# Cycling Biomechanics: A Literature Review

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*This review of current literature on cycling biomechanics emphasizes lower extremity muscle actions and joint excursions, seat height, pedal position, pedaling rate, force application, and pedaling symmetry. Guidelines are discussed for optimal seat height, pedal position, and pedaling rate. Force application in the power and recovery phases of cycling and the relationship of force application to pedaling symmetry are discussed. The need for a biomechanical approach to cycling exists since a great deal of the literature is primarily physiologic in nature. The purpose of this review is to make cyclists and their advisors aware of the biomechanics of cycling and guidelines to follow. This approach is also important because cycling is a very common form of exercise prescribed by physical therapists for clinic or home programs. Biomechanical aspects of cycling should be considered by cyclists at any level of participation and by physical therapists in order for goal-oriented, efficient cycling to occur.*

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Whether a cyclist's goal is rehabilitation, recreation, or racing, cycling can play a primary or secondary role in achieving that goal. Certain biomechanical aspects need to be considered to ensure injury-free, goal-oriented cycling. The rehabilitation of any of the lower extremity joints is often geared toward increasing the joint's range of motion and strength. Cycling can augment rehabilitation and help control certain lower extremity stresses. Whether recreational cycling is a progression from rehabilitation or a long-term fitness activity, it may be the role of the physical therapist to advise patients on biomechanical aspects, including seat height, pedaling rate, and/or pedal position. These considerations become particularly important for the competitive or cross training cyclist who focuses on overall efficiency. The purpose of this review is to discuss topics such as optimal seat height, pedal position, pedaling rate, force application and symmetry, and the muscle actions necessary for proper joint excursions in cycling.

## REVIEW OF LITERATURE

### Joint Excursions

The range of motion at the hip joint during cycling, unlike hip motion during other forms of exercise or activity, occurs only in the flexion part of the range of motion. For example, the hip extends approximately 35° and flexes about 25° during moderately fast running (2). Several researchers have examined total joint motions during cycling (Table 1). The smaller amount of hip flexion recorded was 28–30°; the greatest amount was 90° (2,13). Instead of continuing to flex past 90°, the hip begins to internally rotate and adduct. Additional hip flexion causes an unstable pelvic position due to the small base of support from the seat and the extended position of the opposite lower extremity (13).

In a study by Houtz and Fischer, the seat heights were 21 and 25 inches from the center of the pedal spindle (13). In Cavanagh and Sanderson's work, the seat height was an experimental variable; however, specific measurements were not stated (2).

The knee joint, like the hip joint, never reaches full extension, although maximum knee and hip extension occur simultaneously (13). Cavanagh and Sanderson found 74° of total knee motion, with the mean values of 37° knee flexion at 180° in the pedaling cycle and 111° flexion at the 0° crank position (2) (Figure 1). In an earlier study, Houtz and Fischer found 40–65° total knee motion in cycling (13). The increased range of motion reported by Cavanagh and Sanderson may have been due to the fact the riders studied were elite pursuit cyclists riding with their trunks positioned about 35° from the horizontal (2). The subjects in the study by Houtz and Fischer were riding stationary bicycles with upright handlebars (13). The knee ranges, along with those at the hip and ankle, will change as riding conditions change, such as during hill climbing, when the cyclist pedals while off the seat.

In terms of ankle motion, a difference has been found in what had been recommended and in what experienced cyclists actually did. The technique called ankling was often recommended. It involved pushing the pedal across the top of the pedaling cycle (0°) with the foot in the

| | Total Hip Motion | Total Knee Motion | Total Ankle Motion |
|---|---|---|---|
| Cavanagh and Sanderson (2) | 43° | 74° | 50° |
| Houtz and Fischer (13) | 20-40° | 40-65° | |

**TABLE 1:** *Lower extremity joint excursions during cycling.*

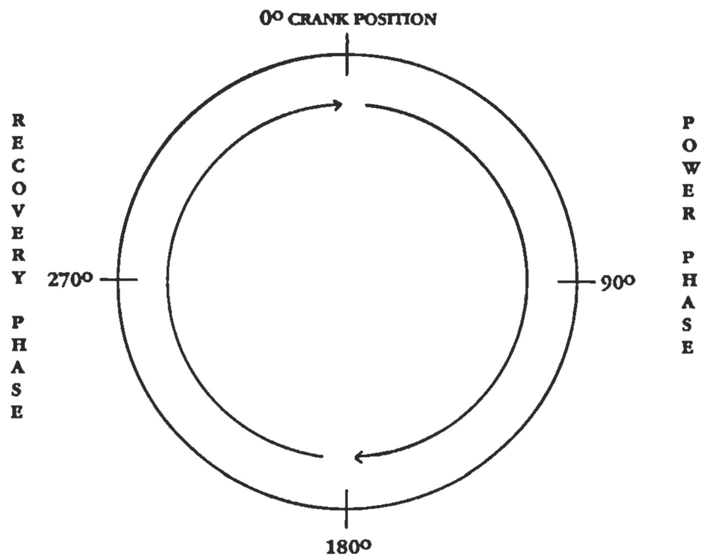


**FIGURE 1:** *The two phases of the pedaling cycle. (Adapted from Faria and Cavanagh (9).)*

dorsiflexed position and pulling across the 180° point of the cycle with the foot plantarflexed (9). Houtz and Fischer indicate maximum dorsiflexion occurs with maximum hip and knee flexion during the 337–23° crank position. Plantarflexion is said to occur maximally at the end of the hip and knee extension phase, just as hip and knee flexion begins past the 180° crank position (13). Toe clips were not used in this study.

In the study of elite riders, the pedal orientation went only slightly below the horizontal into the heel-down, dorsiflexed position. The heel-down position occurred at the 90° position of the crank. The maximum plantarflexed position occurred at approximately 285° (2). Traditionally, studies have suggested that the heel should be dropped (dorsiflexion) during the 330–30° position, and the toes should drop (plantarflexion) across the bottom part of the pedaling cycle (2,13). Cavanagh and Sanderson conclude that this ankling pattern is anatomically and mechanically impossible if the rider remains in the seat. These researchers found the total ankle motion to be approximately 50°. The range, with 90° being equal to the neutral position, was 103°–53°. As stated earlier, the maximum dorsiflexed position (13°) occurred at the 90° crank position, and the maximum plantarflexion (37°) occurred at the 285° crank position.

***A simple vertical force is the least effective angle of force application to the pedal.***

## MUSCLE ACTIONS

Muscle actions enable the previously mentioned joint excursions. A study was conducted to determine if highly successful competitive cyclists could be distinguished from less successful, but trained cyclists on the basis of selected muscle and/or metabolic characteristics. No difference was found in these two groups in the percentage of slow-twitch or fast-twitch muscle fibers or in the total area of the two fiber types (1). The results suggest that an extremely high percentage of fast-twitch or slow-twitch fibers may not be a requirement for competitive cycling success, similar to the results of some studies on running (1).

In a related study, Suzuki examined the mechanical efficiency of fast- and slow-twitch fibers during cycling. When cycling below 80 percent maximal oxygen uptake ($VO_2max$) at 60 revolutions per minute (rpm), efficiency was unaffected by the muscle fiber composition. The efficiency of the slow-twitch group decreased at 100 rpm compared to 60 rpm. Conversely, the fast-twitch group showed increased efficiency at 100 rpm. At high pedaling rates, the predominant use of slow-twitch fibers may lead to an increase in energy expenditure (19).

### Hip Muscle Actions

Electromyographic (EMG) studies in cycling have documented muscle activity and the timing and duration of muscle activity during the revolution of the pedals. At the hip, the gluteus maximus works to extend the hip only for a brief period of time (Figure 2). During the first 45° of the pedaling cycle, beginning at the 0° position of the crank, the gluteus maximus acts alone to extend the hip. During the last 45° of hip extension range of motion, ending just past the 180° point of the cycle, the hamstrings work alone.

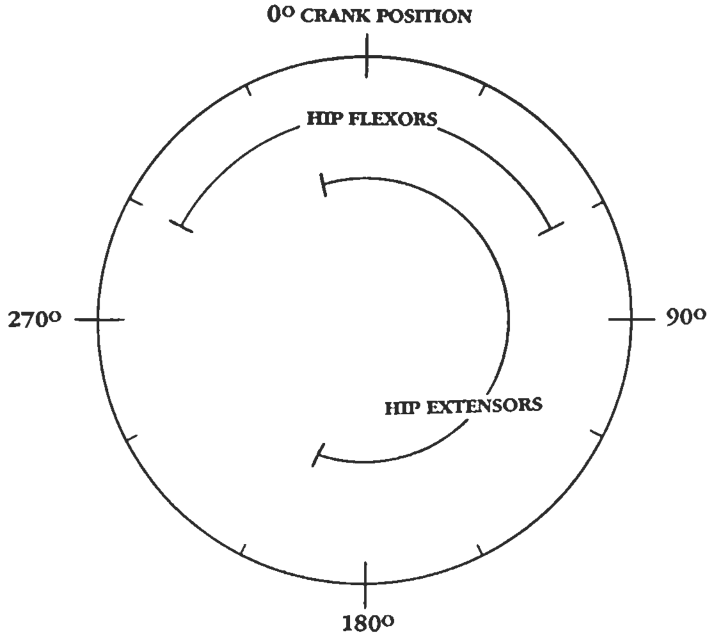


**FIGURE 2:** *Hip muscle activity during a pedaling cycle. (Adapted from Faria and Cavanagh (9).)*

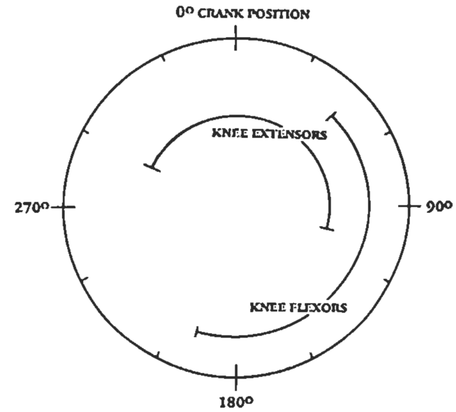


**FIGURE 3:** *Knee muscle activity during a pedaling cycle. (Adapted from Faria and Cavanagh (9) and Houtz and Fischer (13).)*

The gluteus maximus and the hamstrings work together during the middle part of the hip extension action, which corresponds to a crank angle of approximately 45–125° (9).

The hip flexor muscles, the iliopsoas, and the rectus femoris are partly responsible for the motion of the leg during the recovery phase. The recovery phase occurs when the pedal is in the 180–360° position. The remaining half of the pedaling cycle is called the power phase, from 0–180° (9) (Figure 1). (The activity of the iliopsoas is an estimation, since deep anatomical position makes monitoring the activity difficult.)

During the last half of the recovery phase, the rectus femoris contracts, flexing the hip. The rectus femoris is also active during the first 60° of the power phase, even though the flexion action at the hip is contrary to the dominant extension action occurring at this time in the pedaling cycle (9). Ericson et al state that the rectus femoris is most important as a knee extensor during cycling, since this muscle's primary action occurs during the power phase when the hip and knee are extending (8).

## Knee Muscle Actions

Although knee extension is very important for the power component in cycling, the role of the knee flexors cannot be ignored. The vastii group, which are the primary knee extensors, contract at the 315° point of the 360° pedaling cycle (Figure 3). When the crank is 15° past the horizontal, or 105°, the vastii relax while the knee flexors continue to work. The hamstrings and the vastii muscles are both active for a total of 70° of crank movement. At the 70° crank position, the hamstrings generate a crank turning effect at the knee, contrary to the dominant action of knee extension at this point in the power phase. In order to carry out their action of hip extension, the hamstrings generate a turning effect or moment about the knee. This adds to the actual crank turning, which is regulated by different lever lengths and muscle actions. Alterations in seat height and pedal position can affect the cyclists' ability to turn the crank (9).

***The nature of the asymmetry exhibited in 20 subjects was unrelated to limb dominance and varied day to day.***

Houtz and Fischer found identical timing of action potentials in the rectus femoris, vastus lateralis, and vastus medialis muscles. The duration of the rectus femoris and vastii activity was almost twice that of the hamstrings (13). Additional EMG studies indicated the rectus femoris and the vastii to be active through approximately 180° of the pedaling cycle, from 295–115°, and the hamstrings to be active through approximately 155° of the pedaling cycle, from 45–200° (9).

The hamstrings turn on and off in relation to the rectus femoris and vastii muscles. The rectus contracts first at 295°, followed by the vastii at 315° in the cycle. The hamstrings contract at 45°, followed by the rectus femoris relaxing at 67° and the vastii relaxing at 115°. Lastly, the hamstrings relax at 200° (9,13).

## Ankle Muscle Actions

Even though the powerful plantarflexors attach to the calcaneous, the calcaneous bone is not a part of the true ankle joint. Since the integrity of the foot and ankle is so dependent on ligaments, the forces to the pedal from the gastrocnemius and soleus must be transmitted to the forefoot via the tarsal binding ligaments. The concept of force transmission is different from the muscle activity at the hip and knee, where muscles act directly on bones to provide the force output. The contribution of the muscles that act directly on the metatarsals is small; they cannot generate the forces that the gastrocnemius and soleus can. The gastrocnemius and soleus contract after both the hip and knee extensors are activated. The soleus is active through 27–145° of the pedaling cycle, while the gastrocnemius is active from about 35–260° of the cycle. The gastrocnemius contracts for the longest period of any of the muscles studied (Figure 4). Gastrocnemius activity during cycling is controversial. Houtz and Fischer found the gastrocnemius to have a relatively short contraction phase.

According to these researchers, the tibialis anterior contracts at about the 270° position, as the hip and knee approach maximum flexion, and relaxes at about the 88° position (13). Ericson et al found the tibialis anterior to be active during the 300–60° phase of the pedaling cycle (8). The concept of dorsiflexion occurring at the 0° crank position has been the traditional belief that has been discounted by Cavanagh et al (2).

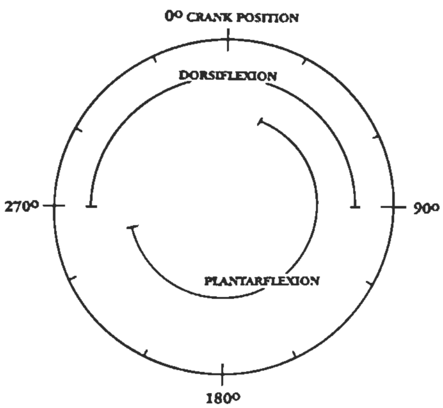


**FIGURE 4:** *Ankle muscle activity during a pedaling cycle. (Adapted from Ericson et al (8) and Faria and Cavanagh (9).)*

## SEAT HEIGHT

The action of every lower extremity muscle during cycling may be changed when the seat is raised or lowered. Adjusting the seat height changes joint angles and ranges of motion and alters length-tension relationships of the lower extremity muscles. The result is that the cyclist consumes more oxygen and works harder with decreasing efficiency (9). An optimal seat height probably exists for which energy consumption at a given power output is minimized (2).

*the rectus femoris is more important as a knee extensor during cycling, since this muscle's primary action occurs during the power phase when the hip and knee are extending.*

Researchers have attempted to determine an optimal seat height by varying seat heights and measuring maximal oxygen uptakes. Seat height was altered and examined in the following studies. No mention was made of seat angulation or handlebar position.

One method to determine optimal seat height is 109 percent of the cyclist's inseam leg length measurement. The numerical value is then used as the distance from the top of the seat to the pedal in the 180° position, measured along the seat tube diagonally (9). One hundred and nine percent of inseam leg length has been found to be an optimal seat height guideline for power output, with 107 percent of inseam leg length being called optimal for minimal energy expenditure (12). However, a discrepancy in the optimal values for seat height determination exists (Table 2). No single optimal position exists for all riders at all times.

Nordeen-Snyder (16) obtained maximal oxygen uptake measurements and described kinematic patterns of 10 women cyclists at three different seat heights. The heights used here were 95, 100, and 105 percent of the distance from each cyclist's greater trochanter to the level ground. One hundred percent of the greater trochanter height was found to be the most efficient. Results of the kinematic studies showed no change in the total hip range of motion when the seat heights were altered; however, the hip angles at the 0° and 180° positions in the pedaling cycle did change. The total range of motion for the knee and ankle increased 14° and 9°, respec-

| Researchers | Optimal Seat Height Measurement |
|---|---|
| Faria and Cavanagh (9) | 109 % inseam leg length |
| Gregor and Rugg (12) | 109 % inseam by length (for optimal power output)<br>107 % inseam by length (for minimal energy expenditure) |
| Shennum and deVries (18) | 103–104 % inseam leg length |

**TABLE 2:** *Optimal seat heights.*

tively, as seat height increased. The knee and ankle positions at the 0° and 180° crank positions also changed. Plantarflexion at the 180° crank position increased by 10 percent as the seat height increased. The major adaptions to increasing the seat height occur in the knee and in ankle plantarflexion (16).

Skilled but untrained cyclists were used to determine the effect of seat height on oxygen consumption ($VO_2$) during ergometer cycling. Maximal oxygen uptake was one of the parameters examined at seat heights equal to 100, 103, 106, 109, and 112 percent of the cyclist's inseam leg length. Oxygen consumption progressively increased as the seat height increased, with the greatest value occurring at the 112 percent setting. The most efficient positions, indicated by the lowest $VO_2$ value per unit of work, were the 100 percent and 103 percent settings, with no significant difference between the two. After examining other physiologic data, the researchers determined that the seat height of choice for efficient cycling should be approximately 103–104 percent of the cyclist's inseam leg length (18).

Although no agreement as to one superior method for determining optimal seat height exists, clearly an improper seat height can affect the knee. Knee pain is often identified as the most common complaint of cyclists (6). Knee pain, usually due to excessive patellofemoral pressure, patellar tendonitis, or bursitis are common complaints of cyclists. A finding related to such complaints was too low of a seat (6).

## Kinetic Changes with Seat Height Variation

Seat height variations have been used in an attempt to control stresses at the knee. McLeod and Blackburn (14) contend that cycling removes the deceleration forces that occur with running by allowing the seat to absorb such forces. Controlled acceleration forces at the knee, produced by muscles, are used by the cyclist and can be regulated. When the tibia is vertical, the tibial plateau has a posterior slope of approximately 9° (15) (Figure 5). In cycling, the tibia appears to be closest to a vertical position in the last 20° of the power phase. The tibia appears angled anterior to the vertical for the majority of the pedaling cycle. When the tibia is angled anterior to the vertical by more than 9°, the tibial plateau slope is anterior and the femur tends to slide anteriorly. The anterior sliding motion is controlled by patellofemoral forces of the quadriceps, with the posterior cruciate ligament making an insignificant contribution to control of the tibial motion in this position (14). The only effective mechanism for retaining the femur on the tibia when the femur tends to slide posteriorly is the combination of the anterior cruciate ligament (ACL), meniscotibial ligaments, and a small contribution from the arcuate and posterior oblique ligaments.

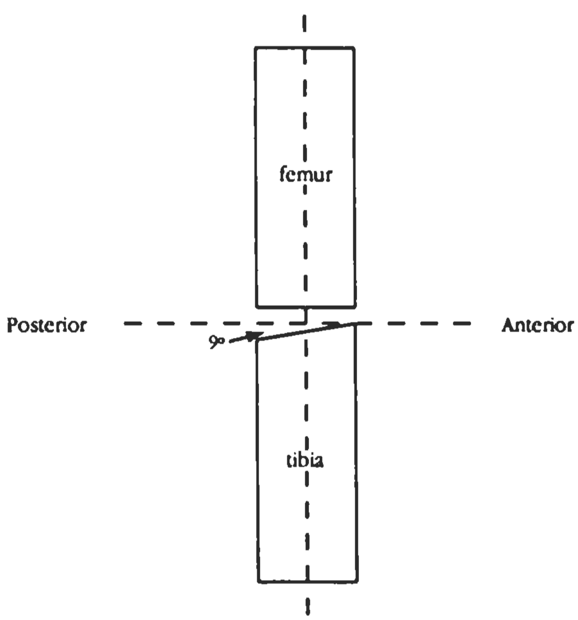


**FIGURE 5:** *A medial view of the femur and tibia showing the tibia with a posterior slope of approximately 9°. (Adapted from McLeod and Blackburn (14).)*

While pedaling, forces are applied to the ACL, the capsular ligaments, and the posterior structures of the knee joint as the tibial plateau is tilted posteriorly. The more posterior the angle of the tibia, the greater the tendency of the femur to slide posteriorly and the greater the load on the ACL (14). The muscles acting on the knee can modify these forces, and since the seat height can influence the muscle actions, the seat height can affect the stresses on the knee ligaments. By varying the seat height and pedal position, the knee ligaments can be relieved of harmful stresses. Particular attention to protecting the knee ligaments from stress is important in the early phases of rehabilitation but also comes into play later in recovery when cyclic stressing of the ligaments may help increase the ligaments' strength. When two seat heights were considered—the lowest possible and a seat position high enough so the cyclist could just reach the pedal with the heel—the major difference with the higher seat position was the tibia approximated terminal extension, causing a greater stress to the ACL and meniscotibial ligaments (14). With the lower seat position, the tibiofemoral joint called on the patellofemoral joint for stabilization (14). Possibly, it appears that the lower the seat position, the greater the need for patellofemoral stabilization and the greater the stress on this joint.

## PEDAL POSITION

An anterior foot position (ball of foot) on the pedal helps to decrease stresses across the knee ligaments and is the most efficient position (7,9). This pedal position gives a maximum mechanical advantage to the powerful gastrocnemius and soleus muscles in turning the crank. A posterior foot position (heel on the pedal), although increasing gluteus medius and rectus femoris activity, does not allow the full ankle range of motion needed to change the orientation of the force vector from the vertical (9). This force refers to the direction the force is applied to the pedal at different crank angles. A simple vertical force is the least effective angle of force application to the pedal, since it is only 50 percent effective when measured at the 30° crank angle. A straight horizontal and a force at the 330° point of the pedaling cycle are 87 percent effective, with a force occurring at the 300° point of the pedaling cycle being 100 percent effective (9). The force effectiveness at different angles changes as the crank angle changes. The use of toe clips or cleats in addition to the type of bicycle used may also influence the efficiency of different pedal positions.



## PEDALING RATE

Pedaling rate varies with riding conditions, such as level ground versus hill climbing, and, in turn, influences cycling efficiency. Most experienced cyclists claim 90 to 110 revolutions per minute is an optimal pedaling rate during steady-state riding; novice riders typically pedal at lower revolutions per minute (2). Ericson et al found that increasing the pedaling rate increased activity in the gluteus maximus, gluteus medius, vastus medialis, medial hamstring, medial gastrocnemius, and soleus (8). Ericson and Nisell (7) demonstrated pedaling rate had no influence on the tibiofemoral compressive and shear force magnitudes. Whether or not the change in muscle activity is the reason for the force magnitudes at the joint remaining the same is yet to be determined.

Pedaling rate has been related to power output. One study involved measuring optimal pedaling rates (defined as the revolutions per minute that resulted in the lowest maximal oxygen uptake for the power output) in novice riders. The subjects' revolutions per minute ranged from 40–120 rpm, and the maximal oxygen uptakes were recorded. The optimal pedaling rate was found to be dependent on the power output. When the power output increased, the optimal pedaling rate also increased (3).

There is a discrepancy in the literature regarding the relationships between pedaling rate, work load, and efficiency. Efficiency here is defined as the cyclist's ability to effectively apply forces to the cranks (2). Seabury et al (17) attributed the discrepancy to the use of a bicycle ergometer versus a racing bicycle. It may also be due to different methods of calculating efficiency, i.e., whether the muscular efficiency is calculated as gross, net, work, or delta efficiency (10). At a constant work load, cycling efficiency decreases with an increase in pedaling rate, regardless of the calculation method (10). Pedaling efficiency is dependent on both speed and work load. At slow speeds and low power outputs, a low cadence is most efficient. As the speed and power output increase, the most efficient cadence will also increase (17). Several factors influence cadence, including: *1*) the type of bike used, *2*) the position of the rider, *3*) whether toe clips or cleats are used, *4*) speed, *5*) gear ratio, *6*) physical condition of the cyclist, and *7*) the cyclist's perception of exertion (2,8,12,17).

Cavanagh conducted a preliminary study holding the power output constant while the riders rode at 60, 80, and 100 rpm. There was a relatively larger negative effective force contribution, that is, a force working against the cyclist, during the recovery phase (180° to 0°) at higher rpms. The mechanics during the power phase were similar at high and low rpms, except for the proportionately smaller forces at higher rpms. The faster a cyclist pedaled, the more the cyclist worked against himself during the recovery phase (2).

## FORCE APPLICATION

As stated earlier, the most effective force application at the start of the power phase is at the 300° point of the 360° (uppermost vertical position) pedaling cycle (9). Effective force application is just as important during the recovery phase. A frequent question concerns whether or not cyclists actually pull up the leg during the recovery phase. When asked, cyclists often report pulling up during recovery, contrary to the results of studies designed to determine forces during the recovery phase. In the recovery phase, as well as the power phase, one of three things occurs: a downward force on the pedal, an upward force on the pedal, or the pedal is unloaded. To unload the pedal, two forces have to be overcome: *1*) the weight of the leg that gravity tends to pull down, and *2*) the inertial force, or the tendency of the lower extremity mass to resist the pedal motion. Pulling up is defined as the cyclist overcoming both of these forces, so the force acting on the pedal is in an upward direction (2).

In a study of steady-state riding of pursuit team riders and recreational riders, only a few examples of pulling up were observed. Occasionally, some unloading of the pedals occurred, but rarely did the riders actually pull up. When an upward force was demonstrated, the force was small and of short duration (2). The results contradict reports in bicycling magazines claiming that pulling up during the recovery phase can increase one's efficiency by as much as 30 percent. If that were true, elite cyclists would show some upward force during the recovery phase (2).

A description of the exact events in each of the three possible pedal conditions mentioned earlier may help explain why even the best cyclists do not pull up in the recovery phase. When a downward force is exerted on the pedal during the recovery phase, the rider is recovering this leg with help from the opposite leg. When the pedal is unloaded during recovery, the rider recovers by the action of that leg's own muscular effort. When an upward force is exerted on the pedal, the leg is recovering by muscle actions on the same side, but the muscle action is in excess of what is needed for recovery, resulting in propulsive torques (2). Literature supporting the finding that pulling up is rarely seen in cycling has been specific and reproducible (2).

This is definitely an area where more research is needed, especially in specific riding conditions such as hill climbing or sprinting. The studies reported here were steady-state riding on level surfaces. It is clear that the literature shows an absence of evidence for the superiority of one form of recovery; however, since the best elite cyclists do not pull up in the recovery phase, some assume that it is not economical to do so. This remains controversial since some studies, especially those determining the effect of toe clips on force application, state that toe clips and perhaps cleated shoes can decrease quadriceps fatigue by enhancing flexor muscle utilization (5).

Flexor moments have also been studied in the power phase of cycling. The hip and knee muscle actions are quite different when examined in relation to the crank during propulsion. During the 0–180° power phase, the moment at the hip is extension, while the knee moment is first extension, followed by flexion. These patterns have been found to be consistent among subjects in the work of Gregor et al (11). The investigators explain the theoretical possibility of using only knee extension forces through the power phase. However, the knee extensors would have to develop forces in excess of the flexor moments generated at the knee by the two-joint hip extensors. Such knee extensor forces would be very inefficient metabolically.

## PEDALING SYMMETRY

A final biomechanical consideration here is symmetry in pedaling. Logically thinking, cycling appears to be a symmetrical activity, with each leg making an equal contribution. Daly and Cavanagh (4) showed the relative contributions of each leg were not symmetrical in recreational cyclists. The nature of the asymmetry exhibited in 20 subjects was unrelated to limb dominance and varied day to day. Changes in pedaling rate caused significant differences in asymmetry, but no consistent relationship was found.

Cavanagh and Sanderson (2) extensively studied symmetry in cycling. A description of force application is broken down into two types of symmetry. The researchers quantified force asymmetry by comparing the effect or impulse of the resultant forces applied by each leg. The ratio of the right impulse over the left impulse is multiplied by 100 to give a relative percentage contribution of each leg. The force-asymmetry ratio is the name given to this measure (2). A ratio greater than 100 infers that the right leg contributed more than the left; the opposite is true if the force-asymmetry ratio is less than 100. Although the force-asymmetry ratio does not give much information about propulsion, the ratio can be considered a measure of muscular effort (2). Strength differences in the lower extremities can manifest as force application asymmetry, as can an injury to one lower extremity.

A second measure, the work-asymmetry ratio, assists in a complete assessment of force application symmetry. The work-asymmetry ratio equals the ratio of the work done by the left leg to the work done by the right leg, multiplied by 100. The ratio reflects only the effective force, i.e., the portion of the applied force that contributes to propulsion. It is possible for cyclists to be dominant in one leg in force asymmetry, with the other leg dominant in work asymmetry. If this is the case, it gives vital information regarding the underlying mechanics of pedaling (2).

When the force and work asymmetries are in favor of the same leg, more work is being done due to more force being applied. If the force and work asymmetries do not agree, the leg that is generating the most force is doing the least amount of work. This implies that the forces applied to the bike are less effective on the side applying more force. This could be caused by strength deficits, injury, anatomical variation, or a training error. When a cyclist demonstrates such an imbalance, which likely leads to poorer performance, biomechanical modification to attempt to achieve a more equal bilateral contribution is necessary (2). Alternate one-legged pedaling may be necessary to help attain the training goals. However, asymmetry in pedaling may be desirable when the goal is passive stretching, through the active muscle contraction of the opposite leg.

## DISCUSSION

Cycling has become a very popular sport recently, and it continues to gain popularity. It is a frequently employed method of recreation, rehabilitation, and even competition. Often in the course of rehabilitation or recreation, the goal is to strengthen one structure while minimizing stress on another. Using the information provided, it becomes easier to identify which anatomical structures are stressed and when they are active. There appears to be an intricate interaction of leg muscles during cycling, as the muscles show overlapping periods of activity. Cycling efficiency may even be influenced by some of the biomechanical factors discussed.

The data presented on seat height, stating high seat heights cause a greater stress to the ACL and meniscotibial ligaments, pose a dilemma for the physical therapist treating a patient who has undergone ACL reconstruction and has some patellofemoral pain and/or crepitus. Keeping the seat high may help decrease patellofemoral pressures (although this has yet to be documented), while potentially increasing the stress on the ACL. Evidence indicates that increasing the seat height decreases the compressive forces at the tibiofemoral joint, although such stresses are small compared to the tibiofemoral stresses in level walking (2–4 times bodyweight), stairclimbing (4 times bodyweight), or rising from a chair (3–7 times bodyweight) (7).

Clearly, more research is needed in all areas of cycling biomechanics. Much of the cycling literature is physiologic in nature. Cavanagh's work on the possibility of the leg pulling up during the recovery phase is said to be specific and reproducible, yet the studies examined were all conducted by the same group of researchers. Power output and pedaling rate during cycling are said to have a linear relationship. How this relationship changes with changing riding conditions or seat heights and how force application is related are all areas that require further study. Mechanical factors relating to biomechanical factors such as air, wind, and rolling resistance, and drafting also deserve to be investigated.

## SUMMARY

In order to have success in rehabilitation, injury-free recreation, and efficient racing, the biomechanical and physiological aspects of cycling as addressed in the present review should be considered by every cyclist or advisor of cyclists. Guidelines for seat height, pedal position, pedaling rate, and force application are presented here to assist in achieving such success. How these parameters influence and are influenced by lower extremity muscle actions and joint excursions are also important considerations. Hopefully the present review provides such cycling consultants with an increased awareness. Simply telling someone to ride a bike for exercise may not be enough, without also stressing the need for a biomechanical assessment for proper fit and technique. The biomechanical assessment may help prevent injuries, protect previous injuries, accomplish specific rehabilitation goals, or improve overall efficiency. JOSPT

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