in women and 94° in men, and mean internal rotation in flexion of 16° in women compared to 7° in men.

When considering extra-articular causes of hip pain, in addition to hip pain provocation tests and assessing the pattern of range of motion loss, anatomic palpation forms an integral part of the examination,[7] especially when assessing for extra-articular hip pathology such as bursitis or myofascial trigger points. The diagnosis of myofascial pain relies on a history of pain aggravated by muscle loading, and examination findings that include all or most of the following: palpation of a taut band of skeletal muscle that contains a particularly tender spot; reproduction of the patients pain during palpation of the tender spot; a local twitch response to snapping palpation of the taut band; and limitation of muscle extensibility with or without pain.[8,25-26] Imaging may be used to exclude other diagnoses rather than to confirm myofascial pain.[26] Clinical observation indicates that cyclists presenting with a primary myofascial pain syndrome related to their sport typically present with buttock or hamstring origin pain that is aggravated by cycling load (either high volume, high intensity or riding with the torso in a lower position such as on a time trial bike which places the posterior musculature on greater stretch when pedaling); physical signs including variable restriction of hip flexion and flexion / adduction, absence of groin pain during acetabular rim provocation testing; palpable signs of myofascial trigger points; and negative imaging findings.

In differentiating myofascial pain from intra-articular hip pain in cyclists, clinical experience suggests that cyclists who present with posterior buttock pain without anterior pain are more likely to have a primary trigger point pain syndrome involving the posterior hip musculature. In contrast, trigger points in the anterior hip region of a cyclist which reproduce anterior hip pain on palpation may, in some cases, be a secondary phenomenon where the primary diagnosis is intra-articular hip pathology. Addressing the intra-articular pathology in the first instance may assist in the management of secondary anterior hip trigger points. Differentiation from lumbar spine and other sources of pain are a routine part of the clinical examination but are beyond the scope of this commentary.

Diagnostic imaging for the evaluation of symptomatic hip pain typically involves assessment of the distribution and grade of articular damage, evaluation of bone shape morphology that predisposes to articular wear and the assessment of associated non-articular or alternative diagnoses. Typically pelvic radiographs are considered a first line investigation of hip pain as structural irregularity or significant joint pathology (such as moderate to advanced arthritic wear) are easily observable with this method.[27] Evaluation of articular hip pathology such as hyaline cartilage or labral injury may be assisted with the use of MRI (with or without arthrography depending on the quality of the images obtained). Bone structure for assessment of FAIS is typically best evaluated by CT (with or without three dimensional or dynamic reconstruction).[27] There are significant limitations in the diagnosis of FAIS by static imaging modalities, with potential future development of dynamic imaging by either reconstructed cross sectional imaging or ultrasound offering the potential to demonstrate actual impingement. In cases of uncertainty relating to articular or non-articular causes of groin pain, diagnostic injection with serial clinical evaluation may be of assistance.[28]

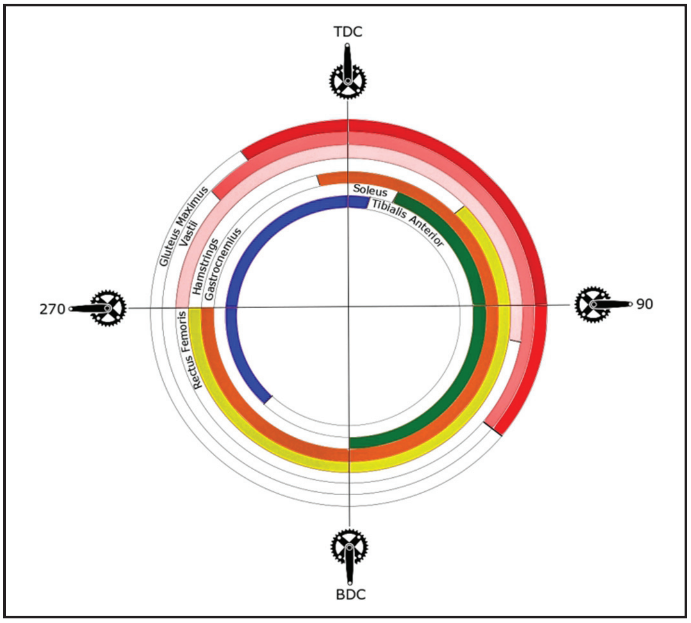
Management of intra-articular hip pathology may involve a combination of rest to unload the hip, Physical Therapy to manage muscle function and extensibility concerns, evaluating the fit of the bicycle to minimize the chance of anterior hip impingement and optimize function of the peri-articular muscles, intra-articular injectable therapies, and surgical intervention such as arthroscopy or hip arthroplasty in advanced articular wear. Managing extra-articular hip pain related to muscle trigger points may require a combination of approaches including unloading the hip via reduced cycling volume or intensity, optimizing position on the bicycle to de-load posterior muscles if they are being placed in an excessively elongated position when activated in the pedaling cycle, addressing any relevant muscle weakness or tightness, and treating any trigger points present via a number of different techniques such as trigger point pressure release, dry needling or injection needling.[8] The choice of interventions is usually tailored to the individual based on examination and history findings including those derived from a musculoskeletal screen noted below. A professional bicycle fit may assist in unloading the hip joint or improving hip muscle function via reducing the range of motion and muscular demands imposed on the joint by the semi-constrained position in cycling in which the cyclist is attached by their shoes to the pedals and in a forward leaning seated posture. Understanding the biomechanical and neuromotor control demands of cycling and how a painful hip joint and its musculature may respond to a change in cycling position forms the primary focus of this article.

CYCLING BIOMECHANICS

Kinematic and kinetic analyses of the cycling action have focused on the sagittal plane, where the majority of motion and power generation occurs.[29] The joints which require the greatest ranges of motion in the pedal stroke are the hip and knee. The knee undergoes approximately 75° of flexion, ranging from 110° flexion at top dead center (TDC) of the pedal stroke to 25-35° flexion at bottom dead center (BDC).[30] The hip has approximately 55° of sagittal plane motion, and the ankle joint 25° during the cycling action.[30] Absolute hip angle is rarely reported in the literature, its measurement being complicated by the forward trunk inclination of the rider and by the selection of anatomical landmarks utilized in different studies. However, peak hip flexion is attained at the TDC of the pedal stroke at an angle that can be sufficient to provoke pain in patients with symptomatic hip joint pathology.

During the power phase or downstroke, both the hip and knee joints extend in the sagittal plane while motion occurring at the ankle is more variable, typically moving into dorsiflexion in the first half of the power phase and plantar flexing late in the down stroke.[30] Force applied to the crank that results in forward motion of the bicycle occurs primarily between 10° to 170°, peaking at 90° or with the crank arm horizontal.[9] Propulsive forces are not usually applied during the upstroke, which corresponds to minimal EMG activity of the major leg muscles.[30] It is the contralateral leg pushing down during its power phase that creates propulsion whilst the ipsilateral leg is relatively relaxed in its upstroke. The primary propulsive muscles are the quadriceps, gluteus maximus, hamstrings and gastrocnemius muscles.[9,31]

The neuromotor control of pedaling is complex and involves both mono- and bi-articular muscles.[9] As shown in Figure 2, the mono-articular extensors of



Figures 2. *Muscle Activation During the Pedaling Cycle Typical onset, duration and offset of the major lower extremity muscles during cycling. Shaded areas denote period of muscle activation. The power phase or downstroke occurs from 10° after top dead center to 10° after bottom dead center of the pedal stroke. The recovery phase or upstroke is the other half of the pedal cycle. (TDC: top dead center or 0°, 90: 90° into pedal stroke; BDC: bottom dead center or 180°, 270: 270° into pedal stroke). Based on material published by So et al,[9] Hug and Dorel.[31]*

the hip and knee, the gluteus maximus and vastii, are co-activated from the top of the pedal stroke to approximately 100-130° and are considered to act as primary power producers.[31] Bi-articular muscles such as the hamstrings and gastrocnemius have a different pattern of muscle activation that might appear inefficient since they are activated at the same time as their mono-articular antagonist (the vastii).[31] This paradox likely occurs to assist in transfer of energy between joints at key moments in the pedaling cycle and to control the direction of force applied to the pedal.[31] For instance the bi-articular hamstring and gastrocnemius muscles co-activate during the downstroke and when pulling through the bottom of the pedal stroke, with the gastrocnemius (and soleus) acting to maintain the ankle and foot as a rigid level to transfer power (generated by the mono-articular muscles) to the pedal during the power phase.[9]

Neuromotor control of the lumbo-pelvic-hip complex in cycling has not been extensively studied, however there is emerging evidence linking aberrations in muscle activation and cycling posture to injury in cyclists.[32-34] The normal spinal posture in cycling is one of mild lumbar and thoracic flexion.[35] There is a well-recognized relationship between lumbar flexion postures and muscle activation in the lumbo-pelvic-hip complex, with excessive lumbar flexion being associated with myoelectric silence of the spinal extensors (flexion-relaxation phenomenon), typically occurring at 80% of maximum flexion range.[36-37] In seated lumbar flexion such as when cycling, relaxation of the extensors (erector spinae and multifidus) occurs significantly earlier in range (typically at 50% of maximum flexion range).[38] No studies have examined whether the deeper muscles of the abdominal wall such as transversus abdominus alter activation in response to lumbar flexion, although clinical observation suggests that cyclists whose spinal posture involves enough lumbar flexion to silence the spinal extensors also tend to have a palpably flaccid abdominal wall. Poor muscle activation in the torso musculature has been associated with poor power output to the pedals[39] and lumbar spine injury.[33] Moreover, there appears to be a relationship between increased muscle activation of the deep abdominal and multifidus muscles and recruitment of the gluteus maximus, with earlier onset[40] and greater magnitude[41] of gluteus maximus activation being demonstrated during non-cycling activities. Trunk posture may alter gluteal recruitment with a more forward inclination such as that present in cycling resulting in a higher level of gluteus maximus activation.[42] Since function of the peri-articular muscles is considered an aetiologic factor in hip disorders,[10] consideration of spinal posture and trunk muscle activation in addition to the range of hip flexion at the top of the pedal stroke is important when evaluating the cyclist with hip pain.

Clinical assessment of muscle function during a dynamic activity such as cycling relies on observatory and palpatory skills. With respect to bike fitting, factors that have been shown to influence the posture of the lumbo-pelvic-hip complex and thus may have an influence on muscle activation include saddle design,[43] saddle tilt,[44] saddle height[45] and a lower torso position such as riding in the drops (hands in the lowest curved section of the handlebar).[46]

Furthermore, altering the position of the cyclist on the bicycle has been shown to alter muscle recruitment[45,47] and hip joint load,[48] implying that helping the rider to achieve an appropriate spinal posture and pattern of muscle recruitment without exceeding the anatomical limits of the hip joint is one of the considerations required when fitting a rider to their bicycle.

PRINCIPLES OF BIKE FITTING AND CLINICAL ASSESSMENT OF CYCLING BIOMECHANICS

When fitting a bicycle to a cyclist, a multitude of inter-related factors require consideration since changing the cyclists position on the bike results in changes in joint range of motion, muscle length and moment arms of the muscles actively producing force for pedaling,[49] which in turn may affect injury risk at different joints or muscles and cycling performance. The demand requirements of the cyclist (racing vs recreational), and the type of bicycle (road, time trial, triathlon, track, mountain bike, touring) all influence any decisions about rider position. A key determinant of cycling position is the amount of anatomic hip flexion available, with cyclists who have a limitation of hip flexion unable to achieve the same position and posture on a bicycle in comparison to more flexible cyclists. The amount of hip and lumbar flexion available will influence the torso angle obtained, with racers preferring a low torso angle for aerodynamic benefits. This position requires significantly greater hip flexion range than the more upright torso position favored by recreational and touring cyclists. For competitive road and track cyclists, compliance with the regulations of the governing body[50] is required. These regulations differ from those of the triathlon governing body.[51]

STEPS IN THE BIKE FITTING PROCESS

During a bike fit, the cyclist's history is taken and two physical examinations with differing aims are performed in the office setting prior to assessing the cyclist on their bike. The first examination is to assess for pathology and identify a potential diagnosis. The second examination measures anthropometric and musculoskeletal variables which are used to inform the bike fitting process. Measurements defining the current dimensions of the cyclists' bicycle and shoes are then recorded. Observational assessment of the cyclist and their posture and dynamic movement on their own bicycle then occurs, followed by objective measurement of the pedaling action including joint angles of the cyclist at key points in the pedaling action. Once this thorough assessment process has occurred, interpretation of all of the factors including history, examination and cycling mechanics should enable the physical therapist to determine the appropriateness or otherwise of the current position and the relationship to symptoms, and adjust the fit of the bicycle to the rider in as optimal manner as possible. Finally the cyclists' bike is re-measured and a report detailing their position provided, which affords the cyclist the opportunity to check their set-up following travel with their bike or following a mechanical service of the bicycle.

MUSCULOSKELETAL EXAMINATION

Physical examination of the musculoskeletal characteristics of the cyclist are obtained prior to performing a bike fit. Determining the anatomical limits to joint motion and muscle length will help to define what position a cyclist can attain on their bike without requiring compensatory movements which tend to result in injury and inefficiency. Cyclists require a large degree of hip and knee flexion, as well as ankle plantar flexion, lumbothoracic flexion and neck extension. A key determinant of cycling position is the amount of anatomic hip flexion available. Hip flexion is maximal at TDC of the pedal stroke, and will be influenced by factors such as crank length, torso inclination and handlebar reach and drop (Figure 3, Figures 4A and 4B). A useful screening test that mimics the lumbar and hip flexion requirements at the top of the pedal stroke in cycling is the seated toe touch test performed with knees straight. A normal minimum value of >3cm (fingertips beyond toes) has been reported in other athletes.[52] This test requires lumbar and hip joint flexion, and flexibility of the gluteal, hamstring and spinal extensor musculature. Differentiation of the different components is then made. Hip flexion, which is influenced by both gluteal length and hip joint range, is measured in supine with a goniometer and recorded as the maximum angle of flexion obtained prior to pelvic motion occurring. Normal

Figure 3. *Bicycle Terminology*
sH: *saddle height, measured in millimeters (mm) from the center of the crank axle to the top of the midpoint of the saddle.*
sS: *saddle setback, measured in (mm) as the horizontal distance between a vertical line projected from the center of the crank axle to the tip of the saddle.*
sT: *saddle tilt, measured in (mm) from the horizontal (saddle nose is usually level or tilted downwards).*
CL: *crank, length measured in (mm) from center of crank axle to center of pedal axle.*
Stem: *handlebar stem, described as length in (mm) and angle (˚). Stems are available in a range of lengths and angles and join the handlebars onto the steerer tube. A negative angle indicates the stem is orientated downwards; a positive angle indicates the stem is orientated upwards to elevate the handlebars.*
tt: *top tube section of bicycle frame.*
Hd: *handlebar drop, measured in (mm) from the centre of the top of the saddle to the top of the handlebars immediately adjacent to the stem.*

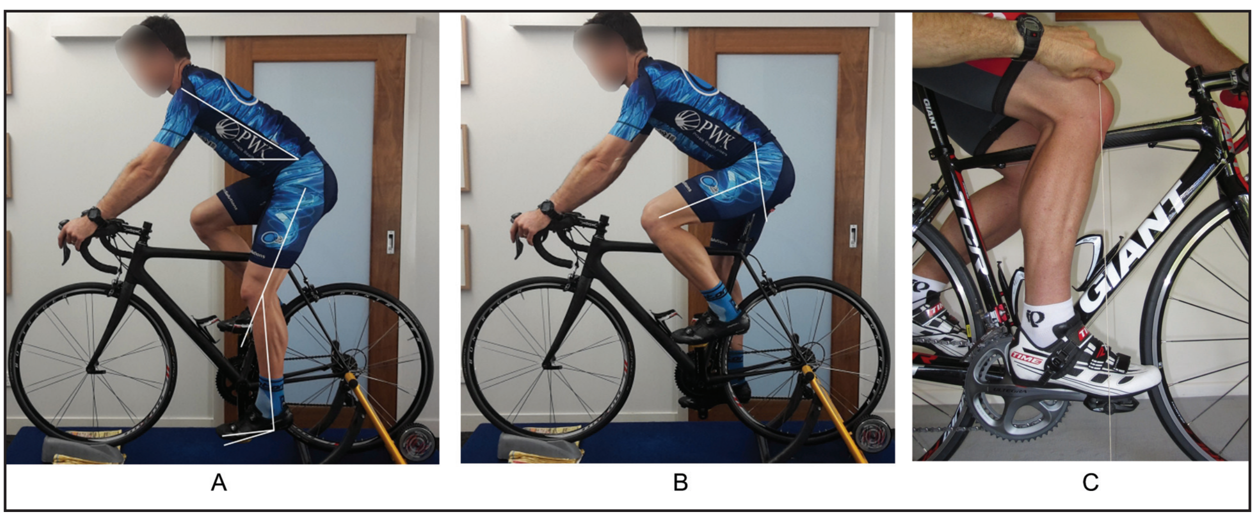


Figure 4. *Selected Measures Obtained at Key Moments of the Pedal Stroke*
(A) Selected kinematic measurements at bottom dead center of the pedal stroke
Angles of ankle plantar flexion, knee flexion and torso inclination are shown.
(B) Angle of hip flexion measured at top dead center of pedal stroke
Angle of hip flexion is the acute angle.
(C) Measurement of saddle fore-aft position (in mm).
With the crank and foot horizontal, a plumb line from the distal end of the femur (lateral femoral condyle) is compared to the center of the pedal axle.

is regarded as ≥120° prior to pelvic motion,[53] with landmarks used for measurement being the center of the iliac crest, greater trochanter and center line of the femur at the knee joint. In the presence of hip pain the angle of pain-free hip flexion is noted. Hamstring length is measured via passive straight leg raise until pelvic motion occurs, with normal being considered 70-80°.[54] Hip rotation range is measured, with a limitation of internal rotation of <20° with the hip flexed to 90° being suggestive of FAIS, and limitation of internal rotation in both the 90° flexed and 0° hip positions being suggestive of acetabular/femoral retroversion. Both patterns of motion loss suggest the possibility of a bony block to motion. If a *bony* block to hip flexion is suspected the position chosen for the rider during the bike fit must accommodate the lack of flexibility, as it is not possible for the rider to improve their range under this circumstance.

Examination of muscle strength and neuromotor control involves assessment of gluteal and abdominal muscle function, particularly in athletes who have a hip or lumbar complaint related to cycling. The screening tests employed for this purpose include the abdominal side plank endurance test using the method described by Evans and colleagues.[55] They report an isometric endurance time of ≥90 seconds in uninjured athletes. For gluteal function, a modified version of the repeated single-leg squat test is used.[56-57] In this test the athlete is rated upon their ability to control five repeated single leg squats on a decline board (which serves to eliminate any limitation of ankle dorsiflexion which can alter the lower extremity control in this test).[58] In addition to using a decline board the other modification we apply to this test is palpation of the gluteus maximus and medius muscles to assess level of contraction. Failure to strongly activate the gluteals results in the test being recorded as poor gluteal function irrespective of whether the athlete can control the motion using other strategies such as recruiting the quadratus lumborum. During the bike fit, correlation of clinical tests of muscle function with palpation of lateral abdominal, multifidus and gluteal contraction when pedaling is performed. The measures of flexibility and muscle function above can be used to guide the physical therapist in clinical decision making and offering musculoskeletal interventions including a home exercise program as required to assist in optimizing muscle control of the pelvis and spine when pedaling or to address deficits which might be relevant for treating any pathology identified.

EXAMINATION OF SKELETAL AND ANTHROPOMETRIC VARIABLES

Analysis of anthropometric characteristics and skeletal alignment are performed. Aberrations in alignment such as genu varum or valgus, tibial varum and torsion, and structural foot alignment such as rearfoot varus, forefoot valgus or other well recognized variations are evaluated.[59] Skeletal alignment has the potential to alter cycling kinematics and may, in some cases, contribute to a range of overuse cycling injuries which the physical therapist may need to account for in the bike fit. As an example, in the presence of excessive external tibial torsion, the cyclist is likely to benefit from a cleat position which positions the foot with a greater angle of external rotation to more closely align with the angle of the cyclists' bone structure.

Anthropometric variables measured include arm, leg and torso lengths, which can provide an initial guide for a starting position during the fit. Note that these static measurements are not accurate for producing an ideal saddle height[60] as factors such as the amount of soft tissue present between the saddle and ischial tuberosities, relative proportion of femur to tibia length, and the cyclists motor program may all result in a different position to that suggested by a simple measure of leg length. To illustrate this point a cyclist whose preferred pedaling technique involves more ankle plantar flexion than another cyclist of identical leg length (with all other things being equal) will require a higher saddle height. Anthropometric proportions are also of importance; for example if the relative proportions of the cyclist involve long legs and short arms, a relatively high saddle height with minimal drop or reach to the handlebars is likely required, which may necessitate a frame with a taller head tube. Note should be made as to whether a structural (skeletal) leg length discrepancy is present, as this may influence lower extremity and spinal motion when the cyclists' body is forced to adapt to a symmetrical machine, especially if the cyclist is using clipless pedals where the shoes are clipped into the pedals and the feet are relatively fixed. In cyclists with hip pathology and a leg length discrepancy, the longer leg will have a greater hip flexion angle at the top of the pedal stroke which may aggravate symptoms associated with FAIS.

BIKE FITTING: OBSERVATIONAL ANALYSIS

To perform a bike fit, the cyclists own bicycle is placed on a stationary trainer ensuring the front wheel axle is level with the rear, with a book, block or shims typically being required to achieve this (Figure 3). Alternatively an adjustable fitting bike such as Exit (http://www.exit-cycling.com/EXiT-Fit-Bike-MkII) or Retul Muve (https://www.retul.com) may be used, which is a stationary bike in which frame and crank dimensions can be altered by the physical therapist. A fitting bike can be especially helpful for a cyclist who might be seeking an opinion prior to purchase as to which position and frame geometry might best suit their individual needs. Visual analysis of the pedaling action is performed from the side, front and rear aspects, noting any aberrant mechanics prior to taking careful measurements of joint motion. For example, a cyclist whose posture involves excessive posterior pelvic tilt with marked lumbar and thoracic kyphosis, and whose movement is associated with deviation of the knee in the frontal plane into an abducted / externally rotated position at the top of the pedal stroke, would be considered to have abnormal posture and movement that might indicate that their range of hip flexion is being exceeded. Table 1 lists some common biomechanical changes that might indicate a limitation of hip flexion or an attempt to avoid hip pain. Palpation of the multifidus, lateral abdominal and gluteus maximus muscles to assess for presence or absence of contraction may be performed at this time, and correlation with lumbopelvic posture noted.

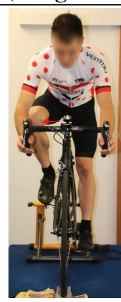
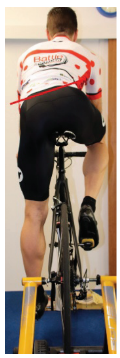
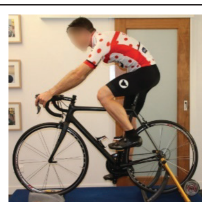
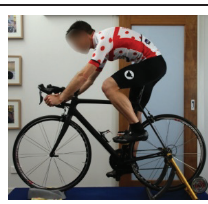
BIKE FITTING: MEASUREMENT OF JOINT ANGLES

Measurements of cycling mechanics, particularly joint angles, are performed on the cyclist's own bike on a stationary trainer. The purpose of the bike fit is to optimize the position of the rider on the bicycle with respect to comfort, power production, postural stability, aerodynamics and bike handling characteristics, and to optimize biomechanics of the athlete with respect to any injuries present without compromising other segments of the body. In other words, a bike fit in which changes are made to unload a symptomatic hip at the expense of creating an overuse injury of the knee or low back is not a desirable outcome.

In establishing an appropriate position on the bike, the aim is to ensure that joint motion is within both the anatomic limits of the individual and within an appropriate range that is considered to result in a comfortable cycling position that enables good postural stability, power and aerodynamics. The "appropriate range" of motion and posture is generally based on empirical experience as there remains a limited level of scientific literature to guide all decisions.[49] Joint angles are measured at key moments in the pedaling action. Measurement can be made via several means which are broadly classified into "dynamic" and "static". Dynamic measures include video analysis with post-hoc measurement using software tools such as Dartfish (www.dartfish.com), or measurements obtained via motion sensors and custom software made specifically for cycling such as Retul (www.retul.com). Static measurements of joint angles aim to take the exact same measures but involve having the cyclist stop pedaling at the point of interest in the pedaling cycle (such as bottom dead center) while the physical therapist uses a goniometer or inclinometer such as Halo (www.halomedicaldevices.com) to record joint angle. When making static manual measurements extreme care is taken to stop the cyclist at the key point in the pedal stroke with all joints in the same position as when moving, which is a skill that requires considerable practice for the physical therapist to develop such that their measurements are both accurate and repeatable. Similarly, accuracy in placement of motion sensors or markers for video analysis affects accuracy in dynamic methods of measuring of joint angles.

Normal values for joint postures in the upper body whilst cycling on a road bike have received little attention in the literature, but are thought to include a shoulder to torso angle of ≤90° flexion when riding on the hoods (the hoods being the brake/gear levers fixed to the handlebar).[61] The landmarks used for this measurement are the center line of the humerus,

Table 1. *Possible clinical observations in cyclists with hip pain or limited hip flexion range.*

	Photograph Demonstrating Biomechanical Fault (Exagerrated)	Observation Suggesting Hip Pain/ Tightness	Possible Alternative Causes for Deviation
Cycling: front view		• Knee abduction / external rotation	• Saddle: height too low • Handlebars: too low • Crank length: too long • Habitual movement pattern
Cycling: rear view		• Pelvic rocking: ipsilateral ilium rises at TDC of pedal stroke	• Saddle: height too low or too high, saddle width too narrow • Handlebars: too low • Crank length: too long • Poor torso control / posture / coordination
Cycling: side view		• Posterior pelvic tilt & associated spinal flexion posture	• Saddle: tilted upwards, or non-ergonomic shape causing perineal discomfort with anterior or neutral pelvic tilt • Handlebars: too close to saddle or too low • Crank length: too long • Poor torso control / posture / coordination
Exacerbation of pain or difficulty riding in drops or getting into time trial position (i.e. unable to cope with positions requiring increased hip flexion range)		• Any of the above deviations (alone or in combination)	• Handlebars: too low or too far away • Crank length: too long • Poor torso control / posture / coordination

center of the shoulder joint and the center of the iliac crest. The elbows are slightly flexed to help absorb shock. Normal spinal posture on the bicycle is one of mild lumbar and thoracic flexion with moderate neck extension.[62] There is minimal lateral rocking of the pelvis (essentially stable to visual observation) and no pelvic rotation, with the absolute range of pelvic lateral rocking or rotation being in the order of

2-6°.[46] The spine is stable whilst pedaling. The angle of trunk inclination in a competitive road cyclist approximates 38° +/- 5°.[63-64] The dynamic range of the lower extremity joints includes knee extension at BDC of 30° (range 25-35°) and flexion of 110° at TDC. The landmarks used to measure knee joint angle are the center of the greater trochanter, center of the lateral joint line of the knee, and center of the lateral malleolus (Figure 4A). Hip flexion angles are unclear in the literature but peak flexion occurs at TDC. Clinical measurement of maximal hip flexion values obtained using the methodology below for uninjured cyclists range from 65-90° at TDC depending on the cyclists own anatomic limits, athletic ability, type of bicycle and preferred position.

Anatomic hip flexion measured on the bicycle is not, to our knowledge, described elsewhere in the literature and warrants further description. This measure is performed by first marking the center of the iliac crest (marked at the top of the crest as the point bisecting the line between ASIS and PSIS). We use the same landmarks for measuring anatomic hip flexion on the bike as we use clinically when measuring the athlete in supine (center line of femur at the knee joint, center of greater trochanter and center of iliac crest). Many bike fitters, when performing static measurements, use the line of the femur, greater trochanter and angle of inclination of the sacrum which is not an anatomic angle of hip flexion and does not correspond to the hip flexion angle measured in supine. In patients with hip pain, anatomic flexion is a crucial measurement which must be accurate and directly comparable between clinical and cycling measures. The maximum angle of hip flexion required in the pedaling action occurs at the top of the pedal stroke and this is where hip flexion range is measured (Figure 4B). The physical therapist has the cyclist stop pedaling and apply their brake with the crank at TDC, and maintain their position for measurement without altering ankle angle. Once measures of joint range and other observations are made, analysis of the information and decisions about adjustments to the bicycle are made.

BIKE FITTING: ADJUSTING THE BIKE TO FIT THE CYCLIST WITH HIP PAIN

Adjusting the bike to fit the cyclist in an individualized manner can result in improvements in pain and performance. The hypothesized mechanisms for clinical improvements are thought to be via improved biomechanics such as reducing excessive hip flexion, or improvements in neuromotor control via improved posture and improved muscle length-tension relationships. In a bike fit this may be achieved via adjustment of the three major contact points between the cyclist and the bicycle, which are the position of the saddle (including height, fore-aft position, tilt), the cleats (including fore-aft position, medial-lateral position, rotation) and the handlebars (reach from the saddle, drop from the saddle). In addition alterations can be made in the dimension of components including frame size and style, crank length, saddle shape and width, and handlebar size and style. Different seat posts (offset and non-offset) and stems of differing angles and lengths are available to assist in obtaining an optimal position. Completing a bike fit is a complex task since changing the location of one contact point such as the saddle alters its three dimensional relationship in space to the other contact points and alters the angles and muscle lengths of all body segments in the cyclist. The methodology for completing such a complex task is to obtain the ideal cleat and saddle position initially as these factors determine key variables such as power output and postural stability, with the handlebars being considered only after these decisions have been made. In this commentary we will focus on saddle position, handlebar position, and crank length, as they have the greatest effect on sagittal plane motion and thus the greatest potential to influence hip kinematics and hip pain. In other pathologies such as knee or foot pain, greater priority might be given to cleat positioning, cleat wedges or custom foot orthoses since frontal and transverse plane deviations are considered to have a higher impact on the knee and foot joints, with no studies having demonstrated a significant impact on hip joint angles in cyclists.[65]

SADDLE POSITION

Saddle Height and Tilt

The literature contains multiple methods for determining saddle height.[49] Some rely on formulas based on static measurements such as trochanteric height, ischial tuberosity height or inseam,[66-69] although these methods if used on the one individual tend to produce variable saddle heights.[70] Reliance on static measures alone for determining saddle height frequently fails to produce an ideal saddle position as it fails to account for dynamic motion whereby, for example, some cyclists may produce power best with more ankle dorsiflexion than others and thus require a different saddle height. Similarly, cyclists with the same skeletal leg length but more soft tissue in the gluteal region will likely require a different saddle height and fore-aft position compared to very lightly muscled athletes as they will be sitting on a differing amount of tissue. Traditional methods based on static measurements, whilst inaccurate, may be used to obtain a very approximate starting saddle height with which to begin the fit.

In determining optimal saddle height based on review of the scientific literature, setting the saddle such that 30° of knee extension at the bottom of the pedal stroke as measured by a goniometer is recommended.[49] In this position the cyclists' pelvis should be stable (not tilted downwards in order to reach the pedal) and the ankle angle between 0-18° of plantar flexion[71] (Figure 4A).

The angle of tilt relative to the ground of the saddle can significantly influence spinal posture and perineal comfort.[44] The saddle is mounted to the bike with no tilt initially, although once the fit is completed some saddle shapes may require the nose of the saddle to be tilted downwards 1mm to 6mm (or more depending on saddle brand/shape) for the rider to achieve perineal comfort. Excessive downward tilt, or for most saddles or any amount of upward tilt, tends to increase the risk of saddle soreness. In addition to perineal discomfort, excessive downward tilt can increase the amount of weight bearing on the arms resulting in upper quadrant complaints.

Saddle Fore-Aft Position

Once saddle height is determined by obtaining the optimum knee angle at the bottom of the pedal stroke, saddle fore-aft position is determined. As shown in Figure 5B, a saddle that is excessively rearwards increases the angle of hip flexion required and places greater load on the hamstring and gluteal muscles for propulsion. This may lead to either myofascial complaints in the posterior hip musculature, or may exacerbate intra-articular hip pain. A saddle that is excessively forward (Figure 5A) places greater load on the quadriceps and extensor mechanism and increases the angles of knee flexion required. An ideal fore-aft position seeks a balance of forces that, as far as possible, shares the workload between the three prime movers (gluteus maximus, quadriceps and hamstrings), and shares the joint

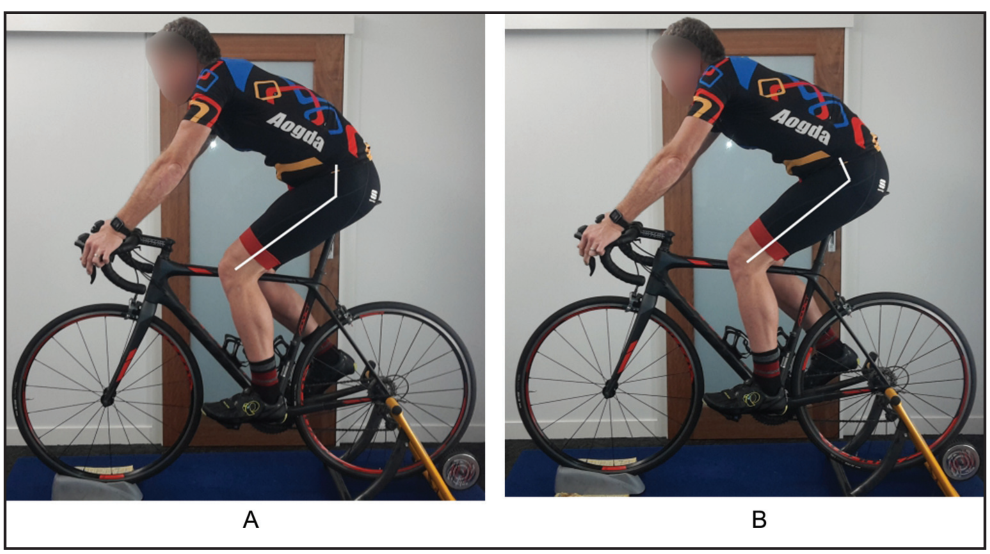


Figure 5. *Effect of Changing Saddle Fore-Aft Position on Hip Joint Angle*
The only difference in cyclist position between Figure 5A and Figure 5B is saddle fore-aft position. With the saddle maximally forwards (Figure 5A) less hip flexion is required. In Figure 5B the saddle has been moved maximally rearwards requiring greater hip flexion during the pedal stroke. Note the concomitant effect on lumbar posture and shoulder angle of this single change.

loads more evenly between the hip and the knee. In cyclists with limited hip flexion range the bias in the bike fit is towards a more forward saddle position to reduce the level of hip flexion required[72] which in turn reduces the chance of anterior impingement and reduces the length over which the posterior musculature must operate if symptomatic gluteal or hamstring trigger points are present.

Measurement of fore-aft saddle position relies on the "knee over pedal spindle" measurement, although this aspect of bike fitting has received much less attention in the literature compared to saddle height. To obtain this measurement, after a warm up period of pedaling and observation has occurred and the cyclist is sitting comfortably on their saddle, the cyclist is asked to stop pedaling. Once the cyclist has stopped pedaling the physical therapist ensures that the cyclist is sitting level on their saddle in their usual position (i.e. without pelvic tilt or rotation and without having slid forwards on the saddle), and uses a spirit level to assist the cyclist to get the crank arm horizontal and sole of the foot horizontal (Figure 4C). A vertical plumb line from the distal femur (lateral condyle at the patellofemoral joint line) is then compared to the centre of the pedal axle. With the exception of time trial positioning, the most anterior saddle position is generally regarded as 0mm (i.e. "knee over pedal spindle")[73] since a more forward saddle position will increase knee joint load.[74] Athletes with more flexible hips and no hip pain may benefit from a more posterior saddle position than this classic "neutral" setback. In certain road and track events there are limitations as to how forward the saddle may be placed, and familiarization with these regulations[50] is essential for the physical therapist who is involved in managing a competitive cyclist.

CRANK LENGTH AND HANDLEBAR POSITION

Once cleat and saddle position have been determined, handlebar position and crank length require consideration. Crank length and handlebar position can alter the posture of the rider on the bike,[75] and can also influence the range of hip flexion required at the top of the pedal stroke (where maximal hip flexion is attained in the pedaling cycle).[76] Greater hip flexion is required if a longer crank length is selected, or if the handlebar is lowered or moved further away relative to the selected saddle position. Handlebars that are too low or too far away from the saddle may exceed the hip flexion range or the reach of the cyclist, resulting in a range of possible adaptive movements or postural changes to reach the bars. For example the cyclist may increase the level of anterior pelvic tilt and hip flexion if this range is available, both of which are likely to aggravate hip pain and the anterior tilt (if excessive) may lead to perineal pain via compression of the ischiopubic rami and perineal soft tissues against the saddle. Conversely posterior pelvic tilt accompanied by increased lumbar and/or thoracic flexion may occur, leading to additional neck extension which may cause pain in the upper quadrant. Other possibilities include abduction of the knees/hips at TDC to permit increased hip flexion (which may cause knee pain) or lateral rocking of the pelvis (which may lead to back pain).

The maximal level of anatomical hip flexion at TDC on the bike can be used as a guide to assist in selecting handlebar position and crank length. The risk of causing hip pain via poor positioning and the likelihood of compensatory motion are both reduced if the physical therapist ensures that the maximal level of hip flexion is within a safety margin of 15-20% or at least 15° *less* than the athletes maximum measured range in supine. For example, if the cyclist has 90° of hip flexion (without obligatory external rotation or abduction) as measured supine then a maximum anatomical level of flexion at TDC of the pedal stroke with the hands on the brake hoods should be ≤75° using the landmarks outlined above. When fitting the cyclist in this way the additional range of anatomical hip flexion available enables the cyclist to ride with their hands in the handlebar drops, a position which requires greater anterior pelvic tilt and hip flexion range. The angle of hip flexion required while cycling in the drops can be measured to ensure that the pain-free range available to the cyclist is not exceeded in this lower torso position.

Handlebars and cranks come in a range of sizes, and making an appropriate selection may assist the cyclist with hip pain. Selecting a bar of appropriate width (equal to the acromial width of the cyclist)

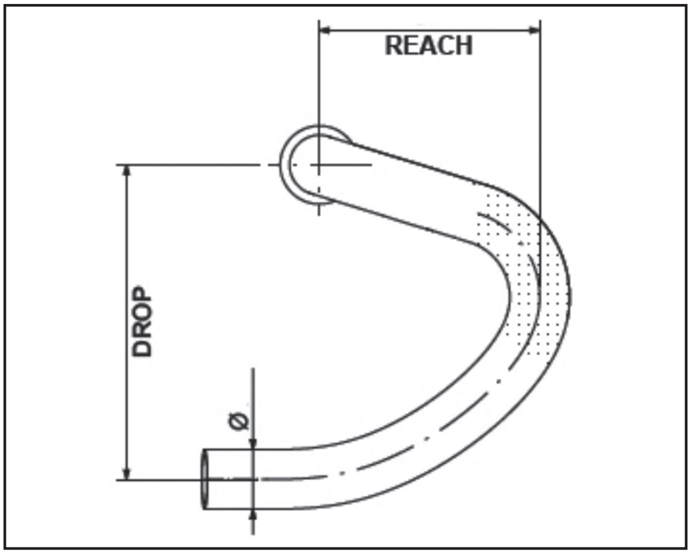


Figure 6. *Handlebar Drop and Reach*
Side view of road/track handlebars illustrating drop and reach (also termed throw). Shallow drop (120-130mm) and short reach (70-80mm) are desirable for cyclists with limited hip flexion range.

that is both shallow drop and short reach (Figure 6) will make it easier for a cyclist with hip pain or limited hip flexion to reach the bars more easily. If the handlebars are raised as far as is able on the cyclists' bike, and assuming that the frame is of an appropriate geometry, then shortening crank length may be required to permit pain-free cycling. Cranks are made in 2.5mm increments with the major manufacturers offering sizes from 165mm to 180mm. Shorter lengths including 145mm, 155mm, 160mm are also available. Most flexible elite male cyclists ride 170, 172.5 or 175 mm crank lengths. However for riders with shorter legs or inflexible hips or hamstrings, a shorter crank may be required in order that the hip flexion range of the cyclist is not exceeded at the top of the pedal stroke. Determination of ideal crank length may require the use of a fully adjustable fitting bike which has an adjustable crank arm length. Note that shortening crank length will require the saddle and handlebar height to be re-evaluated once the shorter cranks have been fit; for example shortening the crank by 5 mm would typically require the saddle to be raised by 5 mm. As with all decisions regarding ideal fit of the bicycle, in selecting crank length it is important that a smooth pedaling movement is obtained without unwanted compensatory movement of other body segments. For example excessively long cranks may cause compensatory abduction and external rotation of the knee whilst pedaling, excessive posterior pelvic tilt with associated spinal flexion and neck extension, excessive pelvic lateral tilting ("rocking" on the saddle), or a combination of these movements. Considerations in the bike fit specifically for patients with hip pain or limited flexion range are summarized in Table 2. Figure 7 demonstrates the differences in position before and after a bike fit in a patient with anterior hip impingement pain.

CONCLUSION

Professionally fitting a bicycle to a cyclist is a complex task, particularly if the cyclist has an injury.

Figure 7. *Improved Position in a Cyclist with Hip Pain Following a Physical Therapy Bike Fit. (A) Position before bike fit, (B) Position after bike fit*

Table 2. *Considerations for fitting the bicycle to cyclists with hip pain or limitation of hip flexion range.*

Component / Adjustment	Recommendation for Cyclists with Hip Pathology or Restricted Range	Effect of Recommendation
Frame size and style	• Endurance geometry: high frame stack height relative to frame reach	• Permits higher handlebar position to reduce hip flexion required at TDC
Saddle height	• Same height with respect to BDC measurements as other cyclists	• Optimizes power output to pedals • Excessively low saddle requires greater hip flexion at TDC compared to optimal saddle height
Saddle fore-aft position	• Anterior position 0mm (classic "knee over pedal spindle" position)	• Minimises hip flexion required at TDC (minimizes risk of anterior impingement); • Gluteals & hamstrings not forced to contract in an elongated position (reduces risk of developing myofascial trigger points)
Crank length	• Typically shorter than flexible, pain-free cyclist of same leg length	• Minimises hip flexion required at TDC
Handlebar size & style	• Short reach • Short drop	• Less hip flexion required at TDC to reach handlebars, reduces elongation of posterior musculature during cycling
Handlebar position	• Minimal drop from saddle to handlebars	• Minimises hip flexion required at TDC
Brake hood length	• Shorter (60-65mm)	• Longer brake hoods require greater reach & greater hip flexion at TDC
Ensure hip flexion at TDC is ≤80% of patients anatomical limit	• This is recommended for all cyclists irrespective of the presence of hip pain	• Forcing the cyclist to pedal at or near the limit of joint range results in undesirable compensatory movements prior to the actual limit of flexibility being reached
Low sole thickness (stack height) of cycle shoe	• Thinner soled shoes are desired	• Minimises hip flexion required at TDC
Structural (osseous) leg length inequality (of cyclist as measured by CT scan)	• Correction via cleat shim, in-shoe shim or differing cranks lengths (or combination of the above)	• Enables saddle height to be set for the long leg (minimizing hip flexion at TDC); enables the short leg to still reach the pedals

BDC= Bottom dead center of the pedal stroke (crank at 6 o'clock position).
TDC= Top dead center of the pedal stroke (crank at 12 o'clock position).

This necessitates the involvement of a physical therapist trained not only in movement analysis and pathology but one who has received additional practical training in fitting a bicycle. It is common for doctors and specialists to refer to a qualified physical therapist for this service. Multiple considerations specific to fitting a bicycle to a cyclist with hip pain have been presented, including specific measurements and their methodology, and considerations relevant for incorporating clinical findings into the bike fitting process. Typical areas of focus during a bike fit for a cyclist with hip pain include selecting crank length, handlebar size and handlebar position that do not exceed the athletes' range of hip flexion at the top of the pedal stroke; ensuring that the height of the saddle is not too low or that the fore-aft position of the saddle is not excessively rearwards which requires greater hip flexion range and requires the posterior hip musculature to contract at a longer length; ensuring that the pedaling action is smooth without compensatory movements in the hip or other joints; and ensuring that the lumbo-pelvic posture permits low level contracture of the torso musculature such as transversus abdominus and multifidus whilst pedaling along with recruitment of the gluteus maximus in the power phase. In an injured cyclist, an important overall aim of the bike fit is to eliminate the bicycle as a cause of the cyclists' symptoms, meaning that any remaining issues are likely related to impairments in the neuromotor control or musculoskeletal attributes of the cyclist. A physical therapist is then able to assist the cyclist in addressing these components as indicated.

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