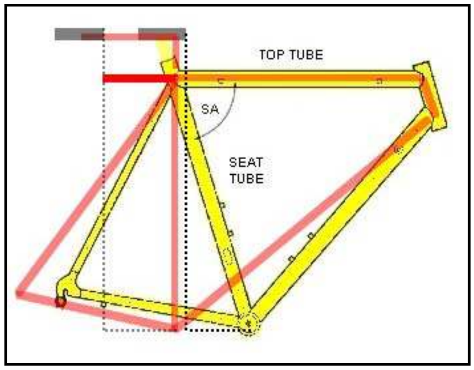

4TH EDITION

Bike Fit

Arnie Baker, MD

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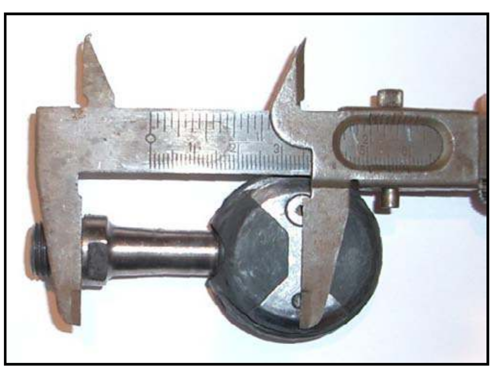

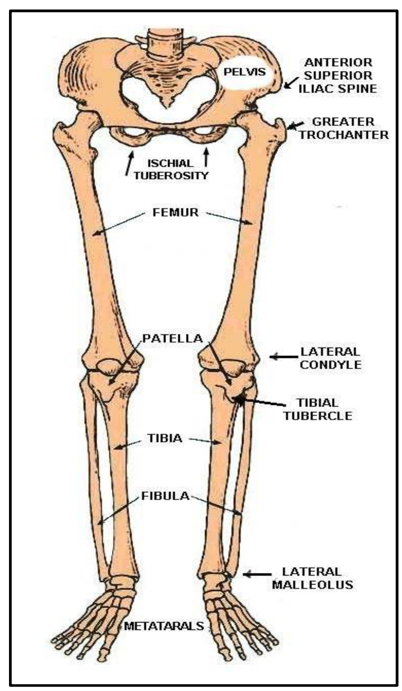

4TH EDITION

Bike Fit

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Arnie Baker
C·Y·C·L·I·N·G

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Coach and Author

Arnie Baker, MD

Dr. Arnie Baker has been coaching since 1987. A professional, licensed USCF coach, he has coached racers to several Olympic Games, more than 100 U.S. National Championships, and 35 U.S. records. He is the National Cycling Coach for Team in Training. This endurance-training program of more than 800 coaches and 30,000 participants raises more than $80,000,000 each year for the Leukemia & Lymphoma Society.

Arnie has a Category 1 USCF racing license. He has held eight U.S. 40-K time-trial records, has won multiple national championships, and has won more than 200 races. An all-round racer, he was the first to medal in every championship event in his district in a single year.

Dr. Baker is a licensed physician in San Diego, California. He obtained his M.D. as well as a master's degree in surgery from McGill University, Montreal. He is a board-certified family practitioner. Before retiring to ride, coach, and write, he devoted approximately half of his medical practice to bicyclists. He has served on the fitness board of Bicycling magazine as a bicycling-physician consultant. He has been a medical consultant to USA Cycling and the International Olympic Committee.

Arnie has authored or co-authored 18 books and more than 1,000 articles on bicycling and bicycling-related subjects.

Also by Arnie Baker, MD:

- Altitude Climbing Endurance (ACE) Training for Cyclists
- Bicycling Medicine—Cycling Nutrition, Physiology and Injury Prevention, and Treatment
- High-Intensity Training (HIT) for Cyclists
- Nutrition for Sports
- Psychling Psychology: Mind Training for Cyclists
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Thank you.

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I thank Gero McGuffin, Jimena Florit, Chuck Gilbert, Tom Hendricks, Janel Holcomb, and Butch Richardson for serving as models.

1 Here it is: A little mention of CONI. *Cycling* was published in 1972 by CONI, Comitato Olimpico Nazionale Italiano (the Italian Olympic Committee). It was the first authoritative book on cycling I read, the then bible of bicycling. The book contains a wealth of information. It is also wordy and often obscure, at times more difficult to read in its English translation that any medical text I have ever studied. Consider CONI on bike fit changes to pedal position:
My style: "Make changes gradually, allow the body time to adapt."
The CONI wisdom: "Any changes in respect of a satisfactory position are not adopted race by race, that is, according to the diversity of the race itself, since the position, once established, should not be modified. In fact, to change the position of the foot is equivalent to modifying the aptitudes which the muscles and nerves of the lower limbs have assumed with time and work, until such aptitudes have become veritable habits, so that if such habits are suddenly changed, the cyclists will be subject to pain in the legs and cramps."

Disclosure

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Table of Contents

Within a perfectably acceptable range, choose a bicycle position to reflect your riding style, accommodate your anatomy, or treat an overuse injury.

Seat height is the holy grail of power.
Seat fore-aft is the holy grail of balance.
Torso angle is the holy grail of aerodynamics.

Fit the bike to the rider, not the rider to the bike.

All positions require adaptation. Good positions require less.

Forward

Just How Important is Bike Fit?

More or less than you might think.

I teethed into bicycle racing in the 1980s, watching the three M's: Merckx, Martens and Moser. Merckx, perhaps the greatest bicycle racer of all time, famously and typically changed his seat height many times during the course of a single ride.

On the other hand, I have ridden tandem with Floyd Landis for years. As long as I eyeball his seat height to within an inch of his usual position, he is happy. Happy to be training different muscles than he is used to, or happy because a new position may work away the pain from his hip replacement.

I have ridden tandem time trials for years. With some riders, it has taken scores of rides for my partner to adjust and get used to tandem positioning.

On the other hand, when I met Jane Gagne, we rode about 10 minutes one Saturday before she said: "Okay, I'm fine. That's enough." The next day we set the US mixed tandem 40-kilometer record.

I have fitted riders who have complained of nagging shoulder pain, related to cycling, for years. Observing a modest arm length difference, they have marveled that I have eliminated their pain by offsetting their brake levers by just a few millimeters (mm).

On the other hand, I have fitted track racers who have had two different length cranks (say a 165-mm on the left and a 170-mm on the right) for months or years without ever having noticed.

Sean Kelly's saddle position was low and his reach short by any current bike-fitting standard. Nonetheless, he was the world's number one racer for more than four years. Perhaps he could have been even better.

I believe a change in Sarah Hammer's position helped her. She had already won the 2006 World Track Pursuit Championships in April. Two months later, in June, I was asked to consult about her position. We lowered her aerobars, improving her aerodynamics. In October, at the US National Championships, she rode more than 4 seconds faster, setting a record in 3 minutes, 32.865 seconds.

Most people who ride bicycles never get a bike fit. Some high-end stores routinely offer comprehensive fits for all customers buying a new bike.

In my experience, almost everyone can benefit from a 5-minute or less eyeball fit. A club coach, an experienced bicycle store employee, or experienced rider can help.

If you are a performance athlete, an experienced bike fitter may help you improve your performance. An annual bike fit "check-up" may be a worthwhile investment.

If you have a bicycling-relating overuse injury, read the section on *Aches & Pains* on page 110. An experienced bike fitter, especially one with expertise in medical-grade bicycle fits, may help or cure your woes. A medical-grade fit may take an hour or more.

Regardless of your fitness or the presence of overuse injuries, reading this book may help your riding.

Forward

How I Know—The Basis for Advice

I provide more information than many readers want or need. If so, skip the details. Read just the first few paragraphs of a topic, typically headed: "Rule of Thumb."

Throughout this book, I let you know not only what my advice is, but why. I also let you know about alternative opinions.

Recommendations are made for one or more of the following reasons:

- *Tradition, conventional wisdom*. Sometimes recommendations are based on conventional wisdom. Parroting the advice of our teachers is common.
  Conventional wisdom example: Riders with a 32-inch inseam should ride 172.5-mm cranks.

- *Empiricism*. Experience. I have been a bicycle rider almost all of my life, a bicycle racer (Cat 1), and a coach for more than two decades. My coaching practice has extended from relative beginners hoping to complete their first century to Olympians. I am also a coaches' coach, having trained more than 1,000 individuals. Where companies have provided me product at no cost or reduced cost, I disclose those companies, as on page 7. I sell no bicycle products and refuse kickbacks or commissions from manufacturers.
  Empiric example: Time trialists have the most power in a forward, high seat height position.

- *Logic*, including mathematical models.
  Logic example: Sprinters: Consider shorter cranks. Since the legs travel a shorter distance with each revolution, it makes sense that one may be able to spin faster cadences.

- *Scientific study*. Relatively few bicycle fit recommendations are based on solid scientific study. Much of what has been published has been of limited value, of a limited relevance, or provided little guidance. As is often the case, studies have provided seemingly contradictory results.[2, 3] Nonetheless, where scientific evidence exists, I let you know.
  Scientific example: Too low or too high a seat height worsens economy (metabolic cost).

---

2 For example, at the Second Serotta Science of Cycling Symposium, it was reported that Maury Hull concluded that floating pedals are of no use in preventing knee injuries and that 10° of valgus canting was beneficial. Andy Pruitt concluded that floating pedals have greatly reduced knee injuries and that varus canting was beneficial. Zinn, L. VeloNews. Jan 29, 2008. Linked and accessed Jan 30, 2008.

3 As one Tour de France champion, the recipient of conflicting advice, has said: "When we don't have any problems, I wish these guys would stop trying to fix us and just let us ride our bikes." Floyd Landis. Personal communication. Feb 6, 2008.

Rules of Thumb Summary

The right size bicycle frame and components, and their adjustment, is important. Proper fit allows you to be comfortable, ride safely, and work effectively. It reduces or treats overuse injuries. Proper fit makes you a better rider.

Bike Fit Rules-of-Thumb Summary

These and other bicycle-fit elements are discussed in detail throughout this book. There are numerous exceptions to almost all rules of thumb.

Frame Size Road: 2/3 inseam. Mountain: subtract 14 from inseam in inches.
Cranks Inseam to 31 inches: 170 mm. Inseam 31 to 33 inches: 172.5 mm. Inseam 33 or more inches: 175 mm.
Seat Height Knee bent 30° at bottom of pedal stroke.
Seat Position Fore-Aft Front of knee and pedal spindle in vertical line.
Saddle Angle and Shape Set level. Choose shape for comfort.
Foot/Pedal Fore-Aft Cleat axis between center and front of pedal axis.
Foot/Pedal Rotation Angle Point toes the way you walk.
Handlebar Width Road: width of the shoulders. Mountain: hands slightly wider than shoulders.
Handlebar Shape Select for comfort and riding style.
Brake Levers Tips in line with handlebar drops.
Handlebar Angle Point ends to middle of seat stays.
Stem Height Handlebar tops to at most a fist width below saddle.
Torso Angle / Reach Stem extension, height, and rise set at comfortable torso angle.
Shoulder Angle 90° with hands on hoods and elbows bent 15°.

Part 1: Frames

Size

You need the right-size bicycle so that you will be able to achieve correct leg extension, reach, and balance.

Rules of Thumb

For a road bicycle, choose a conventional frame size that is two-thirds of your inseam.

For a mountain bike, subtract 14 from your inseam in inches.

Figure 1. Measuring inseam. Measure from the floor to the top edge of a level or book snug against the crotch. Here, inseam is 30 inches.

Discussion

Frames are traditionally sized based on the length of the seat tube.

Determining your frame size is based on inseam measurement. To determine your inseam measurement, stand with your back to a wall with a level or the spine of a 1-inch-thick book against your inner leg, snug against your crotch.

Measure from the floor to the top edge of the level or book.

Most road racing bicycles are sold in metric sizes. One inch is 2.54 centimeters (cm). If you used inches, convert to metric by multiplying by 2.54. For example, if your inseam is 30 inches, or 76 cm, choose a 50- or 51-cm bike.

If a bicycle is too big or too small for you, you may lose control and fall.

Other Methods

When you stand over a road bicycle in stocking feet there should be 0 to 1 inch of clearance from the top tube to your crotch, and about 1 to 2 inches when you are wearing shoes. If your crotch touches the top tube, the bicycle is certainly too big.

If you are sizing a mountain bike, you will need at least another inch of clearance over the top tube.

Figure 2. Road bicycle frame size. Left: Allow at least 1 inch of clearance between the top tube and your crotch. Right: Compact road frames, like mountain bikes, will allow even more room.

Small Sizes

Small frames have more potential for the problem of toe overlap. When you turn the front wheel, your forward toe may hit the wheel and cause a crash.

If your road frame size is under 50 cm, consider a bicycle with 650c wheels (standard is 700c).

Non-Traditional Sizing

The precise way in which manufacturers size their frames varies.

Traditionally frame size is the seat tube length from the center of the bottom bracket to the center of the top tube.

Some manufacturers measure either to the top of the top tube or to the top of the seat tube. For example, a traditionally measured 54-cm bicycle (center-to-center) is about 55 cm from the center of the bottom bracket to top of the top tube and 56 cm to the top of the seat tube.

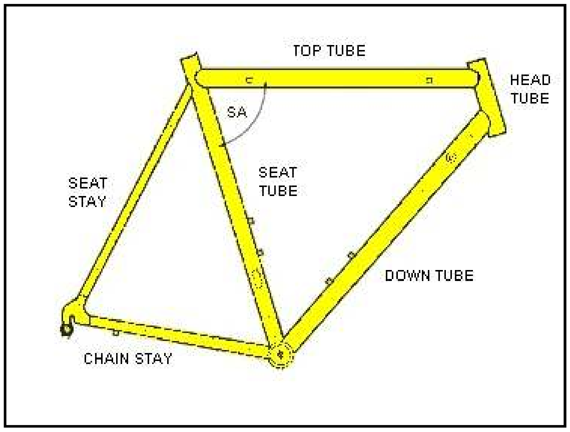

Figure 3. Traditional road frame and component tubes. Also shown is the angle between the top tube and the seat tube, the seat tube angle (SA). SA is an important dimension affecting the seat position fore-aft and will be discussed on page 19 and page 40.

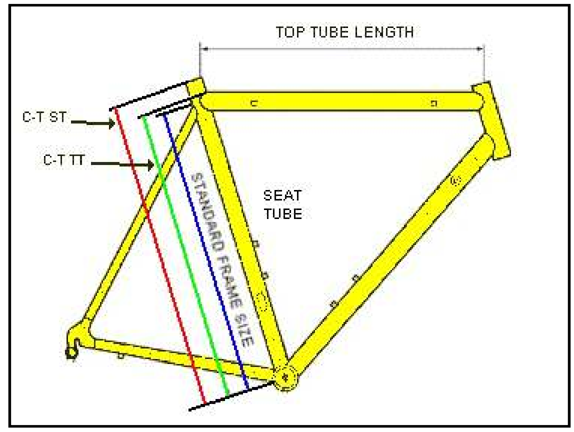

Figure 4. Frame size. Traditional frame size is based on the distance from center of bottom bracket to center of top tube (BLACK). Some manufacturers base size on the distance from center of bottom bracket to the top of the top tube (C-T TT, GREEN) or to the top of seat tube (C-T ST, RED).

Measuring to the top of the seat tube makes sense, especially for non-traditional frame designs with sloping top tubes or no top tubes.

It also makes sense to measure to the top of a virtual, or imagined, extension of the seat tube by a virtual horizontal top tube. Again, the issue is complicated: the measurement point of the virtual top tube may be at the center of where the top tube meets the tube, or at the top of the head tube (see Figure 5).

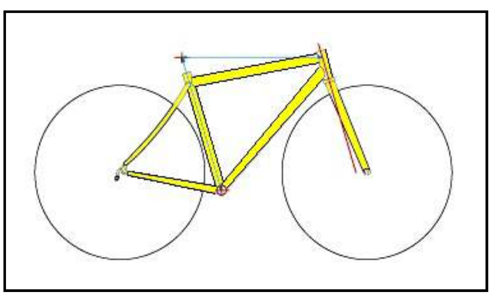

Figure 5. Compact Litespeed frame sizes are based on the intersection of the virtual horizontal top tube and virtual seat tube. The actual size is based on the virtual seat tube length. The virtual seat tube is measured from the center of the bottom bracket shell to the point where the virtual top tube meets the centerline of the seat tube extending into the seat post region. The virtual top tube is the horizontal line parallel to the ground and extending from the point at which the centerline of the top tube meets the centerline of the head tube.

Some non-traditional frame geometries do not lend themselves to any predictable size measurement (see Figure 6).

With improved material strength, compact frame geometry, and long seat tubes, it often makes sense to choose a frame based on top tube length.

Indeed some frame manufacturers size their frames based more on what the *top tube* length of their bicycles would be if the geometry of their bicycles were traditional. For example, a manufacturer may size a bicycle 58 that has exactly the same seat tube length as its 56 model, but a longer top tube.

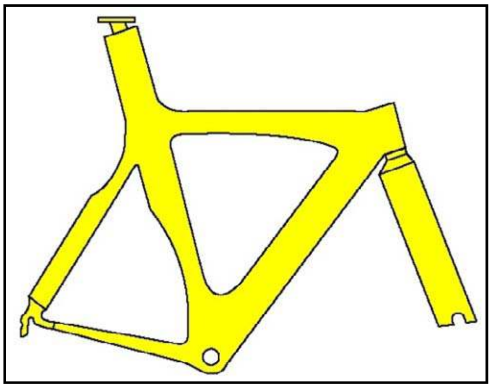

Figure 6. Assigning a size to this Trek time-trial frame is tricky.

The multitude of non-traditional sizing methods makes it impossible to predict what size you will need for any given bicycle unless the sizing method is defined.

Top Tube Length

Although frame size is the most important factor in choosing the frame that is right for you, different manufacturers may also have different length top tubes for the same size frame.

As stated above, with improved material strength, compact frame geometry, and long seat tubes, it often makes sense to choose a frame based on top tube length.

Where non-traditional frame geometries are used (compact bicycles, mountain bicycles—generally where there is a sloping top tube), or where there is no top tube (some monocoques), the top tube length is often imputed from a horizontal from where the top tube intersects the head tube to the seat tube or its seatpost extension. Some manufacturers measure from the center of the head tube top. Some frame geometries do not lend themselves to any predictable size measurement.

Some manufactures have "women-specific" models with shorter top tubes. Studies do not support the conclusion that women have shorter upper bodies and need relatively shorter top tubes than men need.[4, 5, 6, 7, 8] These frames may be a good choice for both women and men with shorter upper bodies.

Adjustment can be made to the effective length of the top tube (reach) by the use of handlebar stems of different lengths.

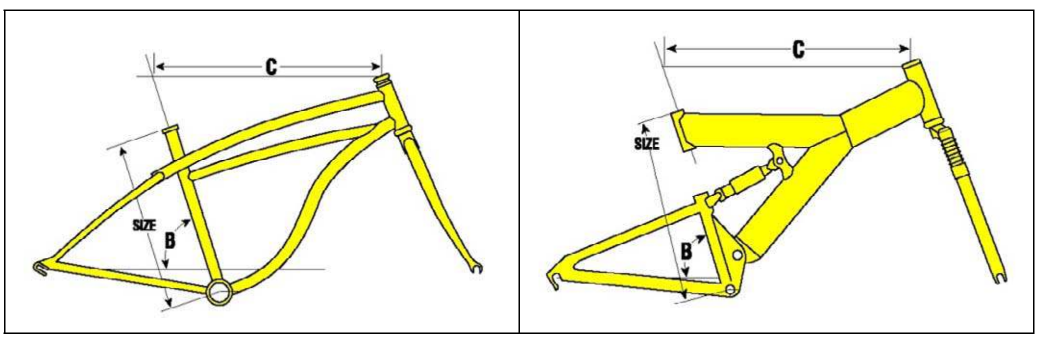

Figure continues below.

4 Contrary to the common belief of many, men have relatively longer legs than women do. Men have relatively shorter torsos than women do.
5 Tilley, AR. *The Measure of Man & Women*. John Wiley & Sons, Inc. New York. 2002.
6 Sokolovas, G. *Olympics Trials Summary Report. Anthropometrics*. Accessed and linked Mar 16, 2009.
7 Bogan. B, et al. *The Relationship of Sitting Height Ratio to Body Mass Index and Fatness in The United States, 1988-1994*. Human Ecology Special Issue. (15): 1-8. 2007. Accessed and linked Mar 16, 2009.
8 University of Wroclaw. *Adaptive preferences for leg length in a potential partner.* Accessed and linked Mar 16, 2009.

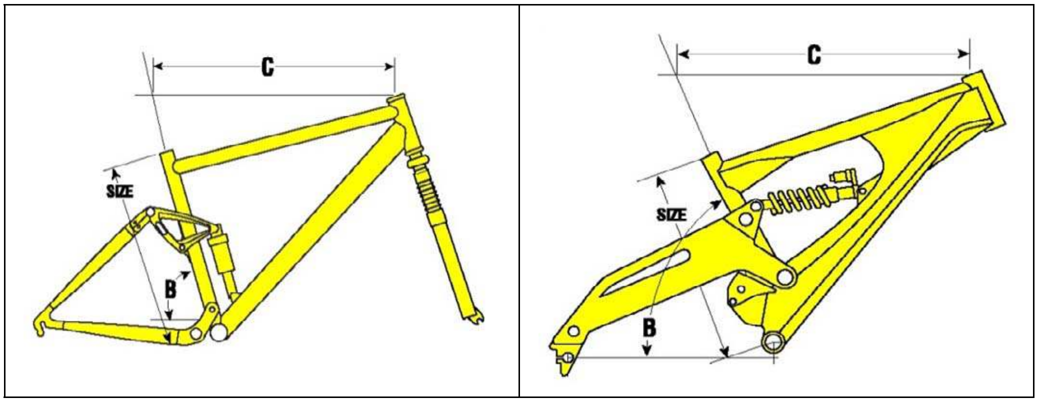

Figure 7. Top tube length (C). In non-traditional frame geometries, including those of almost all mountain bikes, the top tube length may be imputed from the horizontal distance from the head tube to the seat tube or its extension. Pictures: Trek Bicycles. Frame size and seat tube angle (B) are also indicated.

Seat Tube Angle

The seat tube angle is the angle of the seat tube from the horizontal.
A vertical seat tube has a 90-degree seat tube angle.

Seat tube angle, contributes to how far forward or aft of the bottom bracket the rider sits. For a fuller discussion of saddle fore-aft, see page 40.

For most riders, every degree change of seat tube angle changes fore-aft by about one-half inch.

Road bicycles typically have seat tube angles of about 73°; mountain bikes have seat tube angles of about 72°.

In general, the smaller the bicycle the steeper the seat tube angle—the higher the number.

The steeper the seat tube angle the more over the bottom bracket the rider sits. In general, the steeper the seat tube angle the harsher the ride and the more responsive the bicycle.

Track sprinters typically prefer steeper seat tube angles—say 75°. Recreational riders typically prefer shallower angles—say 72°.

Time trialists and triathletes often prefer steeper seat tube angles because the more forward position results in an opening up of the hip angle and more power.

However, steeper seat tube angles place more weight forward on the bicycle. They often handle relatively poorly, especially on descents.

Seat tube angles are indicated in Figure 3, Figure 7, and in Figure 8.

Effective Top Tube Length

If two bicycles have the same top tube length and one has a steeper seat tube angle, when saddle fore-aft is set the same on both bicycles, the one with the steeper seat tube angle will have a longer effective top tube length.

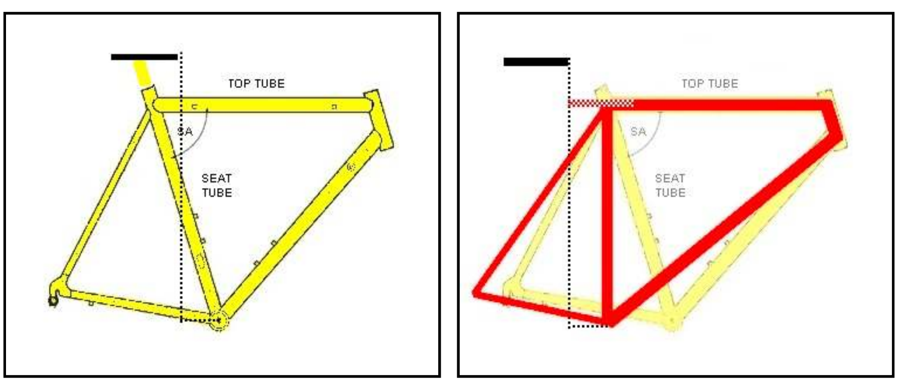

Figure 8. Left: YELLOW conventional road frame with 73-degree seat tube angle. Right: RED frame, with same length top tube, has 90-degree seat tube angle. To get the same saddle fore-aft (dotted black lines show equal saddle distance behind bottom bracket), the effective top tube length of the 90-degree frame is increased by the length of the checkered RED top tube line.

Crankarm Length

Rule of Thumb

Inseam to 31 inches: 170 mm crankarms.
Inseam 31 to 33 inches: 172.5 mm crankarms.
Inseam 33 or more inches: 175 mm crankarms.

Discussion

There has been much debate, some empiric evidence, and little convincing scientific study to support the above recommendations.

Consider the wide variation in rider size (whether we measure trochanteric leg length, inseam, or femoral leg length): a 5-foot rider differs from a 6-foot rider by about 20%. The roughly 3% small differences in commonly marketed crank lengths do not differ enough to make physiologic sense.[9]

Although it makes perfect sense for short riders (inseam less than 30 inches) on 700c road bikes or 26" mountain bikes to use 165-mm crankarms, and although most manufacturers make them, they are often special orders. Shorter crankarms are not produced in the lines of many major manufacturers, although they can be obtained from specialty manufacturers.

Although it makes perfect sense for tall riders (inseam more than 34 inches) on 700c road bikes or 26" mountain bikes to use 180-mm crankarms, and although some manufacturers make them, they are often special orders. Longer crankarms are not produced in the lines of most manufacturers, although they can be obtained from specialty manufacturers.

Track riders often choose crankarms up to 10 mm shorter and mountain bikers up to 5 mm longer than the above recommendations.

Shorter crankarms allow for faster cadences and improve cornering clearance on velodromes and in criteriums.

Although longer crankarms have been favored for hard steady efforts such as time trialing, hill climbing, and mountain biking, studies have shown that they change pedal force, not torque or power, as they require the rider to pedal a larger circle.

In time trialing in an aerodynamic position, longer crankarms mean that the knees rise higher, and hence closer to the chest—which may result in *worse* biomechanical function. The rider may close the hip angle, *reducing* power.[10]

---

9 A limited crankarm selection makes economic sense for component manufacturers.
10 Some savvy riders flout tradition and use shorter crankarms for time trialing. For example, National time-trial champion and frame builder Glen Swann uses 165 mm, when he time trials.

Background and Theory

Force and Optimal Crankarm Length

Archimedes had a physics lesson for us when he said, “Give me a lever long enough and I will move the world.” What he failed to mention, was that as the lever grew longer, it would take longer to move the lever and the world.

Since (1) power is the time rate of doing work, or the product of force and velocity, and since (2) at a given bicycle speed, if the gearing hasn’t changed, the cadence remains the same… many coaches and authors have mistakenly concluded that the power requirements with longer cranks are also reduced.[11]

Studies have examined the pedal force required to maintain a given bicycle speed. Not surprisingly, less pedal force is required to turn the cranks when crankarm length is increased.

In rotational motion, power is equal to the product of torque and the angular velocity with which the torque is applied.

Torque is force times the perpendicular distance from axis to line of action of force.

Although the pedal force required is less, torque (and therefore power) for a given speed is the same, because torque is the product of force and crank length.

You may say: “But the leg force required is less, so either you should be able to save energy with longer cranks, or go back to applying the same force and then torque will increase, and longer cranks will allow you to apply more power.”

Again, this argument is wrong. The required force may be less, but the legs will have to travel farther around a larger circle, moving faster for a given rpm. You will not be able to maintain the same cadence, or the force you can apply will go down. Again, we are back where we began.

The bottom line is that the same studies that show a reduction in pedal force with longer cranks also show that *the power requirement does not change*.

From the limited studies available, examining pedal force, torque, or power has not helped us decide optimal crankarm length.[12]

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11 Example: America’s most successful Olympic cycling coach, Eddie Borysewicz, misstated the science in his now-classic book *Bicycle Road Racing* (Vitesse Presse, 1985). “For a given gear ratio and pedaling cadence, it takes less power to maintain road speed as crankarm length increases.”

As the table he provided shows, what Eddie called power was *pedal force*. Power is the product of torque and rpm. *Torque*, the product of force x crank length, was, within the measurement accuracy, *the same* with all crank lengths.

Gear Ratio	RPM	Crank Length	Power/Pedal Force	Torque
48x14	117.1	165	30.89	5096.85
		170	29.98	5096.60
		175	29.13	5097.75

Changing crank length does not change torque or power required to travel a given speed. First four columns from Borysewicz. Last column, Torque, calculated from the product of columns 3 and 4, crank length x pedal force.

12 At the Second Serotta Science of Cycling Symposium, it was reported that Jim Martin found no difference in maximal sprint power using 120, 145, 170, 195, and 220 mm cranks. Zinn, L. VeloNews. Jan 29, 2008. Linked and accessed Jan 30, 2008.

Cadence

Empirically, it is well know that shorter cranks allow for faster cadences. Where distance traveled is proportional to cadence, rather than power, shorter cranks win out.

For this reason, roller races often set a lower limit on crankarm length of 165 mm.

Logically, shorter cranks mean that the legs do not travel as far per pedal revolution, and so more revolutions can be accomplished per minute.

Shorter cranks have other benefits that improve cadence:

- If shorter cranks are used, the knee arc, as defined and described in Figure 15 on page 32, will also be shorter. This will be true regardless of whether the seat height is adjusted to reflect the same degree of knee flexion at the bottom of the pedal stroke.
- If shorter cranks are used, the hip angle will be larger (more open) at the top of the pedal stroke. The leg will not rise up as far at the top of the pedal stroke. This will also be true regardless of whether the seat height is adjusted to reflect the same degree of knee flexion at the bottom of the pedal stroke.

Crankarm Length (Mm)	**Knee Flexion Angle Bottom of Stroke**	**Knee Arc**	**Hip Angle Top of Stroke**
No Change in Seat Height			
165	32.4	31.20--Shorter	40.3—More Open
170	30	32.51	39.7
175	27.4	33.89--Longer	39.2—More Closed
Change Seat Height			
165	30	31.77--Shorter	40.8—More Open
170	30	32.51	39.7
175	30	33.25--Longer	38.7—More Closed

Table 1. Changing crankarm length: Regardless of whether seat height compensates for a change in crank arm length or not, shorter cranks always result in a shorter knee arc, a more open hip angle, and potential for higher RPM. Baseline value is 170 mm crankarm length with a knee flexion angle of 30° at the bottom of the pedal stroke. For other methodology and assumptions, see Figure 15 and description on page 32.

Acceleration

Conventional wisdom has it that shorter crankarms allow one to accelerate more quickly. This is the approach of velodrome racers.

This opinion is not universal. Some riders report that longer crankarms accelerate more quickly but that high rpm cannot be maintained.

BMX riders traditionally use long crankarms. For example, here is a typical sizing chart.[13]

Inseam	27”	28”	29”	30”	31”	32”	34”
Crank Length	171	175	177	180	182	185	190

Figure 9. Typical BMX crank sizing chart.

13 From Wiregrass BMX. Linked and accessed Jan 14, 2008.

Custom Bikes

Most riders do not need bicycles with custom dimensions.

Riders generally need custom bicycles when they require a bicycle with longer or shorter top tubes relative to frame size. That is to say when their reach is out of normal proportion to their leg length. Improved material strength and longer seat posts make this situation less common today than years ago.

For the purposes of discussion here:

- Leg length is the distance from the ground to the greater trochanter of the femur.
- Bicycle reach is a combination of torso and arm length. With the hand comfortably straight up over the head, bicycle reach may be defined as the distance from greater trochanter to the first webspace, the crotch between the thumb and second finger.

  Comfortably straight up over the head means not hyperextending: the elbow is a few degrees short of full extension and the shoulder on the extending side is level with the shoulder on the non extending side.
- Reach height is leg length and bicycle reach.

The leg-length to reach-height ratio is about 42% for normally proportioned riders.

When racers' lower body to total reach proportions are less than 40% or more than 45%, they may need a custom frame.

Since beginners and recreational riders tend to sit more upright, their effective reach is shorter.

When riders who prefer a torso angle of 60° have a lower body to total reach ratio of more than 44%, they may prefer a custom frame.

Riders whose reach is disproportionally shorter than their leg length, whether male or female, may still be able to ride stock bicycles if they find frames with relatively short top tubes, sometimes marketed as having "women's-specific" geometries.

Such bicycles are often also a good choice for beginners, recreational riders, and obese riders who prefer a more upright position.

Some manufacturers specialize in stock bicycles proportioned for tall riders.

Riders who require frames less than 50 cm may find that their toes overlap the front wheel when they turn the bicycle, and may require a bicycle with custom geometry to avoid this safety problem.

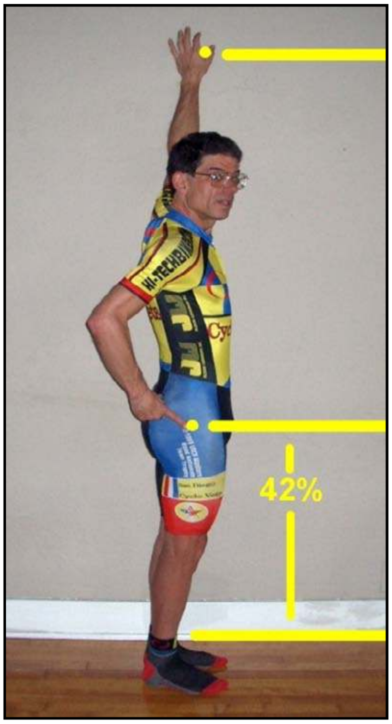

Figure 10. The ratio of leg length to total reach is normally about 42%. The rider points with his right middle finger to the bump of the greater trochanter of the femur.

Other Methods

If your arm span is within 1 inch of your height, height divided by inseam will give a good measure of your bicycle reach.

If height divided by inseam is more than 2.2, you have a relatively long torso. You will need a bicycle with at least as long a top tube as your frame size.

If height divided by inseam is less than 2.0, you have relatively long legs. You will need a bicycle with a top tube at least 2 cm shorter than your frame size.

Figure 11. Arm span vs. height.

Part 2: Bike Positioning

Principles

Fit Window

For most riders, there is a “fit window,” or range of perfectly acceptable bicycle positions. Position is a compromise. Position is different for optimizing muscle power, aerobic efficiency, comfort, bicycle control, and minimizing injury.

Position may be modified within the fit window in response to overuse or traumatic injuries.

Here are some simple ways to make sure your position is within an acceptable fit window.

Be Safe

Never make adjustments to bicycle parts that extend them beyond their safe limits. The stem and seatpost normally have limit lines marked with either “maximum extension” or “minimum insertion” warnings.

Be certain to tighten bolts properly after making adjustments. Many bike fit problems and mechanical failures result from parts slipping from incomplete tightening or breaking from over tightening.

Make Modest Modifications

Seasoned riders have adapted to their positions, whether good or bad.

To prevent overuse injuries, especially when adjusting seat height, generally make modifications gradually, allowing time to adapt to new positions.

Do not change seat height more than 3 mm (1/8 inch) every 300 miles.

Another option, less commonly used, is to immediately fit the “best” position, and then ride a limited volume and intensity. Gradually increase duration and ride difficulty until adapted.

Set-Up, Tools

You or your position adviser (bicycle shop seller, frame builder, friend, or coach) can approximate good bicycle fit by a quick road test.

For a more precise fit, set the bicycle on a trainer. Level the bicycle with a trainer block or an about two-inch block of wood under the front wheel. If the bicycle has a top tube parallel to the ground when off the trainer, the top tube should be parallel to the ground on the trainer.

You will need bike tools, a plumb line or straightedge, a level, a tape measure, calipers, and a recording sheet and pen. An assistant, a goniometer (angle-measuring device), a calculator, and a clipboard are helpful.

Warm Up

Riders ride differently when warmed up.
Pedal at least moderately hard for 10 minutes before making adjustments.
Pedal moderately for a few minutes between adjustments.

Riders ride differently during hard efforts.
A comprehensive fit includes observing riders during maximal ramped power and sprint efforts.

Where to Start

The order in which you perform adjustments is important since some measurements are dependent upon others. The order used in the following pages works best for most riders.

Seat Height

Seat height is the most important bicycle-position setting.

Seat height is the holy grail of power.

Many non seat-height bike-positioning recommendations are often work-arounds to mitigate a suboptimal seat height.[14]

After seat height is initially set, it may need to be adjusted if cleat fore-aft, seat fore-aft, cleat thickness, pedal height, crankarm length, shoes, or saddle are changed.

Rule of Thumb

Set the seat height so that the knee is flexed about 30° at the bottom of the pedal stroke. Power riders may set the saddle higher. Beginners may set the saddle lower.[15]

Figure 12. Seat height. A seat height that results in 30° of knee flexion is a good compromise for many riders. Red dotted anatomical landmarks, from the top: Greater trochanter of hip, lateral condyle of knee, lateral malleolus of ankle. Racers may prefer a higher position. Beginners may prefer a lower position.

14 For example, suggestions to move the seat back for anterior knee pain (patellofemoral dysfunction), or use medial wedges for medial knee pain (anserine tendonitis), or move the cleats back for time trialing, or use longer cranks for time trialing, may merely be substitutes for raising the saddle. Suggestions to move the seat forward for iliotibial band pain or hamstring strain, or move cleats forward for sprinting, may really be substitutes for lowering the saddle.

15 Genzling, C. Claude, in the 1970s, was one of the first authorities to popularize and set seat height not only by inseam formulas but also by knee flexion at the bottom of the pedal stroke, advocating 25° to 30° of knee bend.

Discussion

Set seat height based on knee flexion (leg extension):

Angles are measured in degrees of flexion from a straight leg (this is the same as the number of degrees short of full extension).

By convention, knee angles are measured when the leg is at the bottom of the stroke (6 o'clock position) and the foot is horizontal. The angle is determined by the greater trochanter of the hip (femur), the lateral condyle of the knee (femur), and the lateral malleolus of the ankle (fibula).

For an illustration of lower limb bones and landmarks, see Figure 84 on page 120.

This conventional method is practical because it is easy to have the crank vertical and the foot horizontal.

However, this method has minor drawbacks because it may not account for effective seat tube angle and ankling (ankle motion). Although positioning the shoe horizontally standardizes the measurement, not all riders pedal flatfooted. Many riders pedal toe down; some drop their heels while pedaling.

Too low a saddle is one of the most common fit errors and is associated with pain in the front or sides of the knee. Front of the knee pain is the most common knee overuse injury I see. A low saddle can exaggerate the natural knees-in or knees-out riding style inherent in any given rider, and so contribute to both inside of the knee (medial) and outside of the knee (lateral) knee pain. For more about knees-in and knees-out pedaling styles, see page 91.

Too high a saddle is associated with back of knee, outside of the knee (lateral), hamstring, and Achilles pain.

This standard method of measuring knee angles may need to be modified depending upon rider style.

Many riders come forward for hard effort on level ground or when sprinting, effectively increasing knee flexion.

Time trialists come forward because the loss of leg extension and power is more than compensated for by the opening up of the hip angle. This is not ideal: better is to come forward *and* raise the saddle. Read more about time-trial position on page 76.

Since acceleration and fast cadence is a requirement for sprinters, this makes sense when the tradeoff in power is the ability to increase rpm. Read more about sprinting on page 32.

Professional riders often prefer a slightly lower seat height to help keep balance when jostling in large packs.

When seat height, conventionally measured along the seat tube, is set by formulas based on inseam or leg length, moving the cleats forward or back effectively decreases or increases seat height. However, cleat position may not be the reason why sprinters like a forward cleat position and time trialists a rearward one. As you may read starting on page 32, the reason may have more to do with seat height.

Generally, the higher the saddle the more power you can generate, and the less the aerobic cost. However, too high a saddle may cause your hips to rock—wasting energy and thereby worsening economy (metabolic cost)—or restrict your leg speed, your ability to pedal fast cadences.

Seasoned racers tend to have more of a toe-down pedaling style. Beginners and recreational riders tend to pedal more flat-footed.

For this reason, a racer may have the same knee angles while pedaling the bicycle with a higher saddle position.

- Beginners, recreational riders, sprinters, mountain bikers, and those with tight hamstrings prefer a knee angle about 30° of knee flexion.
  For a discussion about why a lower saddle may improve sprinting, see page 32.
- A knee angle of 25° to 30° knee flexion is a good compromise between performance and injury prevention for seasoned racers.

Time trialists, especially those with good back and hamstring flexibility, may fit at knee angles just 10° knee flexion in part because their angles increase as they come forward on the saddle when pedaling at time-trial pace. For examples of minimum knee flexion and time trial set-up, see Figure 54 on page 76, or Figure 58 on page 82.

Since mountain bikes have a higher bottom bracket than road bicycles, and since bicycle control and center of gravity is a little better with the saddle slightly lower, mountain bikers adjust their seat height down to allow up to 5° more flexion in the knee.

Since it is easier to develop high rpm with a saddle slightly lower, sprinters may also prefer to adjust their seat height down to allow up to 5° more bend in the knee. Read more about this starting on page 32.

Figure 13. Mountain bikers often prefer a slightly lower saddle than road riders do. The center of gravity is lower and bicycle control may be improved. Riders are able to more easily move backward and forward on their saddles on descents and climbs to improve traction.

Other Methods

Knee Angle Variations

Authorities have recommended knee flexion angles between 25° and 44°.[16]

Some authorities align the crank with the down tube. Aligning the crank with the down tube generally extends the knee a few degrees more.

Not all bicycles have simple, straight down tubes that allow the crank to be precisely positioned. Not all riders sit center-aligned with the down tube; many are forward or rearward of this position. Many riders sit back on the saddles when climbing, effectively extending their legs and decreasing their knee flexion.

Some authorities do not use standard anatomical landmarks, centering the goniometer on "the middle of the knee" and tracking the crankarms along the axis of the leg and of the thigh.

Formulas

Formulas based upon inseam measurements or other body dimensions can only give approximate results and can only provide starting points.[17] Cleat fore-aft, seat fore-aft, cleat thickness, pedal height, shims and orthotics, crankarm length, seat tube angle, foot length, and pedaling style are often not considered in such formulas.

Most popular formulas are based on studies of racing cyclists, decades old, developed before the use of clipless pedals.

If formulas are based on scientific study, they are usually based on trochanteric leg length or inseam, and on minimizing oxygen consumption. Formulas have not generally been based on injury prevention, maximizing power output, or maximizing leg speed. [18, 19, 20, 21, 22, 23.]

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16 John Howard recommends a flexion angle between 30° and 44°. Personal communication Feb 3, 2008.

17 Peveler, in a study of 19 riders, showed that setting seat height by 88.3% of inseam (the LeMond method), results in knee flexion from 14° to 42°. Using 109% of inseam results in knee flexion from 9° to 42°. Using the heel-on-pedal method results in knee flexion from 21° to 42°. Peveler, W et al. *Comparing methods for setting saddle height in trained cyclists.* Journal of Exercise Physiology. 8. (2005).

18 Gonzalez, H and Hull, ML. 97% of trochanteric leg length. Results in the least oxygen consumption. *Multivariable optimization of cycling biomechanics*. J. Biomechanics. 22 (11/12). 1151-1161. (1989).

19 Guimard, C and LeMond, G. 88.3% of inseam equals seat height to bottom bracket.

20 Hamley, EJ and Thomas, V. *Physiological and postural factors in calibration of the bicycle ergometer.* J Physiol. 91(2). 5-56. (1967). 109% of inseam or 100% trochanteric leg length equals seat height to pedal.

21 Hodges, M (1982). Reported by Borysewicz, E. *Bicycle Road Racing*. Vitesse Press. Page 47. (1985). 96% of trochanteric leg length equals seat height to pedal spindle. Account for and subtract cleat thickness and half pedal thickness. Results in the least oxygen consumption.

22 Nordeen-Snyder, K. *The effect of bicycle seat height variation upon oxygen consumption and lower limb kinematics.* Medicine& Science in Sports & Exercise. 9. 113-117. (1977). 105% of trochanter leg length.

23 Shennum, PL and deVries, HA. *The effect of saddle height on oxygen consumption during bicycle ergometer work.* Medicine & Science in Sports & Exercise. 8. 119-121. (1976). 100% of trochanteric leg length.

My preferred easy-to-remember, rough rule-of-thumb formula is that the distance from the center of the bottom bracket along the seat tube to the top of the saddle should be 90% of inseam measurement for racers, a little lower for recreational riders.

Heel on Pedal

Figure 14. Yellow ring encircles the heel on the pedal.

Some set the seat height so that the heels just touch the pedals at the bottom of the pedal stroke.

This method tends to give lower seat height than most formulas.

Again, this method has problems because cleat fore-aft, seat fore-aft, cleat thickness, pedal height, shims and orthotics, and pedaling style are not considered with this rule.

As High as Possible

Since power improves as seat height increases, some riders purposefully raise their saddles too high—then lower the saddle so that they can (1) reach the pedals (not rock), (2) have enough leg speed to sprint, or (3) prevent/treat an overuse injury.

Rocking

Rocking the hips while pedaling can be a sign that the saddle is too high. Nevertheless, everyone rocks at pedal cadences faster than their neuromuscular fitness, and some riders rock no matter what their seat height.

Why a Lower Saddle Improves Sprinting

The ability to spin at a high cadence is one of the attributes of an excellent sprinter. (Peak power, tactics, and skill are others.) Keep in mind a low position sacrifices economy (metabolic cost) and steady-state power. Read more about this on page 35.

A lower saddle makes it easier to achieve a high cadence.

Prove it Yourself

You can prove this to yourself easily. You will need a cadence computer. Mount your bicycle on a stationary trainer. After a 15-minute warm-up, pedal in your easiest gear with a cadence of about 80 rpm. Increase cadence 5 rpm every 15 seconds until you max out. Now lower your saddle 1 cm (about half an inch). Perform the same test. See how fast a cadence you can work up to. Repeat the test with the saddle back at its higher position. Most riders can spin faster at the lower saddle position.

Trigonometry Helps Explain It

Here is one explanation why a lower saddle improves leg speed:

The leg travels a shorter distance when the saddle is lowered, and so more revolutions per minute can be generated.

For math buffs, here is the basic trigonometry. Please see Figure 15.

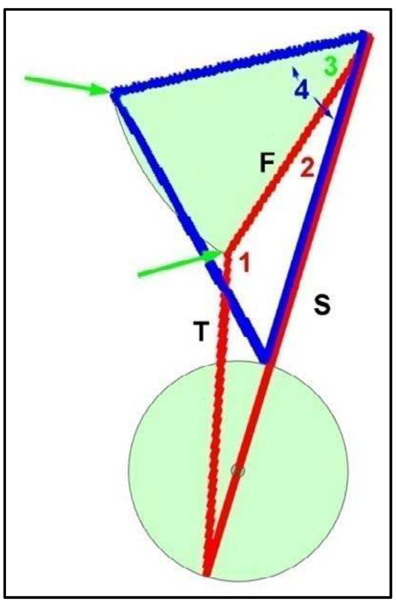

Figure 15. Schematic representation of the hip, knee, and foot position at the top and the bottom of the pedal stroke. F = femur. T = tibia. S = saddle to pedal segment. Red triangle diagrams the bottom of the stroke. Blue triangle diagrams the top of the stroke. The green pie slice and arc between arrowheads represents the distance the knee moves. The green circle represents the pedal circle. See text.

For relative simplicity, assume that:[24]

The leg is represented by a femur segment (F) and tibia segment (T).

The S segment distance is the distance from the saddle to the pedal. It is close to seat height, plus or minus the crank length, depending upon whether one is considering the bottom (red triangle) or top (blue triangle) of the pedal stroke.

The upper end of the thigh is fixed to the pelvis, attached at the hip.

The knee moves in a circular arc, the radius of which is determined by the length of the femur.

The length of the arc (between the green arrowheads in the figure) is shorter when the saddle is lower.

Detailed Calculations

Assume a femur (F) segment of 40 cm (about 16 inches) and a tibia (T) segment of 50 cm (about 20 inches). The tibia segment includes the length of the foot.

If the seat height is set so that the knee has 25° of flexion, the Red Triangle Angle 1 will be 155°. The Red S segment can be calculated. It is 87.9 cm (about 34 inches), representing seat height plus crank arm length. If crank length is 17 cm (170 mm, about 6-3/4 inches), then seat height is about 70 cm (about 27-1/2 inches). The value can be calculated based on the cosine rule, as applied in this situation: $S^2 = F^2 + T^2 - 2(F)(T)$ (cosine 155). The cosine rule will allow many of the calculations that follow.

The Red Triangle Angle 2 can now be calculated. It is 13.9°.

Once the S segment at the bottom of the pedal stroke is known, the corresponding segment length at the top of the stroke is this value minus twice the length of the crank arm. As the crankarms are 17 cm (170 mm) the corresponding Blue S segment will be 53.9 cm.

Now Blue Angle 4 can be calculated. It is 62.3°. The Green Angle 3, by subtraction, is 48.4°.

Now the Green Arc distance between the Green Arrows can be calculated. It is 33.8 cm. The value can be calculated based on arc's percentage of the formula diameter = 2π (radius). Here the distance = $2\pi (40)(48.4/360) = 33.8$.

Consider the situation if the seat is lowered so that the knee has 35° of flexion. This will be about 2 cm lower. The Green Arc distance will be 31.4 cm.

The Green Arc distance is 2.4 cm shorter, about 7 % of the original length.

If leg speed is the issue, other things being equal, a rider might be expected to be able to pedal about 7 % faster.

24 Yes, it is simplistic. The affect of ankling (ankle motion) and its interaction with cadence is ignored. The upper end of the femur segment is above the seat height. Pedal/cleat/shoe thickness is not considered. There is a difference between 30° of knee flexion at the bottom of a pedal vertically aligned with a seat set back 17° (seat tube angle 73°) rather than when the pedal is aligned with the seat tube. Motion outside the sagittal plane is not considered. Nonetheless, complicating the model will not change the relationships shown.

Knee Flexion Angle	Seat Height (cm)	Knee Arc (cm)	Result	Possible Effect
15	72.2	36.7	Longest Distance	Slowest RPM
20	71.7	35.2		
25	70.9	33.8		
30	70.0	32.5	Intermediate Distance	Intermediate RPM
35	68.9	31.4		
40	67.6	30.3		
45	66.2	29.4	Shortest Distance	Fastest RPM

Table 2. As the seat height is lowered and the knee bend at the bottom of the stroke increases, the knee travels a shorter distance as the foot moves from the bottom to the top of the pedal stroke. Leg speed may improve. Here the distance the knee travels is based on an assumed femur (thigh) segment of 40 cm, a tibia (leg and foot) segment of 50 cm, and a crank length of 170 mm. See text discussion.

Moving the Cleat Back May or May Not Change Leg Speed

As discussed beginning on page 47 and specifically in reference to arch cleats on page 50, moving the cleats back on the shoe may worsen leg speed ability if seat height is based on inseam or leg length.

However, if seat height is based on knee flexion at the bottom of the pedal stroke, the knee arc will be shorter and leg speed ability may improve modestly. To help understand this principle, use the model described above. Consider the foot an extension of the lower leg, simplistically ignoring ankling.

Consider a rider with knee flexion of 30° at the bottom of the pedal stroke and a seat height of 70 cm (about 27-1/2 inches):

Moving the cleat back 2 cm (about 13/16 inch) will *increase* the knee arc about 2.9 cm if the saddle is not lowered. This might be expected to *worsen* leg speed.

Moving the cleat back 2 cm *and* lowering the seat to compensate—to have the same flexion angle at the bottom of the pedal stroke—will *decrease* the knee arc about 0.4 cm and might be expected to modestly *improve* leg speed.

Row	Lower Leg Segment (cm)	Knee Flexion Angle	Seat Height (cm)	Knee Arc (cm)	Possible Effect
1	50	30	70.0	32.5	Standard Leg Speed
2	48	18	70.0	35.4	++++ Slower RPM
3	48	30	68.1	32.1	+ Faster RPM

Table 3. From a standard position (Row 1), moving the cleat back might be expected to worsen leg speed performance if the seat height is not changed (Row 2). It might be expected to modestly improve performance if the seat height is lowered proportionally (Row 3).

A Higher Saddle Improves Power and Economy—To a Point

Seat height is the holy grail of power.

A low seat height robs power on both the downstroke and upstroke.

It is difficult to predict precisely from biomechanical models how seat height affects power. The issue is complex. It involves multiple muscles, the variable attachment points of the muscles on bones, resting muscle length, complex joint interactions with six degrees of freedom, and the absolute and relative length of the bones. Cadence is also a consideration. This issue is one where "one test is worth a thousand expert opinions."[25] Moreover, as is usually the case in science, we need more than just one test. Unfortunately, there has been little scientific study of seat height and power.

I believe a higher saddle improves power not so much because of what happens at the *bottom* of the stroke but because of what happens at the *top* of the stroke: the closure of the hip angle.

Consider two classic bicycling leg strength-training exercises: squats and step-ups.

Power lifters know one can lift heavier weights performing quarter squats than half squats, and lift heavier weights in performing half squats than full squats. A power lifter might quarter squat 800 pounds, half squat 650 pounds, and full squat 525 pounds.[26]

One can lift more weight up a 14-inch step than a 20-inch step.

When the knee and hips flex, when the knee and hip angles close, there is less strength.

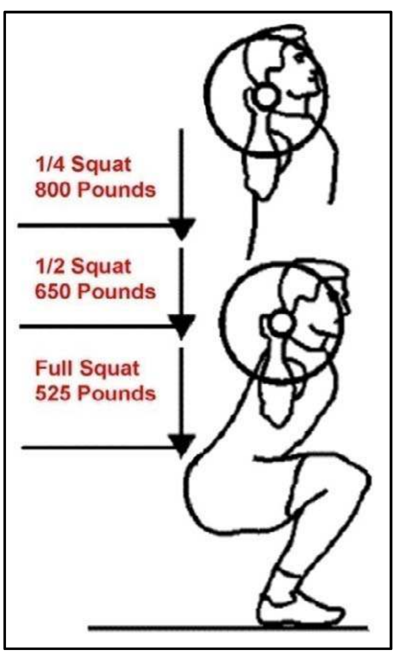

Figure 16. The more the hips and knees bend, the less the weight that can be lifted. It is the same on the bike: The more the hips and knees bend, the less the power that can be developed.

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25 Attributed to German rocket scientist Wernher von Braun.

26 Thibodeau, C. *Band training for big gains*. t-nation.com. (2004) Linked and accessed Jan 19, 2008.

As shown in Table 4, when seat height is lowered, the hips and the knees bend more. With more bend, less power can be developed.

Seat Height (cm)	Knee Flexion (Degrees) Bottom of Stroke	Knee Flexion (Degrees) Top of Stroke	Femur Angle (Degrees) Top of Stroke	Hip Flexion (Degrees) Top of Stroke	Result
72.2	15	120.4	12.1	97.9	Least Bend, Most Power
71.7	20	120.7	11.5	98.5	
70.9	25	121.1	10.7	99.3	
70.0	30	121.6	9.7	100.3	Intermediate Bend
68.9	35	122.2	8.4	101.4	
67.6	40	122.9	7.3	102.7	
66.2	45	123.6	5.8	104.2	Most Bend, Least Power

Table 4. As the seat height is lowered and the knee bend at the bottom of the pedal stroke increases, the hip and knee flexion increase at the top of the pedal stroke—resulting in less power. The model/table is based on a femur (thigh) segment of 40 cm, a tibia (leg and foot) segment of 50 cm, and a crank length of 170 mm. Hip flexion angle assumes 20° of pelvic tilt.[27]

Loss of power relates not only to increased bend in the hips and the knees. The more the body (torso) is bent over, the more the hip angle (the angle formed between the femur and the torso) closes. Closure of the hip angle is also associated with a loss of power, independent of hip flexion (the angle formed between the femur and the pelvis).

Seat Height (cm)	Knee Flexion (Degrees) Bottom of Stroke	Hip Angle (Degrees) Top of Stroke	Result
72.2	15	42.1	Open Hip Angle, Most Power
71.7	20	41.5	
70.9	25	40.7	
70.0	30	39.7	Intermediate Hip Angle
68.9	35	38.6	
67.6	40	37.3	
66.2	45	35.8	Closed Hip Angle, Least Power

Table 5. As the seat height is lowered and the knee bend at the bottom of the pedal stroke increases, the hip angle closes at the top of the pedal stroke—resulting in less power. The table is based on an assumed femur (thigh) segment of 40 cm, a tibia (leg and foot) segment of 50 cm, a crank length of 170 mm, a torso angle of 30°, and a 73 degree seat tube. For more information about torso angle, see page 68.

27 Hip flexion is the flexion of the femur with respect to the pelvis. If the pelvis is anteriorly tilted, flexion increases. Pelvic tilt is not readily measured and differs between riders. Femur angle is easily measured, or computed as in the modeling here. It equals (90 + pelvic tilt – hip flexion) degrees.
Sauer et al showed that males have about 21° and females about 24° of pelvic tilt. Sauer, JL et al. *Influence of gender, power, and hand position on pelvic motion during seated cycling*. Medicine & Science in Sports & Exercise. 39 (12). 2204-2211. (2007). Linked and accessed Jan 27, 2008.

Prove it Yourself

You can prove the importance of hip angle to yourself easily. A cadence, speed, or power computer is helpful, but not necessary.

Mount your bicycle on a stationary trainer.

After a 15-minute warm-up, unclip one of your feet, and pedal with one leg. Rest the other leg on the back of your trainer.

With your hands on the tops, pedal in a moderate gear with a steady cadence, say at 60 rpm.

After one minute, change your hand position to the drops.

Continue pedaling in the same moderate gear, still at the same steady cadence.

After another minute, return to the tops.

The tops are easier, aren't they?

The reason: When bent over in the drops, the hip angle closes, and power is lost. That is why seated climbers do not climb in the drops. (On level ground, sometimes the power lost is more than made-up for by improved aerodynamics).

Hip Angle Economics

As discussed above, a lower saddle improves leg speed. However, a lower saddle may worsen economy—it may take more oxygen to provide the same power. This may worsen steady-state performance in climbing or time trialing.

Economy in sport science is similar to economy for your car. Economy relates to fuel efficiency, miles per gallon. It is one of many important aspects of human performance.

Most studies of the 1970s and 1980s noted that by raising seat height, oxygen consumption was minimized. Most riders used to ride too low for optimal economy. For example, Edward Borysewicz noted in his now classic *Bicycle Road Racing*, that his Junior National Coach Mark Hodges found that economy was improved, for a majority of riders tested, by raising their seat height.[28] He also noted that this optimal height was higher than the traditional heels-on-pedals method.

Economy relates not only to changing seat height and the resulting change in hip angle. Economy relates also to the changes in hip angle with the same seat height In one study, aero-position oxygen cost was 1.5 mL/kg/min and heart rate 5 beats per minute higher compared with upright cycling.[29]

A Simple Test May Show Why Raising Seat Height Improves Economy

Try this: Stand on one leg. Lift the knee of your other leg up. Raise it as high as you are completely at ease and comfortable. Do not force things; do not try to raise your knee up as high as you possibly can.

If you are like most people, you can comfortably raise your knee so that your hip forms an angle with your thigh and torso of about 90°. If you work it, you may be able to raise your knee another 20° or so, to about 110° of flexion. If you lie down, flat on your back, and use your hands to pull your knee toward your body, you may achieve another

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28 Edward Borysewicz. *Bicycle Road Racing*. Vitesse Press. Page 47. (1985).

29 Gnehm, P, et al. *Influence of different racing positions on metabolic cost in elite cyclists.* Medicine & Science in Sports & Exercise. 29 (6). 818-823. (1997). Linked and accessed Jan 27, 2008.

25° or so of motion, for a total of 135° of flexion—the normal range of motion for young, healthy, uninjured, non-arthritic adults.

The message: it takes muscular work to bend your hip more than 90°.

In some ways, raising the knee is like a cartridge in a spring-loaded ballpoint pen. The cartridge slides in easily until it meets the spring. Then more pressure (energy) will slide the cartridge in further against the spring. Finally, the limit is reached.

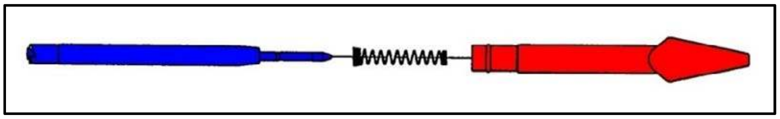

Figure 17. Cartridge (blue) slides easily into nose body of ballpoint pen (red) until it meets spring. Pressure will push it in further.

Now repeat the standing test. This time before raising the knee, bend about 60° forward at the waist. Now raise you knee. Keep track of how far you raised your foot, stand up straight, and with the knee raised to the same position measure the angle of hip flexion. It is less, perhaps 75°.

The message: it takes considerably more muscular work to bend your hip more than about 75° when you are bent over about 60°, typical for a bicycle rider.

Now look at Figure 18 and Table 6.

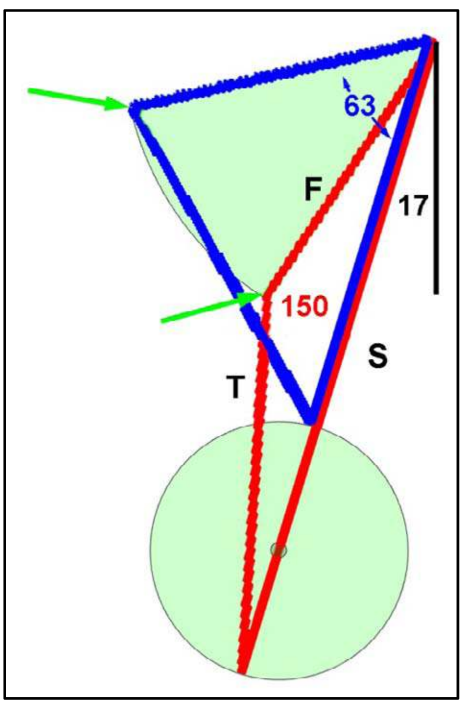

Figure 18. Hip flexion angle. In this model, with a seat tube angle of 17°, a level pelvis and saddle, and 30° of knee flexion at the bottom of the pedal stroke (knee angle 150°), the hip will flex 80° (63° + 17°) at the top of the pedal stroke.

Seat Height (cm)	Knee Flexion Angle Bottom of Stroke	Hip Flexion (Degrees)	Result
72.2	15	97.9	
71.7	20	98.5	
70.9	25	99.3	Best Economy
70.0	30	100.3	
68.9	35	101.4	Intermediate
67.6	40	102.7	
66.2	45	104.2	Worst Economy

Table 6. Hip flexion. As seat height is lowered, (1) the knee bend at the bottom of the stroke increases, (2) the hip angle closes and (3) more hip flexion is required. Other things being equal, economy worsens. The model/table is based on a femur (thigh) segment of 40 cm, a tibia (leg and foot) segment of 50 cm, a crank length of 170 mm, and a 73-degree seat tube. Hip flexion angle assumes 20° of pelvic tilt.

With a knee flexion of 30° at the bottom of the pedal stroke (knee angle of 150°), 170-mm cranks, and the model assumptions outlined on page 32, the hip will need to flex 100° at the top of the pedal stroke.

This may be okay if the rider is sitting up. However, as soon as the rider bends over, to a torso angle of 30°, the rider may be beyond the limits of comfortable flexion.

The rider *will* be able to lift the hips higher—either by (1) recruiting muscle fibers on the same side, or (2) by pushing the leg up by pedaling force on the other side. Extra muscular work will require more energy and worsen economy.

There is an upper limit to seat height economy. One possible explanation: Once the seat is so high that the hips rock to reach the pedals, non-propulsive muscular work is being performed and economy worsens.

If the rider wishes to keep this position (for example, for aerodynamic reasons), and wishes to improve economy, options include (1) rotating the pelvic to open the hip angle, (2) moving the pelvis forward (moving the seat forward), (3) raising the pelvis (increasing seat height), or (4) the increasing seat height equivalents: shorter cranks or cleats more aft.

Seat Position Fore-Aft

Rule of Thumb

Set saddle position fore-aft so that a straightedge placed against front of kneecap and the front of pedal spindle is vertical.

Discussion

If seat height is the holy grail of power, *seat fore-aft is the holy grail of balance*: (1) control for descending and cornering, and (2) weight distribution for the prevention or treatment of upper extremity overuse injuries.

My approach to seat positioning fore-aft is a variation of the classic K*nee*-O*ver*-P*edal*-S*pindle* or KOPS method—described in more detail on page 43.

Seat position fore-aft is adjusted to optimize bicycle balance and align the legs over the bottom bracket to best produce power and minimize overuse injury.

Do not change fore-aft position to set torso angle or reach. Adjust the stem or choose a bicycle with different geometry.

When the cranks and shoes are horizontal, a plumb line from the front of the knee should fall flush in front of the pedal spindle.

The knee may also be up to 2.5 cm (1 inch) behind this plane for taller or long-distance riders. Sprinters, track pursuiters, time trialists, and triathletes sometimes come forward.

Figure 19. Seat position fore-aft. Side view. With the crank forward and horizontal, a straightedge placed against the front of the knee and the front of the pedal spindle is vertical.

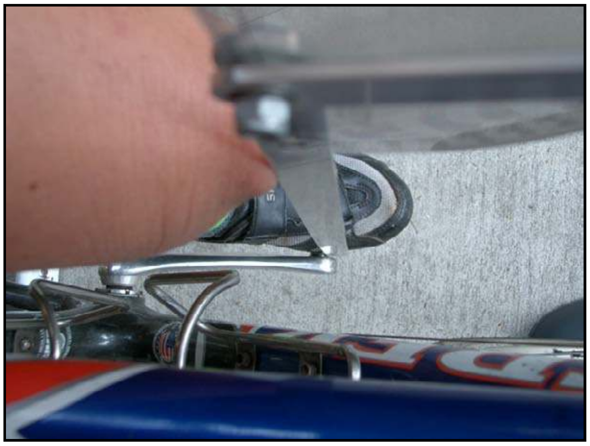

Figure 20. Seat position fore-aft. View from above. With the crank forward and horizontal, a straightedge placed against the front of the knee and the front of the pedal spindle is vertical.

Position fore-aft is also determined by seat tube angle and seatpost offset. Seat tube angle is not adjustable on a bicycle, although some rear-suspension systems result in changing seat tube angles. Seatpost offset is also not generally adjustable, although different seatposts can be used to modify position if the seat position fore-aft cannot be properly adjusted within the length of the saddle rails.

Weight Distribution

The rider comes into contact with the bicycle at three points: the saddle, the handlebars, and the pedals.

Bicycles are designed to handle best when 55% to 60% of bicycle and rider weight is on the rear wheel and 40% to 45% is on the front wheel.

Like bicycle fit in general, proper weight distribution allows you to be comfortable, ride safely, and work effectively. It reduces or treats overuse injuries. It makes you a better rider.

When too much weight is forward, bicycle control, handling, and safety may be a problem, especially on descents.

When too much weight is forward, upper body aches and pains are common—including hand numbness; tired arms and shoulders; and neck, shoulder, and upper back pain.

When too much weight is aft, bicycle control may be difficult in corners; front-wheel slide out can be a problem. Front-end shimmy on descents is more common.

Weight distribution changes with terrain. Riders often slide forward or aft on their saddles to change weight distribution as they ride. On mountain bikes, proper distribution is critical. Riders must be able to balance a forward distribution for uphill climbing traction and an aft distribution for descending.

Weight distribution results from almost all elements of bicycle fit, including pedal fore-aft, seat height, seat fore–aft, torso angle and reach. Most of these elements are adjusted to optimize position for other reasons—such as power production or overuse injury prevention.

Seat fore-aft is the principle element of adjustment affecting weight distribution. Adjustment of shoulder angle within the reach range is a secondary adjustment element.

Good weight distribution is generally achieved with the position advice given above.

Although weight distribution can be checked by weighing the bike and rider and then seeing what percentage of that weight is on the front wheel while on a stationary trainer, discussion with the rider about their needs and reactions to the bike's current set-up is generally the most productive approach.

Again, seat position fore-aft is important for power production, overuse injury prevention, comfort, bicycle balance, maneuverability, and safety.

Background and Theory

Many, though not all, riders are comfortable with the traditional, empiric, knee roughly over the pedal spindle method.

Here are some of the factors that determine best fore-aft positioning:

Seat height (knee flexion/leg extension) and reach can be set independently of seat position fore-aft.

Logically, biomechanically, as long as the hip angle is open enough, one might argue that seat post position fore-aft has no effect on power. Consider that: (1) One can keep leg extension and reach the same while rotating around the bottom bracket axis, (2) The recumbent cyclist's knees are far behind the pedal spindle.[30]

There *is* certainly an effect on power when the hip angle is closed. As the hip angle closes, less power can be applied. Time trialists, whose bent over aerodynamic position closes the hip angle, therefore often prefer a forward position.

Pressure on the hands and buttocks can be reduced or increased depending upon seat position fore-aft. This can affect overuse injuries such as hand neuropathy and saddle sores.

Seat position fore-aft certainly affects weight distribution on handling—just try riding a forward-position time-trial set-up down a steep technical descent—even with standard handlebars. However, superior bike handling may not be important to many riders who live in relatively flat locations, who are happy/prefer to descend slowly, or who avoid technical descents.

Seat position fore-aft may affect rider versatility.

Generally, a higher saddle means more power, but fewer rpm can be generated.

The all-round rider may want to (1) increase power by moving back on the saddle—effectively increasing seat height, leg extension, and power and (2) move forward on the saddle—effectively decreasing seat height—to increase rpm in a sprint.

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30 Although it is logical, it is not necessarily true. Some studies have shown differences, perhaps due to gravity-different effects on stability, muscle, or blood flow. For high power outputs, active use of the arms is also different. Too, D. *The effect of trunk angle on power production in cycling*. Research Quarterly for Exercise and Sport. 65 (4). 308-315. (1994). Linked and accessed Feb 4, 2008.

When the seat is over the bottom bracket, sliding back on the saddle does not change effective seat height as much as it does when the saddle is more rearward.

If the seat fore-aft is set too far back, and the reach adjusted correctly, riders may hit their knees on the handlebar when they stand ascending climbs or sprinting. This effect is more noticeable as the grade of the climb increases.

Other Methods

Traditionally, a plumb line from the tibial tubercle bisects the pedal spindle. This is shown in Figure 21. This conventional position of the Knee Over the Pedal Spindle is known by the acronym KOPS. This rule of thumb is an injustice to anatomical variants and specialty riding priorities, as noted here and by other authors.[31]

In bike-fitting practice, it is much easier to set a straightedge against (1) the front of the knee (flush against the patella) and (2) against the front of the pedal spindle, and eyeball whether the edge is vertical, or how far off vertical it is. This is shown in Figure 19 and Figure 20.

Problems with the traditional method include: (1) novice bike fitters do not know what a tibial tubercle is, (2) a plumb line is required, and (3) the plumb bob cannot fall freely and bisect the pedal spindle because the foot and pedal are in the way.

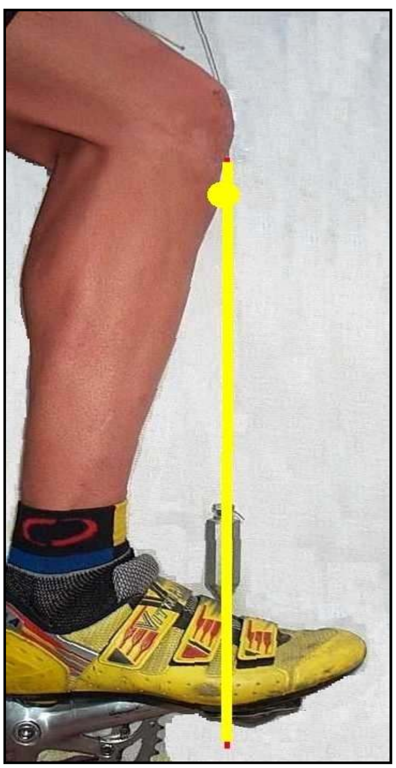

Figure 21. Traditional method of establishing seat position fore-aft. A plumb line dropped from the tibial tubercle bisects the pedal spindle with the crank horizontal. The figure demonstrates a common fitting error: The crank is not quite horizontal.

31 For example, Bontrager, K. *The myth of KOPS, updated*. (1998). Linked and accessed Jan 1, 2008.

Some riders position the seat fore-aft by measuring the distance a plumb line from the nose of the saddle falls behind the bottom bracket. Road riders tend to have the saddle an inch or more back. Sprinters and time trialists tend to have a more forward position.

Road racers governed by UCI (Union Cycliste Internationale) regulations must position their saddles so that this distance is at least 5 cm (2 inches). Since a forward seat position improves time trialing, most racers subject to UCI rules set the saddles at this 5 cm point.

However short-legged riders (more specifically, short-femured riders) have difficulty meeting this 5 cm requirement. Riders may have their saddles forward of this position unless "using a plumb-line…while pedaling…the point of the rider's knee when at its foremost position passes beyond a vertical line passing through the pedal spindle."[32]

For more on UCI bike fit rules, see page 122.

For most standard road bicycles, recreational and general road racers usually have their saddles all the way back on the rails, time trialists all the way forward, and criterium riders in between.

After you have adjusted the fore-aft position, repeat the determination of your seat height, since adjustment of saddle fore-aft may change the seat height.

32 *UCI Cycling Regulations Chapter III, Equipment, Section 2, Bicycles 1.3.013*.

Saddle Shape & Angle

Rules of Thumb

Choose saddle shape to match your anatomy.
Set the saddle level.

Shape

Most saddle pressure should be concentrated around your sit bones, but not all.

Since cyclists often change their fore-aft position while riding, there is more to saddle choice than matching the distance between your sit bones to some dimension on the saddle.

Many riders, looking for a comfortable saddle, mistake cushiness for support. Although broadly speaking riders with wider hips prefer a wider saddle, it is hard to predict saddle comfort just by looking at the saddle or at the rider.

It may take a few tries to find a saddle shape that fits your anatomy. Although most men's pelvises are shaped similarly, women's are not. Women, more than men, frequently must try several saddles to find one that fits.

Genital numbness is a common problem in both men and in women. Although saddle cut-outs help some riders, they concentrate pressure on the sides of the cut-outs for others. One-sided genital swelling is a common problem in women who ride a lot; saddle cut-outs can worsen this problem.

(For information about saddle soreness, see *ABC Publications* at the end of this book on page 126.)

Angle

Most riders ride best when their saddle is level.

Some saddles have a significant rise in the back. Instead of setting a straightedge or level across the entire length of the saddle, which would result in a nose-up saddle, place the straightedge only the sitting portion of the saddle.

Some riders have the noses of their saddles slightly up or down to suit their anatomy. This is generally only a matter of 1° or 2° from horizontal.

Racers governed by UCI regulations must position their saddles level.

Set your bicycle level on a stationary trainer. Pedal with no hands. Do you feel you are sliding forward? Your saddle nose may need to come up. Do you feel all the pressure is on your sit bones or have genital numbness? Your saddle nose may need to go down.

Preferences for a degree or two of nose-down saddle are so common as to be almost the rule for certain groups of cyclists.

Where aerodynamics are important, a slightly nose-down saddle position helps roll the pelvis forward, flex the back, and achieve a flat, low torso.

Mountain bikers often prefer a slightly downward saddle angle to reduce the tendency of their shorts to catch on the nose of their saddles.

Figure 22. Saddle angle. The saddle is level.

Those with genital numbness may find that having the noses of their saddles slightly down improves the problem. (Genital numbness is also associated with a saddle that is too high.)

A slightly down saddle nose often helps with crotch discomfort in women or with the use of aerobars (a specialty type of handlebar that allows a low, aerodynamic profile).

Be cautious: too far down results in more pressure on your shoulders, arms, and hands.

Background and Theory

Saddle discomfort is a nearly universal complaint. Traditionally made out of leather, saddles used to require a break-in period. Rituals of soaking saddles or riding in the rain, or applying leather-softening greases to the saddle were customary practices.

Beginners often have trouble finding a comfortable saddle—for at least two reasons: (1) their tissues are not adapted to riding, and (2) their legs do not push as hard—and so they sit heavier on the saddle.

It is for this second reason that experienced riders are most likely to experience saddle discomfort on long, easy days.

Some feel that setting the saddle angle horizontal is intuitively logical for balance and distributing pressure when riding on level ground.

Consider a ride that is a third uphill, a third downhill, and a third on level ground. Most time will be spent climbing—where speeds are the slowest. A horizontal saddle on level ground will point up when climbing. When climbing hard, some cyclists feel they are pushing themselves off the back of the saddle. Since a saddle set nose down on level ground will be closer to horizontal when climbing, it also makes sense to have a slightly nose down saddle if you climb a lot.

Foot/Pedal Fore-Aft

Rule of Thumb

Position cleat so that ball of the foot lies between the center and the front of the pedal spindle.

From a practical point of view, considering the current drillings of most shoes, this is often the most rearward cleat position the shoe allows.

Discussion

Position the cleat so that the ball of the foot is *over* the center of the pedal spindle or up to 10 mm (1 cm, ½ inch) *in front* of the spindle.

Since pedal spindles are up to 20 mm in diameter, positioning the ball of the foot over the *front* of the pedal spindle amounts to a distance up to 10 mm forward of center.

It is easiest to assess this in the power position: with the crankarm in the 3 or 9 o'clock position (for the right or left foot respectively) and the foot horizontal.

The ball of the foot is the knuckle of the first metatarsal head and big toe. This corresponds to the bump that sticks out at the base of your big toe—where some people get bunions.

To adjust the shoe forward, move the cleat rearward. For most riders, for most shoes and pedal systems, I position the cleat at its most rearward position on the shoe.

Traditionally, the ball of the foot is positioned *over* the center of the pedal spindle.

This traditional position is the most rearward shoe position (most forward cleat position) I generally advocate.

Figure 23. Yellow circle: First metatarsal head.

Figure 24. Foot fore-aft, looking down. Left foot, 9 o'clock position. Yellow oval: Edge of the first metatarsal head, just in front of the pedal spindle.

Medical Considerations

Positioning the ball of the foot forward is beneficial because it results in less Achilles' tendon problems and less forefoot pain (sometimes experienced as "hot foot"). Standard shoe drillings may not allow you to place the shoe position far enough forward (the cleat rearward) to alleviate forefoot pain. Custom drillings may be required.

A rearward shoe position (forward cleat position) results in more pivot up and down of the heel while pedaling and is associated with Achilles' tendonitis.[33]

A forward shoe position may spread pressure over more of the foot and therefore explain why such a position helps many riders with forefoot pain.

Generally Minor/Potentially Major Additional Considerations

The more rearward the cleat position, the lower the saddle to fit seat height with the same knee angles. (Very rough rule of thumb: Lower seat height one-third of rearward set-back. If you move your cleats 6 mm rearward, lower your saddle 2 mm. Suggested method: Reset your seat height by knee angle at the bottom of the stroke as described on page 27.)

Rearward cleat position (1) lowers the center of gravity, potentially improving balance, (2) improves aerodynamics.

If exiting clipless pedals requires appreciable force, the closer the cleat to the midfoot, the more difficult it is to exit. If exiting clipless pedals requires a certain degree twist of the foot, generally the closer the cleat to the midfoot the easier it is to exit.

For riders who pedal toes out, the more rearward the cleat position, the less the heels hit the crankarm.

Positioning the foot forward on the pedal may result in more toe/front wheel overlap. This may be a problem, and risk a crash, especially on small frames.

Background and Theory

There has been some empiric evidence and little convincing scientific study to support the above recommendations.

Cyclists may have taken their positioning from the biomechanics of runners. Many decades ago, cycling shoe soles were soft. They bent at the ball of the foot

With the advent of toeclips, and their limited sizes, long-footed cyclists often resorted to multiple washers on the toeclip fixing bolts to avoid pinching their toes.

Cleat placement may be less important than it used to be because of stiffer soles. However, stiffer carbon soles are associated with higher peak foot pressures[34] and so may be associated with more "hot foot."

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33 Frame and Dugan showed that ankle angles varied approximately 10° with a traditional ball-of-foot position and half as much, 5°, with a radically-rearward heel position. Frame, JW and Dugan, EL. *Kinetic and kinematic effects of altering cleat placing during cycling.* American Society of Biomechanics. 2006 Annual Meeting. Abstract. Linked and accessed Dec. 19, 2007.

34 Jarboe, N and Quesada, P. *Effects of cycling shoe stiffness on forefoot pressure.* Foot and Ankle International. 24, 10. (2003).

Consider that until relatively recently, most bike fitters used formulas based on leg length or inseam to set seat height.

If the cleats are moved rearward without a change in seat height, such a change may result in more power for general riding.

However, such a forward position may limit leg speed and the ability to produce the high cadence (rpm > 140 rpm) often required in sprinting. Sprinters, who require high cadences, may therefore prefer to have their feet back on the pedals a little more and be more on their toes.

However, if knee angles are used to set seat height, as I advocate, riders who move their cleats rearward will lower their saddle. In this case, there is no evidence that power or high-cadence performance will change. For details, see the discussion in *Seat Height* on page 34.)

Limited Scientific Theory

With traditional cleat placement, in transmitting force to the shoe and pedal, the first metatarsal head is the structure that provides the greatest contact surface area.

If maximizing aerobic power is the goal, it is logical that aligning the maximum forces over the pedal spindle makes biomechanical sense.

Sanderson and Cavanaugh[35] measured forces on a specially designed insole with 256 discrete force-measuring elements. Using three-dimensional computer modeling, they showed that at a power level of 400 watts and at a cadence of 90 rpm, the highest pressure occurred *behind* the first metatarsal head. They used a platform pedal with the first metatarsal head positioned slightly rearward of the pedal spindle.

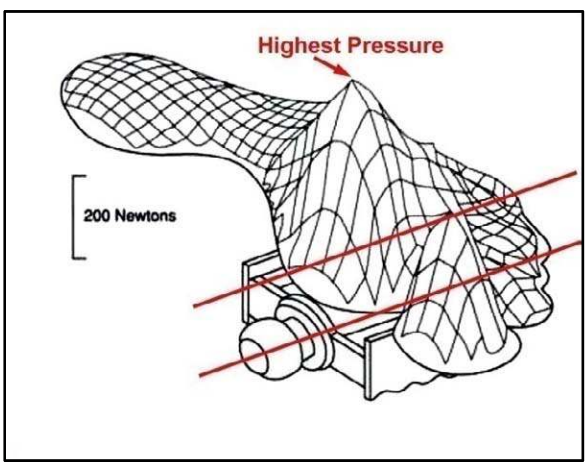

Figure 25. 3D image contour of peak pressure on the bottom of the foot during cycling. Red diagonals run through the ball of the foot and the pedal spindle. Adapted from Sanderson.[36]

35 Sanderson, DJ, et al. *An investigation of the in-shoe pressure distribution during cycling in cycling or running shoes.* Proceedings of the 12th International Congress of Biomechanics. Umeå, Sweden. 903-907. (1985).

36 Illustration adapted from Cycling, Nike. *Sport Research Review*. Advertising Section. May/June (1990).

Using this point of highest pressure as a rational for foot placement, however, may be a circular argument. What would the peak pressure contour have looked like if the midfoot or hindfoot had been placed on the pedal?

In addition, consider that weight lifters do not perform squats or leg presses on their toes; they maintain a flat foot and are often taught to push through their heels.

Other Methods

A minority of authorities advocate using the second or third metatarsal head as the anatomical landmark. These structures may be a little rearward of the first metatarsal head. Sanderson advocates the fifth metatarsal head.[37]

Some use the second metatarsal head because this is closer to the center of where force is transmitted to the shoe and pedal. Others use the third metatarsal head because there are five toes and the third is the middle one.

However, these landmarks (1) are more difficult for novice bike fitters to identify, especially when riders have their cycling shoes on; and (2) it is more difficult to align these landmarks with the pedal axle.

Another method is to place the cleat one-third the way back on the shoe.[38]

Arch Cleats

Some riders and coaches have experimented with cleat placement at the midfoot (arch). Caution: This risks toe/front wheel overlap and crashing.

As long as seat height is set by knee angle, there are limited, if any mechanical reasons why high-cadence performance should change. (The excursion of the knee arc will be similar. Hip and knee angles will be close to the same. This is *not* the case if seat height is set by leg length or inseam. For a detailed discussion, see page 34.)

If propulsive power is derived from lower leg or foot musculature, it makes sense that midfoot cleat placement *could worsen* performance. However, if lower leg or foot musculature provides only stabilizing forces, it makes sense that midfoot cleat placement *could improve* performance. Furthermore, even if the lower leg or foot musculature provides propulsive power, reducing this workload *could* allow the primary propulsive muscles (quadriceps and gluteals) to work more effectively.[39]

In a 1989 study, Gonzalez and Hull found that a longitudinal foot position on the pedal equal to 54% of foot length corresponded to the lowest metabolic cost function.[40]

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37 Sanderson, David. Personal communication. Jan 20, 2008.

38 Empfield, Dan. Slowtwitch.com. Linked and accessed Feb 3, 2008.

39 Ericson found that the plantar flexors contributed 20% of the total positive work. The quads were responsible for 39% and gluteals 27%. Ericson, MO, et al. *Power output and work in different muscles groups during ergometer cycling.* European Journal of Applied Physiology. 55(3). Pages 229-235. (1986).

40 Gonzalez, H and Hull ML. *Multivariable optimization of cycling biomechanics.* Biomech. 22. 1151-1161. (1989).

On the other hand, in a more recent study, Van Sickle and Hull found that adjusting the anterior–posterior foot position on the pedal *does not* affect cycling economy (metabolic cost) in competitive cyclists pedaling at a steady-state power output eliciting approximately 90% of ventilatory threshold.[41]

Frame and Dugan found no change in power between a traditional position and a heel position.[42]

Further studies are lacking. Effect on maximum steady-state power, peak power, maximum cadence, fatigability, and acceleration are unknown.

Results are therefore inconclusive.

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41 Van Sickle, JR and Hull, ML. *Is economy of competitive cyclists affected by the anterior–posterior foot position on the pedal?* Journal of Biomechanics 40, 1262-1267. (2007). Linked and accessed Dec 12, 2007.

42 Frame, JW and Dugan, EL. *Kinetic and kinematic effects of altering cleat placing during cycling*. American Society of Biomechanics. 2006 Annual Meeting. Abstract. Linked and accessed Dec. 19, 2007.

Foot/Pedal Rotation Angle

Rule of Thumb

Set fixed cleats or the mid-point of floating cleats/pedals to point the toes the same way you walk. (Read about pedal float on page 54. Read about pedal stance width and stack height on page 104.)

Discussion

Riders may walk with their feet pointing straight ahead, outward (duck-footed) or inward (pigeon-toed).

Nowhere in bike fit is it more important to "adapt the bike to the rider, not the rider to the bike."[43]

Figure 26. Rider walks and pedals with toes straight ahead.

Figure 27. Duck-footed rider walks and pedals with toes pointing out.

Figure 28. Pigeon-toed rider walks and pedals with toes pointing in.

43 Attributed to Andy Pruitt, PA. Boulder Sports Medicine.

The cleats should generally be positioned so that the toes point as the rider walks. As riders do not necessarily walk with the toes of each foot pointed in or out to the same extent, neither should their cleats be adjusted symmetrically.

Some riders prefer to ride a little with their cleats slightly loose on a trainer to see where they are most comfortable before final tightening.

Partial rotation systems should be adjusted so that the mid position of rotation allows the foot to rotate to either side of its natural orientation.

Cleat position is not as critical with free-rotation systems, which allow the foot to rotate while still fixing it fore-aft, side-to-side, and up-and-down. Free rotation systems are most helpful for riders with moderate to severe duck feet

Whether fixed or freely rotating, proper cleat foot/pedal rotation angle allows the rider to disengage the pedal easily when desired and helps avoid unwanted release.

Duck-footed riders who hit their heels on the crankarms may prefer pedals with longer axles or pedal/stance spacers.

If the knees track in a vertical plane and if (1) the outside of the knee hurts, generally adjust the cleats to point the toes a little more outward; (2) if the inside of the knee hurts, point the toes a little more inward.

Other Methods

Traditionally, some riders and cycling authorities set the cleat so that the toes point straight ahead.

When cleats are set this way, duck-footed riders may get lateral knee (iliotibial band) overuse injuries. Pigeon-toed riders may get medial knee (anserine) tendonitis.

Some set the cleat position based on the position of the feet when the rider is sitting, feet dangling, and ankles at 90°. This method can be fine.

However, (1) riders are more likely to consciously or unconsciously point their feet straight ahead if they are being observed, and (2) I can always observe riders walking, but do not always have, in a field setting, a suitable table from which riders can dangle their feet.

Foot/Pedal Float

Rule of Thumb

For most riders, float is a good idea.

Discussion

Most current pedal/cleat systems allow some rotation on the horizontal plane of the pedal. Nine degrees of float is enough for most riders.

My experience suggests that overuse injuries, especially iliotibial band syndrome, are more common in riders who pedal without float.

Too much float causes some riders to develop a hamstring overuse injury. However, hamstring overuse injuries are among the least common knee overuse injuries I see.

Best viewed from behind, riders who are unable to stabilize the foot, whether due to general weakness or ride-specific fatigue, may wiggle their heels while pedaling, especially at the bottom return of the pedal stroke.

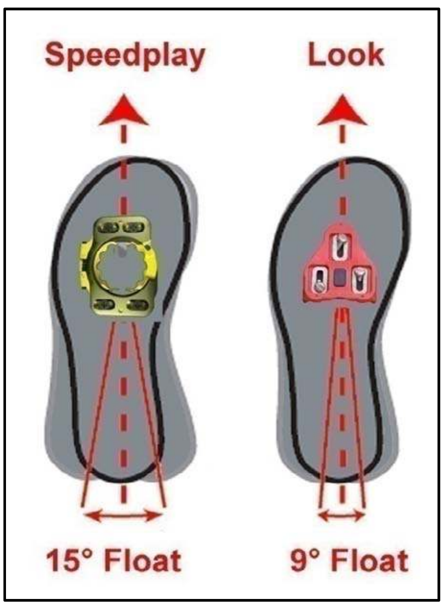

Figure 29. Both Speedplay (15°) and Look (9°) pedals have appreciable float.

Background and Theory

Traditionally, old-style pedals with toeclips allowed a few degrees of float. It was not that the float was planned, but it happened.

Traditionally, riders were positioned with their feet pointing straight ahead, and those with overuse injuries relocated their fixed cleats pointing their toes toward the side that hurt—to shorten the path of the tendon on the injured side.

Clipless pedals were initially marketed without float. Many riders developed iliotibial band syndrome and other knee overuse injuries.

Pedal	Float (degrees)
Campy Record	6, spring centered
Chorus	6, spring centered
Crank Bros. Egg Beater	6
Look PP206	9, friction
CX6, CX6 Ti	9, friction
CX7 Cant adjustable	9, friction
Shimano DA	6, friction
Ultegra	6, friction
SPDR540	10, friction
M-series	8, friction
Speedplay X-series	35+, free
Zeros	15, free, adjustable
Frogs	26
Time EQ	10, spring centered
Impact, Impact Mag	10, spring centered

Table 7. Float, selected pedals. Information from manufacturers' websites.

Although a straight-ahead no-float position may be (perversely) aesthetically pleasing to some, it is misguided. The knee has more than a hinge motion of flexion and extension (bending and straightening). It has a relevant twisting motion.

During the pedal stroke, the lower leg (tibia) twists about 15° relative to the upper leg (femur).

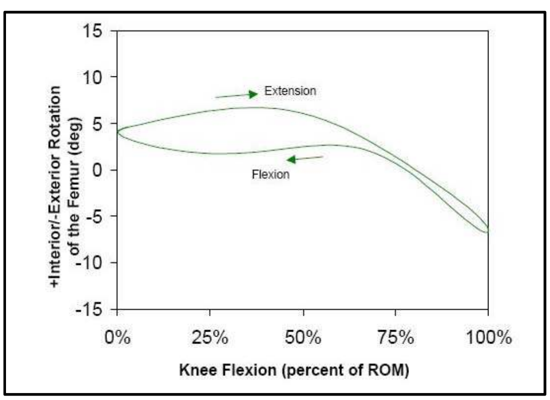

Figure 30. As the knee flexes and extends (bends and straightens) during cycling, the tibia and femur twist relative to each other. From Chaudhari. For more details, see page 94.

Power

Some sprinters prefer the secure feeling of no float and feel that they can develop more power without float.

On the one hand, as float may require accessory muscle use to stabilize the foot, it might be marginally uneconomical.

On the other hand, if float allows the muscles to work through their preferred angles of function, power might be expected to increase.[44]

Some have stated that float robs power.[45] Others that there is no evidence from studies that power is reduced.[46]

I am not aware of any published studies.

44 Arguments about power production for and against float have parallels with the arguments to move the cleat rearward to decrease ankling.

45 "The less float your cleats have, the more power you can produce." Matheny. F. *Andy Pruitt's Compete Medial Guide for Cyclists.* VeloPress. (2006).

46 "Is there any loss of power from pedals with rotational float? No. Several independent studies have concluded there is no loss of power from float, yet float can be instrumental in preventing repetitive-motion injuries due to misaligned joints." Speedplay website. Linked and accessed Jan 29, 2008.

Foot/Pedal Side-to-Side

Some pedals and cleats allow adjustment of the foot toward or away from the cranks.

In general, narrow-hipped riders ride with their feet closer to the cranks; wider-hipped riders with their feet further from the cranks.
If your shoes rub the cranks, you are too close.

Duck-footed riders need to allow enough clearance to not hit their heels on the cranks.

Almost all riders who pedal with a knees-out (bow-legged) style do best adjusting their pedals or cleats away from the crank. Many of these riders benefit from the additional clearance provided by a 2-mm pedal (stance) washer.

A closer-in position may be more aerodynamic and allow for greater power production. This was one thesis of Project 96 bicycle production.
Rider reports are mixed and studies are limited.

Read more about foot/pedal side-to-side on pages 96 and 100.

Handlebars

Rule of Thumb

Handlebar width for road bicycles should be the width of the shoulders.

Mountain bikers use wider bars so that with horizontal hand placement, their hands are slightly wider than their shoulders.

Select shape for hand size, reach, comfort, and riding style.

Discussion

Handlebar size is usually expressed simply by the width, but horizontal bend, reach, drop, and drop bend are also important.

Most riders simply ride the bar that comes with their bicycle. When selecting or replacing a handlebar many riders generally consider only handlebar width. Choosing a bar based on its other characteristics can improve comfort, performance, and safety.

Although bicycle companies generally fit their larger frames with wider bars, many do not consider handlebar drop and reach.

Sprinters prefer a larger clamp size, often referred to as oversized. The increased diameter of the center section of the bar improves stiffness.

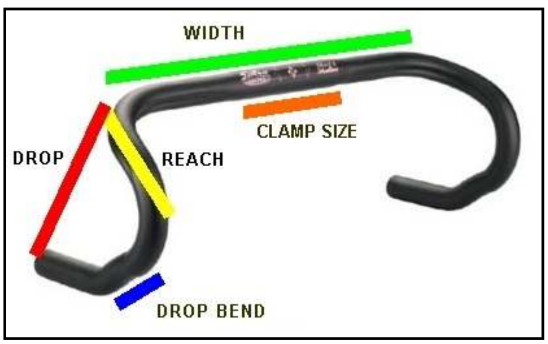

Figure 31. Handlebar size is determined by the width of the horizontal section, the tops, GREEN. The diameter of the center section of the tops determines clamp size, ORANGE. The handlebar drop section is characterized by the forward reach, YELLOW; the vertical drop, RED; and the drop bend, which may be curved or “anatomically” flattened, BLUE.

Handlebar Width

It is best and easiest to evaluate shoulder width with the rider on the bicycle.

The anatomical landmarks are the lateral shoulders and the first web spaces (the space between the thumbs and index fingers). With hands on the brake hoods, a vertical line from the lateral shoulder will pass through the middle of the elbow and the first webspace (see Figure 32, Figure 33, and Figure 34).

Road handlebars are commonly 42 cm wide.

Mountain bikers place their hands horizontally on a bar generally 20 to 24 inches wide (about 50 to 60 cm). Note that although the handlebar is wider, a line from lateral shoulder will still generally pass through the elbow and first webspace.

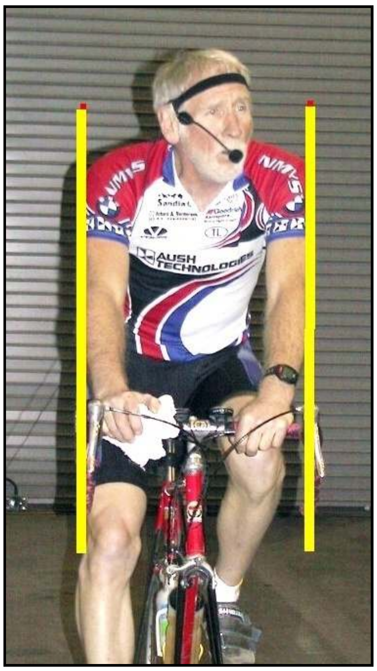

Figure 32. Standard-bars. Vertical yellow lines from the shoulder edges pass through the drops of the handlebars.

Figure 33. Wider bars. Men and women with shoulder widths less than 40 cm (16 inches) often prefer standard 40-cm handlebars that give them better bicycle control for general road riding.

Figure 34. Mountain bike Pro and NORBA Champion Jimena Florit prefers the control that this wider-than-shoulder width handlebar provides.

Shoulder width can be measured off the bicycle. When measured off the bicycle with shoulders back and square, shoulder width is the distance from acromion to acromion. The acromion is a forward projection of bone from the shoulder blade. It is found just to the outside of the collarbone (see Figure 35).

As riders round their shoulders on the bicycle, effectively narrowing their width, these two measurements are about the same.

Too wide a hand placement is tiring, especially when riding in a bent-over aerodynamic position.

Too narrow a hand placement is also tiring and reduces bicycle maneuverability, control, and safety.

A wider handlebar hand position steers more slowly; a narrower position steers more quickly. Another way of saying the same thing: pushing forward 1 inch with one hand when your hands are closer together steers or turns the fork more.

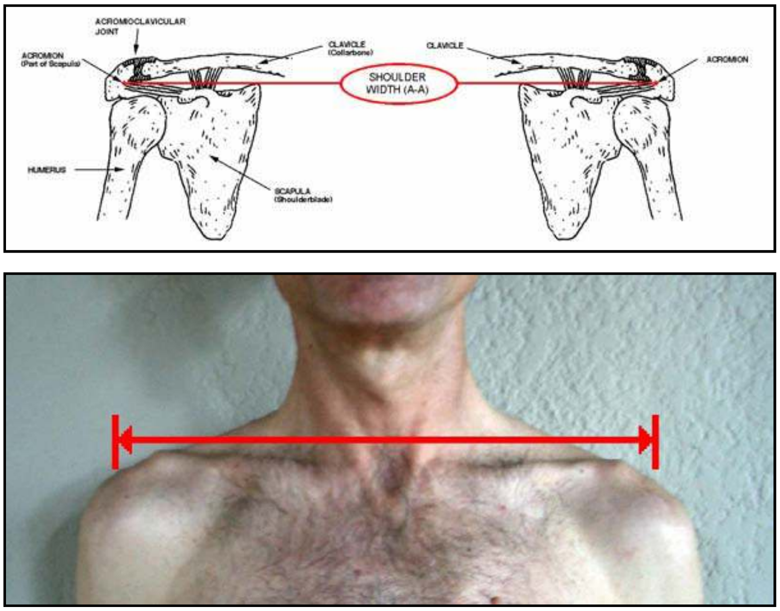

Figure 35. Shoulder width. Off the bicycle, with shoulders back and square, measure from acromion to acromion.

Climbers often desire a horizontal section of handlebar as wide as their shoulders for hand placement. This means that the total width of the handlebar will be up to an inch wider than the shoulder.

Mountain bikers and tandem riders may prefer a wider handlebar position to improve bicycle control, though such riders also commonly find that their arms tire more easily than when riding road bicycles.

The standard narrow handlebar width is 40 cm, measured between the centers of the drops. Smaller sizes are available although many women and men who might otherwise ride smaller handlebars prefer the improved general control of 40-cm bars.

Track and criterium racers often prefer bars 1 or 2 cm narrower than standard to help maneuver their bicycles between other riders. Medium and small track and criterium riders may prefer a 38-cm handlebar.

Although much has been written that narrow bars make it more difficult for riders to breathe, studies show that handlebar width has no effect on ventilation mechanics or respiratory muscle fatigue. Road riders have used narrow, raked bars for years and time trialists often try to get as narrow as possible.

Handlebar Shape

The shape of the handlebar varies with type of riding, hand size, and reach.

Top Bend

For general road riding, a long top horizontal section is preferred for climbing comfort.

Sprinters prefer a rounded curve on the handlebar tops, reducing the horizontal section. This reduces bumping of the handlebar with the wrists when sprinters come out of the saddle to sprint.

	**Figure 36. Traditional road handlebar. Curved drop section. ITM Bar.**
	**Figure 37. Road handlebar with short horizontal top preferred by sprinters. Anatomical drop section. Easton EC90.**
	**Figure 38. Road handlebar with long horizontal top preferred by climbers. Anatomical drop section. FSA K-Wing Carbon.**

Drop

The drop and reach of the handlebar is determined by reach and hand size.

Riders with a long reach prefer the greater drop and reach of a deep bar to improve aerodynamics in the drop position.

Short and shallower bars allow short-reach riders to get aero without overreaching. Shorter-reach riders generally also have smaller hands and shallower bars are generally designed to place the brake levers closer to their hands. Riders with a short reach rarely use the drops of deep bars: If the tops of the bars are properly positioned for climbing, the drops of deep bars stretch them out too far and the brake levers may be too distant to use safely.

Handlebar drop bend is determined by comfort. Some handlebars are flattened in this section and some riders prefer this “anatomical” shape.

	**Standard handlebar for medium to large hands. Drop 155 mm. Reach 100 mm. Salsa Pro.**
	**Short and shallow bar for small to medium hands. Drop 144 mm. Reach 82 mm. Salsa Short & Shallow.**
	**Shortest and shallowest bar for small hands. Drop 140 mm. Reach 70 mm. Salsa Poco.**

Figure 39. Progressively shorter and shallower handlebars for progressively smaller hands. Reach is indicated by the yellow line in the middle picture. Drop is indicated by the red line.

Brake Levers

Rule of Thumb

Road riders: Set the tip of each brake lever in line with a straightedge from each end of handlebar drop.

Mountain bikers: Set the brake levers downward to follow your arm angle.

Discussion

Road bicycle brake levers are most comfortable when positioned such that their tips are in line with the bottom of the handlebar drops.

Almost all road brake levers are designed to be positioned this way, allowing the brake levers to be accessible when the hands are either in the drops or on the hoods.

Figure 40. Brake lever tip is in line with straightedge positioned along the drop of the handlebar.

Figure 41. Mountain bike brake levers are angled at the same direction as the wrist and forearm, not horizontal.

Mountain bikers place their brake levers following the same angle as the arm and wrist rest on the handlebar, 30° to 45° from horizontal.

An angle of about 45° allows the wrist and hand to maintain a neutral position when braking, without the wrist stretching backwards, while standing as well as while seated.

An angle of about 30° allows a neutral position when braking while descending with the buttocks off the back of the saddle—arguably the most critical brake-control position.

Small Hands

Riders with size 7 or smaller hands may require (1) short and shallow handlebars (see page 61) or (2) special brake levers designed for small hands. Keep in mind that it is more the curvature of the handlebar that is important, rather than its specific reach.

Some riders adjust the cable tension on their brakes so that they do not begin to engage the rims until depressed about half way. In this way, small hands can partially depress the brake levers and be ready to brake comfortably. As always when adjusting brakes, make sure that the brake levers do not bottom out on the handlebars.

Using a similar approach and mechanically obliterating the initial brake-lever movement, Shimano makes a quickly-installed insert that positions the levers closer to the bars.

Figure 42. Shimano insert (red circle, held) moves the brake lever closer to the handlebar.

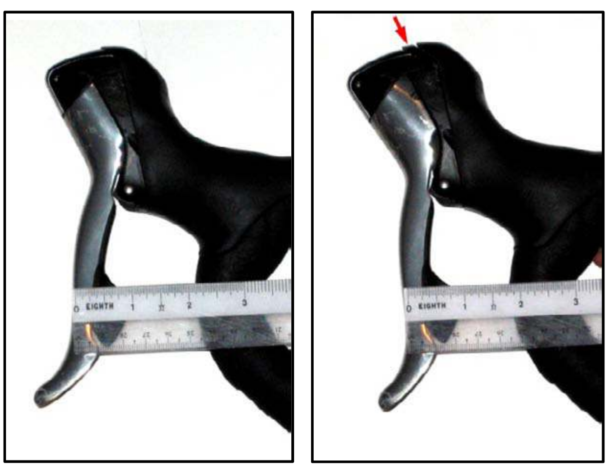

Figure 43. Effect of brake lever insert: Left without insert. Right with insert (arrow): Handlebar lever is about 6 mm (1/4 inch) closer to the handlebar.

Other Methods

Traditionally, as discussed below, mechanics positioned (road) handlebar drops horizontally, rather than pointing toward the rear brake or rear axle. Some still do.

If riders position the levers higher to improve comfort when climbing, this often makes the brake levers inaccessible from the drops of the handlebars.

Handlebar Angle

Rule of Thumb

Point the ends of the handlebar drops to the middle of the seat stays.

Discussion

The handlebar drop ends of road bicycles should be angled so that they point to the middle of the seat stay. This will be a point between the rear brake and the rear dropout.

This means that the handlebar drop ends are pointed down about 10° to 15°.

Positioning the handlebar drops this way generally raises the brake hoods to form a horizontal shelf. This then provides a comfortable hand position, a neutral hand position similar to that of shaking hands, whether riding in or out of the saddle.

When the hoods are lower, the hands twist toward the small finger (ulnar deviation). This is associated with a number of overuse injuries including deQuervain's tenosynovitis and lateral epicondylitis (tennis elbow).

Some handlebars are designed so that smaller hands can more easily reach the brake levers from the drops.

If placing the handlebars in this position creates an uncomfortable hand position when riding in the drops or reaching for the brake levers from the drops, a different shape handlebar may help.

Handlebars frequently slip, so that the brake hoods are down, without the rider realizing it. This commonly occurs when riders ride over a road bump or pothole with their hands on the hoods. A simple adjustment and tightening of the stem's handlebar bolt then gives a more comfortable ride.

Figure 44. Handlebar drops point to the middle of the seat stay. This allows the brake hoods to form a comfortable shelve for the hands.

Other Methods

Many mechanics set the handlebar drop ends horizontal. This method generally results in overstretching the wrists on the thumb side.

Others point the drop ends to the rear brake or rear dropouts—a matter of personal preference.

Handlebar/Stem Height

Rule of Thumb

Set stem height so the handlebar tops are between zero and a fist width below a horizontal straightedge from the saddle.

Discussion

The stem is generally from zero to four inches below the height of the saddle.

At one extreme, beginners and recreational riders are often more comfortable with their stem height level with their saddles.

Figure 45. A horizontal straightedge from the saddle is between zero and a fist width above the handlebar.

At the other extreme, performance time trialists may rest their forearms on pads six or more inches below the height of their saddles.

In general, the higher your stem, the more power you can produce and the better you will climb.

The lower your stem, the more aerodynamic you will be. In fast-paced solo riding on level ground, aerodynamics may more than compensate for the loss of power.

If your stem is too low, you may be uncomfortable—especially in your lower back or neck—or lose power.

Other Methods

Racer mechanics often set stem height too low for their beginner and recreational customers.

As discussed above, these riders will have a more uncomfortable and less powerful ride. Many of them rarely take advantage of the drop position of their handlebars because their handlebars are already too low.

Torso Angle / Reach

If seat height is the holy grail of power, and seat fore-aft the holy grail of balance, *torso angle is the holy grail of aerodynamics*.

Rule of Thumb

Combine stem extension, stem height, and stem rise to set a comfortable torso angle.

Discussion

Top tube length, stem extension, stem height, stem rise, and saddle fore-aft are the major contributors to torso angle. Minor contributors include handlebar and brake lever shape.

Standard torso angle is measured on a level bicycle with the rider positioned with the hands on the hoods.

It is the angle formed by the shoulder (greater tubercle of the humerus), hip (greater trochanter of the femur), and a horizontal.

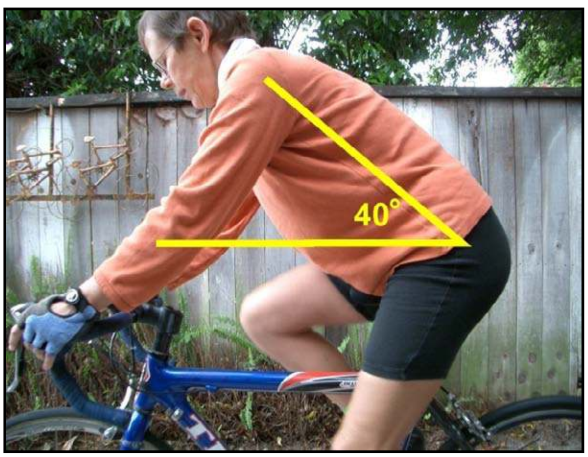

Figure 46. Torso angle of 40° in an experienced recreational rider.

Riders vary greatly in their preferred torso angle.

Torso angle affects aerodynamics, power, and comfort.

Lower torso positions are generally more aerodynamic; they require back and hamstring flexibility. Higher torso positions are generally more comfortable and allow for more power production.

Experienced recreational riders are comfortable and do well riding with a torso angle of about 45°.

Beginners and obese riders prefer to sit more upright, perhaps with an angle of 60°.

Road racers may be lower, with angles of about 30°. With their hands in the drops, racers are able to position themselves more aerodynamically, with drop torso angles of 15°.

Time trialists on dedicated equipment may ride even lower, with their backs completely flat and aero torso angles of less than 10°.

Climbers and mountain bikers, less concerned about aerodynamics, prefer a torso angle of about 45° to open the hip angle and generate maximum power.

A too bent-over position, with a craned neck to see ahead is associated with neck pain. The grocery-shopping image of a rider sitting upright on a bicycle with a food basket is associated with a more jarring ride.

Riding with bent elbows allows the arms to absorb road shock better than straight-armed riding.

Climbing Torso Angle

Regardless of fitness level, combine stem extension, stem height, and stem rise to allow a torso angle of at least 45° when the hands are on the tops.

This allows you to open up the hip angle sufficiently to ride to your power potential up climbs.

Figure 47. With hands on the tops, torso angle should be at least 45°. The landmarks are the shoulder, hip, and a line parallel to the ground. Here the rider is on a stationary trainer with the front end elevated, simulating a ground angle of 15°.

Aerodynamics

Torso angle is the holy grail of aerodynamics.

As speeds increase, an increasing percentage of work is used to overcome wind resistance.

As riders reduce torso angle, they lessen their frontal area and reduce wind resistance. Other things being equal, they travel faster.

Power

At torso angles smaller than 30°, riders commonly experience loss of (1) economy[47] and (2) power associated with the closure of the hip angle. For strategies dealing with this loss of power, see *Time Trialing* on page 76.

Reach

Once you know how stretched out you like to be, measure the distance from the tip of your saddle to your brake hood. Use this measurement as a reference to help you set up different or new bicycles.

(Traditionally, reach is measured from the tip of the saddle to the handlebar tops at the stem. Shimano and Campagnolo brake hoods were elongated, becoming more ergonomic, around 2004. Since most riders now spend most of their riding time on the brake hoods, it makes most sense to now measure reach to the brake hoods—to where one reaches.)

Figure 48. Bicycle reach. Tip of saddle to brake hood.

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47 Compared with upright cycling, aero-position oxygen cost was 1.5 mL/Kg/min and heart rate 5 beats per minute higher. Gnehm, P, et al. *Influence of different racing positions on metabolic cost in elite cyclists.* Medicine & Science in Sports & Exercise. 29 (6). 818-823. (1997). Linked and accessed Jan 27, 2008.

Extension Arc

As stated above, stem extension, stem height, and stem rise combine to determine torso angle. Various combinations will result in the same torso angle, as illustrated in Figure 49, Figure 50, and Figure 51.

The longer the stem for the same extension arc, the more the arms are weight is forward.

Choose the right combination by considering weight distribution, discussed also on page 41, and shoulder angle, discussed next.

Figure 49. Any combination of stem extension, stem height, and stem rise along the yellow arc will combine to set the same torso angle.

Figure 50. Yellow line marks a 60-mm long stem with a 90-degree angle from the steering axis, 2-1/4 inches above the headset.

Figure 51. Computer generated image rotating around the shoulder. The torso angle is unchanged. Now the stem would be about 130 mm long with a 100-degree angle from the steering axis, about 4 inches above the headset. Although the torso angle is the same, the shoulder angle and handling characteristics of the bicycle have changed. This position is not recommended. See the text.

Shoulder Angle

Rule of Thumb

Shoulder angle should be about 90° with the hands on the hoods and the elbows bent about 15°.

Discussion

The anatomical landmarks are the hip (greater trochanter of the femur), the shoulder (greater tubercle of the humerus), and elbow (lateral epicondyl of the humerus).

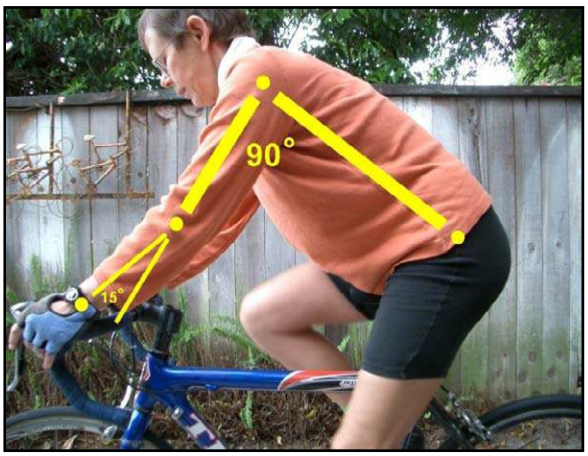

Figure 52. The shoulder should be bent about 90°.

Although road racers and time trialists may have greater angles, if the shoulder is bent much more than 90°, it is uncomfortable and tiring to hold position. Bicycle handling is adversely affected.

Although mountain bikers may sit more upright, if the shoulder is bent much less than 90°, the rider tends to be cramped, overlap the legs and arms, and be more jarred by road shocks. Handling is also adversely affected.

Time trialing with forearm-supported bars is an exception. The bars support the forearms and a more extended shoulder may be well tolerated. Even so, many time trialists drop the forearm supports to six or more inches below the height of the saddle so that the shoulder angle remains around 90°.

Other Methods

A well-known rule of thumb for racers is that with the hands in the drops, the top of the bars obscures the front axle when looking down. This rule applies less often to current frames and forks than it used to apply to traditional diamond design frames and standard raked forks.

Another popular rule for racers on road bicycles is that when the hands are in the drops and the elbows bent about 25°, there should be scant clearance between the elbows and the knees.

Beginners ride better and enjoy riding more with shorter, higher stems and a more upright position. Climbers are also often able to develop more power this way.

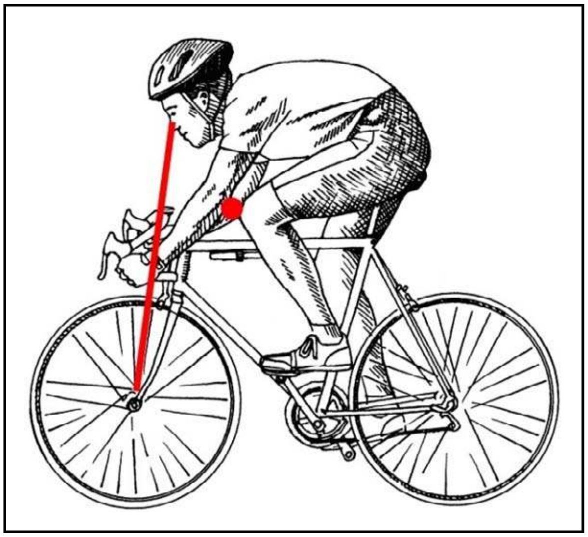

Figure 53. Two traditional older methods of setting stem extension: With the hands in the drops and the elbows comfortably bent about 20°, (1) the top of the handle-bar should just hide the front hub; (2) there should be just a little clearance between the elbow and the knee. Recreational riders do better with shorter, higher stems.

Stems

In order to set torso and shoulder angles properly, many bikes are sized so that most riders end up needing stems 9 to 12 cm in length.

Recreational riders generally use shorter stems.

When stems are short, or seat fore-aft too far back, riders climbing out of the saddle may hit their knees on the handlebar.

When stems are long, riders sprinting out of the saddle may hit their knees on the stem.

When stems are shorter than 60 mm or longer than 130 mm, they generally fall outside the range of the design characteristics of the bicycle. Such bicycle setups do not result in good handling characteristics and can be particularly dangerous on descents or when cornering.

Riders who require such stems may instead need a different size bicycle, a bicycle with different geometry, or perhaps a custom bicycle.

Style Differences Summary

There is a window of perfectly acceptable bicycle fit positions. Formulas and standard positions are only guidelines.

Riders should not struggle to adapt to “standard” positions. Standard positions should be adapted to an individual’s riding style, anatomy, and overuse injury pattern.

Here is a summary of major fit differences based on riders’ general style and anatomy.

	Recreational	**Racer**	**Women**
Top tube length	Medium or shorter	Medium+	Medium
Knee angle	30°	25°-30°	30°
Saddle	Comfort	Narrow	Variable
Torso angle	45°	30°	45°
Stem length	Medium or shorter	Medium or longer	Medium
Handlebar below seat	0-2”	1-4”	0-2”

Table 8. General style-differences summary.

Part 3: Specialty Riding

Bike position variations associated with time-trialing, climbing, sprinting, tandem riding, and cross-country mountain biking have been discussed throughout this book. The following is a more detailed look at some of the essential features of these specialties.

Time Trialing

Time trialists are most aerodynamic when their frontal surface area is minimized: arms and legs narrow; torsos flat and low.

Time trialists have the most power in a forward, high, nose-down saddle position with knee angles less than 25° short of full extension. A slightly nose-down saddle position helps roll the pelvis forward, flex the back, and achieve a flat, low torso.

Economy (metabolic cost) is improved when the hip angle is opened.[48]

Figure 54. Extreme time-trial position, side view. Knee angle 5°. Torso angle 10°. Shoulder angle 110°. Wind drag. 4.5 pounds at 25 mph. Butch Richardson, National Masters TT Champion.

Figure 55. Aero position, front view. Arms in line with or inside of knees. Arms up and hands cupped act as a fairing for the chest. Shoulders rounded. Knees in.

48 Compared with upright cycling, aero-position oxygen cost was 1.5 mL/Kg/min and heart rate 5 beats per minute higher. Gnehm, P. et al. *Influence of different racing positions on metabolic cost in elite cyclists*. Medicine & Science in Sports & Exercise. 29 (6). 818-823. (1997). Linked and accessed Jan 27, 2008.

Power is improved with greater leg extension and when the hip angle is opened. Power is improved not so much because of what is happening at the bottom of the pedal stroke; it is because a high saddle position makes it easier to get over the top of the stroke.

Time trialists move forward to generate more power. Climbers do the opposite, they move backward on the saddle. Why the difference?

Time trialists move forward to open the hip angle. Climbers move back to extend the leg. For time trialists, bent over in an aerodynamic position with a small torso angle, opening the hip angle is a priority. For climbers, who climb with their hands on the hoods or tops, the torso and hip angle is much greater.

Time trialists can, and should, have their cake and eat it too: Move forward *and* raise the saddle.[49]

For riders with a dedicated time-trial bicycle, their seat height may be as much as an inch higher when measured along the seat tube, but it will be close to the same distance measured to where they sit. I sometimes tell time trialists their saddles should feel high when pedaling causally, and just right when training near time-trial power or racing.

High-saddle positions compromise the ability to turn fast cadences, say over 120 rpm.

The forward position of time trialing is also unsuitable for descending. More weight on the rear of the bicycle improves descending balance and control.

For general road riders, a forward position also places more weight on the hands, arms, and shoulders. Too forward a position is associated with upper body overuse injuries and fatigue.

However, time trialists are generally not concerned with fast cadences, bicycle maneuverability, or handling on descents. They rest on forearm-supported aerobars, and upper arm fatigue is rarely an issue.

Time trialists may ride with torso angles of 10° or less. Torso angle may be limited by neck flexibility and strength, being able to see up the road unobstructed by sunglass frames or droopy eyelids, and by the knees hitting the chest. Triathletes may be more comfortable higher.

Review the discussion about extension arc on page 71. A setup with a longer stem will result in the same torso angle with less of a forearm-saddle drop than a setup with a shorter stem.

Shoulder angles may be greater than the standard 90°. Time-trial events are generally an hour or less; the fatigue common to such shoulder angles on standard road handlebars is mitigated by forearm- or elbow-supported aerobars.

The UCI currently prohibits shoulder angles greater than 120° and bars that rise beyond the horizontal level of the saddle.

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49 Price, D and Donne, B. *Effect of variation in seat tube angle at different seat heights on submaximal cycling performance in man*. Journal of Sport Sciences. 15 (4) (1997). 395-402. Linked and accessed Jan 27, 2008.

In order to achieve a flat back and to meet UCI equipment and position requirements, time trialists often require a negative stem in order to ride with their elbows 6 inches or so below the height of the saddles. For UCI rules, see page 122.

Figure 56. World Champion and US Record Holder Mari Holden (left) may be one of the fastest women time trialists ever. Notice how Holden rides on the nose of her saddle, opening her hip angle to obtain more power. Her position is not as slippery as Chris Boardman's (right), the world hour record holder. Boardman is flatter and less cramped. Chris Boardman rode 56.3759-kilometers full aero.

Fore-aft is sometimes adjusted so that the knee is as much as two inches in front of the pedal spindle. This allows the hip angle to open with small torso angles. Time trialists therefore often choose bicycles with steep seat tube angles.

Racers governed by UCI regulations are generally not allowed to assume such forward positions. In order to keep their hip angles open, they ride with higher torso positions.

I do not advocate changing crank arm length for time trialing.

Although longer crankarms have been traditionally favored for time trialing, studies have shown that they change pedal force, not torque or power—they require the rider to pedal a larger circle. Longer crankarms mean that the knees rise higher, and hence closer to the chest—which may result in *worse* biomechanical function. The rider may close the hip angle, *reducing* power. Breaking tradition, National time-trial champion and frame builder Glen Swann uses *shorter* cranks, 165 mm, when he time trials.

To narrow their profile, time trialists choose narrow handlebars—both in overall width and in the position of their forearm pads.

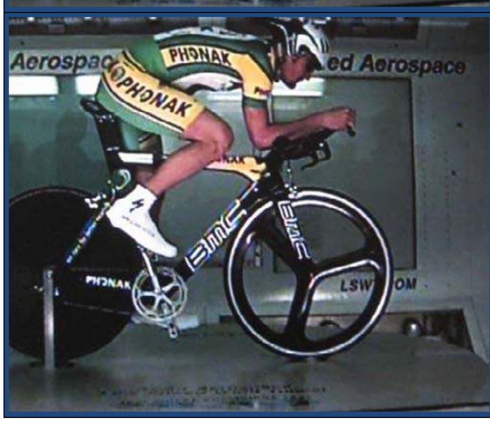
Project 96 (USA Cycling's Olympic program) data showed that a narrow pedal stance (narrow bottom bracket) with a knees-in pedaling style was more aerodynamic and more powerful.

Positioning the arms inside of the shoulders or legs, rolling the shoulders inward, having the forearms slightly up to shield the face (and balance the forward sliding from a slightly down saddle nose), and riding with a knees-in style all improve aerodynamics.

For a time-trial tandem photograph, see Figure 58 on page 82.

Bar Angle Down 20°	Drag, Grams
Wind Angle 0°	2779
Wind Angle 15°	2568
Wind Angle 25°	2568

Bar Angle Horizontal	Drag, Grams
Wind Angle 0°	2756
Wind Angle 15°	2470
Wind Angle 25°	2413



Bar Angle Up 20°	Drag, Grams
Wind Angle 0°	2741
Wind Angle 15°	2456
Wind Angle 25°	2377

Figure 57. Arms up helps Floyd Landis. The expected time savings of an arms-up position was less than Floyd's winning margin in the Tour of California, Tour of Georgia, and Tour de France 2006. Assume 10 grams drag savings equates to 3 seconds in an hour, and figure a 15° effective wind angle: Bars horizontal saves about 30 seconds an hour over bars down, and bars up 20° saves another 5 seconds an hour. Allied Aerospace LSWT, San Diego, January 2005.

Climbing

Climbers generally prefer a long horizontal handlebar top.

Climbers want power and near full-leg extension.

Many climbers therefore raise their seat height to knee flexion angles of about 25°.

If knee flexion angles are about 30° short of full extension, climbers move back on their saddles. With roughly 73-degree seat tube angles, moving back on the saddle effectively raises the saddle about a half-inch and changes knee extension to about 25° short of full extension.

This position also allows riders the option of moving forward on their saddles, effectively lowering their saddle position and improving spin for surges and sprints.

Since climbers generally ride with their hands on the tops of the handlebars, the hip closure penalty is more modest than it is for time trialists who move back to gain leg extension.

Even so, climbers prefer a shorter, higher stem to open up the hip angles and keep power up. Riders who frequently ride off-the-front on flat or rolling terrain may prefer the lower, more aerodynamic position of a longer, lower stem.

Sprinting

Sprinters want a powerful position that allows quick handling and fast pedal cadences.

Sprinters generally want bicycles that are stiff and responsive, rather than comfortable. They like stout tubes and oversized handlebars.

Relatively shorter cranks are preferred by most sprinters. Although longer cranks allow more torque, shorter cranks allow faster acceleration and pedal cadences. Short cranks also improve cornering clearance, occasionally crucial in criteriums and on velodromes.

Sprinters prefer to ride a little more on their toes, with their cleats positioned more forward than for general road riding—although this may have more to do with effectively lowering seat height, as discussed on page 32.

- To provide quick handling, sprinters prefer bicycles with short wheelbases with steep seat tubes.
- To improve the ability to steer through small spaces, sprinters prefer narrow handlebars.
- To allow a more powerful upper-body position, sprinters prefer neutral or shorter stems.
- To improve hand position in the drops, sprinters prefer the drops to be aligned horizontal to the ground.
- To prevent their wrists from hitting the horizontal section of the handlebar when sprinting with hands in the drops, sprinters prefer curved horizontal sections (see Figure 37).
- To allow fast pedal cadences, sprinters prefer lower, more forward saddle positions.

Tandem Riding

Handlebars

To control the bicycle and support the weight of the stoker (rear rider) the captain (front rider) often prefers wider handlebars.

The stoker also often has wider handlebars to clear the hips of the captain. Narrow-hipped captains improve the comfort of their stokers with stoker bars that allow standard hand placement.

Q-Factor (Foot Stance)

The need for a timing chain between the captain's cranks and the stoker's cranks means that a wider bottom bracket must be used on most tandems. This widens the pedal stance of both riders. Riders are generally easily able to accommodate this position; bow-legged pedaling riders are more comfortable with such a position. But high-mileage riders not used to tandems who go long-distance tandem touring together often are not adapted to this difference and may develop anserine (inside of the knee, medial) tendonitis.

Stoker Torso Angle

Many tandems are designed with less room in the back for the stoker to bend over. Keeping the wheelbase short improves handling and reduces stoker lag (the perception when cornering that, like an articulated truck, the captain has already turned while the stoker has yet to turn).

Although a more upright position is comfortable for many riders, others feel cramped, especially when climbing out of the saddle.

A short stoker top tube also mean that the captain's back is in the way of the stoker's head if the stoker tries to ride in the handlebar drops.

Custom-designed time-trial tandems allow the stoker to get flat and aerodynamic.

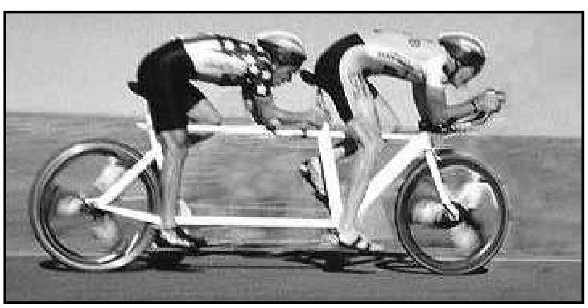


Figure 58. Double trouble: The author's specialty time-trial tandem. Long stoker top tube allows aerodynamic positioning. Stoker has no handlebar and holds onto captain's seatpost. Single-sided single chainring and timing chains allow narrow Q-factor and reduce wind drag. Aerodynamic tubing without conventional double triangle design. Note low torso position of both captain and stoker, narrow arm position, and stoker's leg extension. This tandem has set seven US National Records.

Mountain Biking

As previously noted, mountain bikers prefer a wider hand placement on the handlebars than road riders. Rarely, a narrower handlebar will be helpful in avoiding obstacles on single track.

Mountain bikers place their brake levers following the same angle as the arm and wrist rest on the handlebar, 30° to 45° from horizontal. This allows the wrist and hand to maintain a neutral position when braking, without the wrist stretching backwards, while standing as well as while seated. Brake lever placement is further discussed and shown on page 63.

Position bar-ends to allow you to keep your wrists straight when standing.

Mountain bikers ride with level saddle nose, or slightly down to avoid catching their shorts with their frequent off and on the saddle positioning.

Figure 59. Mountain bikers prefer wider handlebars and lower seat heights.

Mountain bikers need the flexibility to move fore and aft on their saddles easily to maintain traction and control on climbs and descents. A slightly lower seat height allows this flexibility and also lowers the center of gravity, improving balance.

A longer bottom bracket results in a wider Q-factor or stance width. Although this is not usually a problem for most mountain bikers, those mountain bikers who train primarily on road may have overuse injuries if they only occasionally ride hard on their mountain bikes or go mountain bike touring for several days without adaptation.

Mountain bikers, less concerned about aerodynamics than road riders, prefer a torso angle of about 45° to open the hip angle and generate maximum power.

To develop torque, mountain bikers may use cranks 2.5 – 5 mm longer than road riders with the same inseam.

Specialty Differences Summary

	Time Trial	Climb	Sprint	Cross Country
Seat	Higher/ Forward	Back	Neutral/ Forward	Neutral/ Lower
Top tube length	Longer	Shorter	Neutral	Neutral
Stem length	Longer	Shorter	Neutral/ Shorter	Neutral
Handlebar below seat	6”	0-2”	1-4”	0-3”
Seat tube angle	Level -	Level +	Level	Level -
Crank	Neutral/ Longer	Neutral/ Longer	Neutral/ Shorter	Neutral/ Longer

Table 9. Specialty riding fit differences.

Part 4: Anatomical Considerations

We are not all symmetrical. We are not all proportioned according to average. Our bones are sometimes twisted and our joints may be bent from anatomical norms.

Although such differences may be readily apparent with a standard or parking-lot bicycle fit, some anatomical variants can only be uncovered with detailed examination or investigation.

Where overuse or other problems emerge, it may be advantageous to look not only at the rider on the bicycle, but perform a traditional physical examination.

History

Has the rider had previous medical problems, including but not limited to muscle or nerve diseases?

Have there been traumatic injuries? Broken bones? Immobilization of joints, including casting?

Is there a history of low back or neck pain? Disc herniation? Nerve damage?

Spine

Is it straight? This is sometimes best evaluated by looking at the rider's back when the rider bends over.

Does the spine bend side-to-side (scoliosis) or front to back hump (kyphosis) or swayback (lordosis)?

Shoulders

Looking from the front, is one higher than the other? Has the rider previously broken a collarbone or had a shoulder separation? If so, there may be a functional arm-length difference.

Leg- and Arm-Length Differences

These subjects are discussed in detail below.

Foot Size Differences

If foot size is different—more specifically foot length from the heel to the ball—the effect may be similar to a leg-length difference.

Leg Characteristics

Is the rider bow-legged or knock-kneed?

Pigeon-toed or duck-footed?

Pronator or supinator?

What is the anatomic Q-Angle?[50]

Does the rider have the same muscular development on the right and left sides? What is the quadriceps size?

Flexibility

How is back and hamstring flexibility? Can the rider's fingertips touch the ground? Can the rider put the palms on the ground?

Look at the Bike

Look for wear patterns:

Is there wear on one crankarm where the heel hits it? (Sign of a duck-footed rider, and the potential need for increasing pedal Q-factor.)

Is one side of the saddle worn more than the other, or is one side bent down more than another? (Sign of unequal leg length.)

50 In medical practice the Q-angle, or quadriceps angle, is that formed between a line from the center of the patella to the anterior superior iliac spine and a line from the tibial tubercle to the center of the patella. See Figure 84 on page 117.

Leg-Length Discrepancy

What We're Talking About

Many riders have legs of different lengths. This usually does not cause problems, especially if the difference is slight. However, leg-length discrepancy *can* be a cause of leg or back discomfort or of recurrent one-sided saddle sores.

Difference in foot size can also cause the functional equivalent of a leg-length discrepancy.

Traditionally, differences less than 1/4 inch (or 6 mm) are not considered significant. Some have claimed that differences of as little as 1/8 inch (or 3 mm) are significant.

Although some theorize that correcting leg-length discrepancy results in a more effective stroke, there are no published studies showing that correcting leg-length discrepancy improves power or economy (metabolic cost).

Shims, other devices, and cleat positioning can correct for leg-length discrepancy and can help these discomforts.

Measuring and Evaluating Leg Length

Leg-length differences can be in the upper leg (femoral) or in the lower leg (tibial).

Physicians traditionally determine leg length by measuring the distance from the pelvis to the ankle—specifically, the distance from the anterior superior iliac spine to the medial malleolus.

X rays (scanograms) can be used to measure the length of the legs more accurately.

It is easy to quickly eyeball and measure upper and lower leg-length differences:

Sit the rider with the back flat against a hard-backed chair, feet on the ground. Place a straightedge in front of the anterior (forward) protrusion of the kneecaps—point A in Figure 60. If an upper leg-length discrepancy is present, the straightedge will not be level against the knees.

When the straightedge is level against the longer leg, the distance to the straightedge from the shorter leg is the upper-length discrepancy. Differences of a few millimeters are usually insignificant.

Place a straightedge on the superior (top) part of the knee—point B in Figure 60. If a lower leg-length discrepancy is present, the straightedge will not be level on the knees.

When the straightedge is level against the longer leg, the distance to the straightedge from the shorter leg is the lower-length discrepancy. Differences of a few millimeters are usually insignificant.

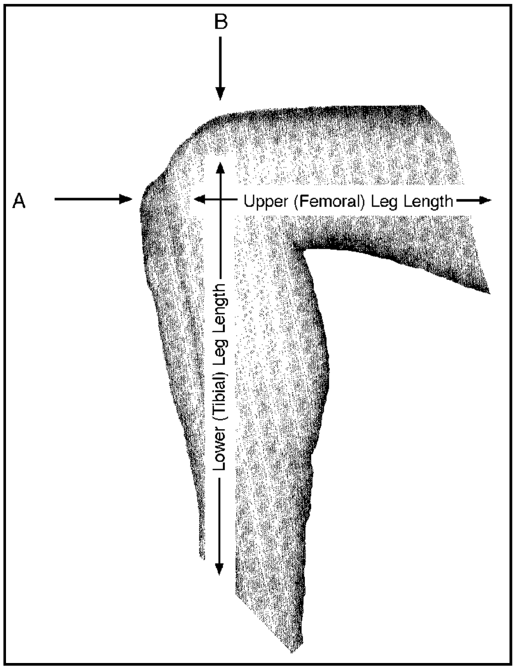


Figure 60. Measuring upper and lower leg lengths

Evaluating Leg Length by Knee Angles

Measuring leg length may not reveal the real issue. Some riders with no leg-length difference, for example, have an effective difference when riding because of pelvic tilt, arthritic changes in the hips, or other factors. Many riders have accommodated to their differences with their pedaling styles.

Another approach is to measure the angles of the knees when pedaling. If they are equal, and if the rider sits squarely on the saddle, then the legs are effectively the same length.

If the knee angles are different, the legs are effectively of different lengths, regardless of actual measurements.

The traditional method of measuring knee angles is to have the rider stop pedaling at the bottom of the stroke and measure knee angle with a goniometer: a protractor with long arms.

Many riders change the angle of the knee when they stop pedaling by changing their ankle position. Measuring knee angles while the rider pedals with an electronic goniometer or by computer algorithm from video imaging gives information that is more accurate.

Correcting Leg-Length Discrepancy

Simplest method: Set the seat height for the longer leg. Shim the exterior sole or cleat of the shoe on the shorter leg to nearly equalize knee angles.

The body partially adapts to leg-length differences. In general, femoral (upper-leg) differences require about one-third correction, tibial (lower-leg) differences about one-half.

For example, a femoral leg-length discrepancy of 6 mm requires about a 2-mm shim. A tibial leg-length discrepancy of 6 mm requires about a 3-mm shim.

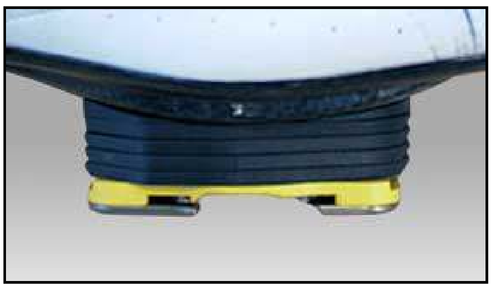


Figure 61. Shims between the cleat and shoe sole.

Simplistically, the femur moves the knee fore and aft; the tibia moves the knee up and down. Since I usually set cleat fore-aft as rearward as commonly-drilled shoes allow, with this model, femoral differences can be accommodated by offsetting the cleat of the shorter leg forward (cycling more on the toes).

Differences of several cm or inches, generally due to medical disease or traumatic injury, can be managed with commercially available crank shorteners, drop pedal devices, or different length cranks. Crank shorteners are commonly marketed by tandem-parts suppliers as child stoker conversion parts. For an example of a drop pedal device, see Figure 81 on page 106.

Other Methods

Small differences are sometimes shimmed with an insole. This often crowds the interior of the shoe and is not ideal. The insole of the shoe of the longer leg is sometimes removed as an easy fix for small differences. Again, a comfortable fit may now not be possible. Different-size shoes to accommodate different thicknesses of insoles are an unusual alternative.

Some practitioners correct leg-length differences with eccentric chainrings, concentrically machined but off-center mounted chainrings. I do not endorse this approach.

Arm-Length Discrepancy

Many riders have arms of different lengths. This usually does not cause problems, especially if the difference is slight.

Spinal twist (scoliosis), shoulder separation, and broken collarbone may also result in the functional equivalent of an arm-length discrepancy.

Arm-length discrepancy *can* be a cause of shoulder or upper-back discomfort.

Aches or pains are typically at the front of the shoulder of the longer arm or at the upper back or shoulder blade of the shorter arm.

Brake hood placement need not be symmetrical. Placing the brake hood closer to the shorter arm and further away from the longer arm can help the rider sit squarely on the bicycle and improve comfort.

Using offset or different length aerobars are options for time trialists.

Figure 62. Left: Longer right arm. Middle: Offset brake hoods. Longer reach to right brake hood on road bike. (Distance to red arrow line is different on left and right brake hoods.) Right: Offset aerobars on time-trial bike.

Part 5: Knee Alignment

Rule of Thumb

Know your knee alignment pedaling style, and consider modifying alignment if overuse injuries are a problem.

Discussion

Some authorities advocate trying to align the hip, knee, and foot in a vertical (sagittal) plane while riding. The anatomical landmarks used are the hip (head of the femur), knee (mid patella), and foot (second toe).

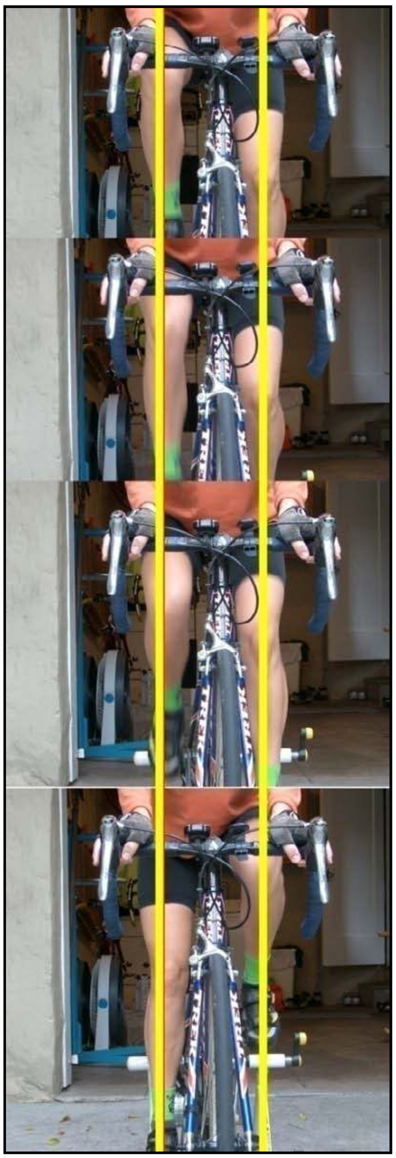


Figure 63. As the vertical yellow lines show in this composite of four photographs, this rider's knees stay well aligned during up and down of pedal stroke.

This approach may be aesthetically appealing to some, and some feel that this approach results in more effective power production, reducing wasted shearing forces. Studies are limited and contradictory.

Knee alignment can be easily changed with the use of wedge-shaped shims or washers placed under the cleat.

Knees-In Style

Some authorities have ascribed a knees-in style to forefoot varus.

Most riders have a neutral foot position in which the big toe is higher than the small toe. As riders apply power to the ball of the foot, the foot and knee may move medially, toward the center of the body.[51]

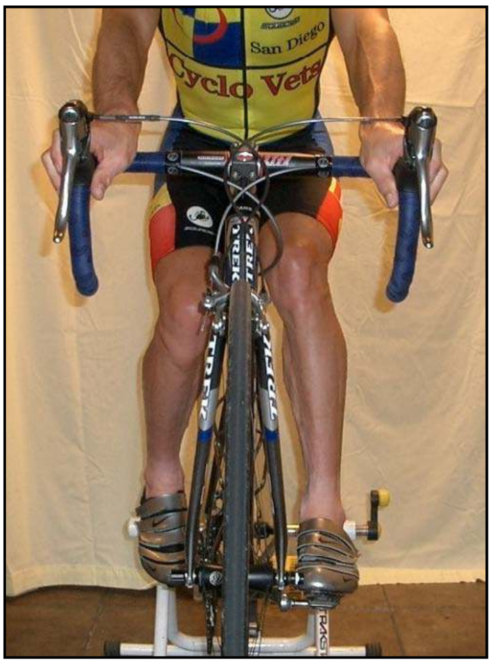


Figure 64. Knees-in pedaling style.

In general, medial wedges or varus-canted shoes reduce the common forefoot varus, or turning in of the front of the foot, and help straighten the alignment of those who pedal knock-kneed—with their knees toward the top tube.[52]

If forefoot varus is present in about 80% of the population, as a couple of studies have suggested, some have argued that bicycle shoes should incorporate this tilt in their design.

Specialized has worked on just such a design.[53]

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51 Brown LP and Yavorsky, P. *Locomotor biomechanics and pathomechanics: a review*. Journal of Orthopaedic and Sports Physical Therapy, 9(1):3-10. 1987.

52 Hilden, T, et al. *Effect of cycling shoe design on medial excursion at the knee*. Medicine & Science in Sports & Exercise. (5), abstract 75, page S17, 2003.

53 Andy Pruitt owns the patent, which is assigned to *Specialized* shoes. Linked and accessed Jan 7, 2008.

Studies showing any value to injury prevention are limited. [54]

Studies showing any value to varus correction in improving performance are quite limited. A single abstract published by the shoe designer group[55] showed a reduction of 2.7 beats per minute after 1 hour and 3.1 beats per minute after 90 minutes with the shoes. There were no significant differences in VO2, perceived exertion, or blood lactate. There were no significant heart rate differences at 30 minutes. Other unpublished studies by this group, for many different intervals, did not show any differences.[56]

Figure 65. Medial wedge inserted between shoe outsole and pedal cleat.

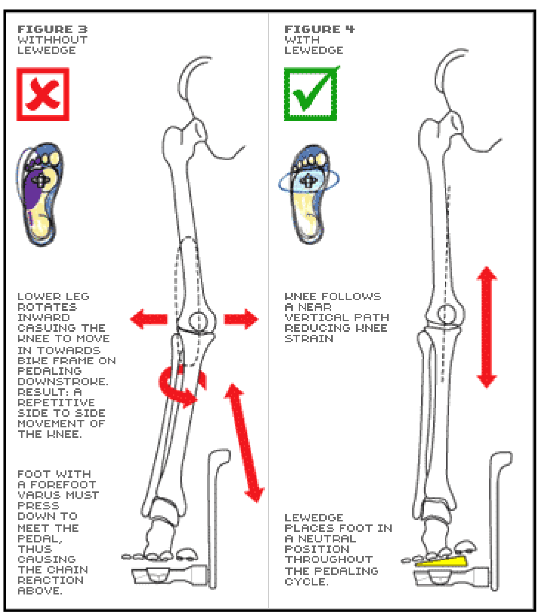

Figure 66. Medial wedges change a knees-in pedaling style to a vertical up and down style.[57]

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54 At the Second Serotta Science of Cycling Symposium, it was reported that Maury Hull concluded that 10° of valgus canting was beneficial. Andy Pruitt concluded that varus canting was beneficial. Zinn, L. VeloNews. Jan 29, 2008. Linked and accessed Jan 30, 2008.

55 Henderson, NA, et al. *Physiologic responses to cycling in biomechanical adapted versus traditional cycling shoes.* Medicine & Science in Sports & Exercise. (5), abstract 74, page S16, 2003.

56 Andy Pruitt, personal communication.

57 Proprietary figure courtesy Paul Swift, LeWedge.

I believe in changing this knees-in style of pedaling only if an overuse injury emerges.

Most of the general population has some degree of forefoot varus; most riders who pedal knees-in also have forefoot varus. However, it does not necessarily follow that riders who pedal knees-in do so *because* of forefoot varus.

Although forefoot varus may play a role in the tendency of some riders to pedal knees in, the situation may be considerably more complicated.

Although many consider only the hinge motion of the knee—the flexion and extension (bending and straightening)—knee motions are considerably more complex.

For example, Chaudhari et al[58] showed that during the pedal stroke, the lower leg (tibia) slides forward and backward almost an inch on the upper leg (femur), and that the tibia twists about 15° relative to the femur. Further, these changes have elements of hysteresis—the amount of anterior-posterior motion and twist at any given angle of knee flexion is dependent upon whether one is the push or pull phase of the pedal stroke.

This hysteresis may help explain the figure-of-8 pedaling motion of some riders.

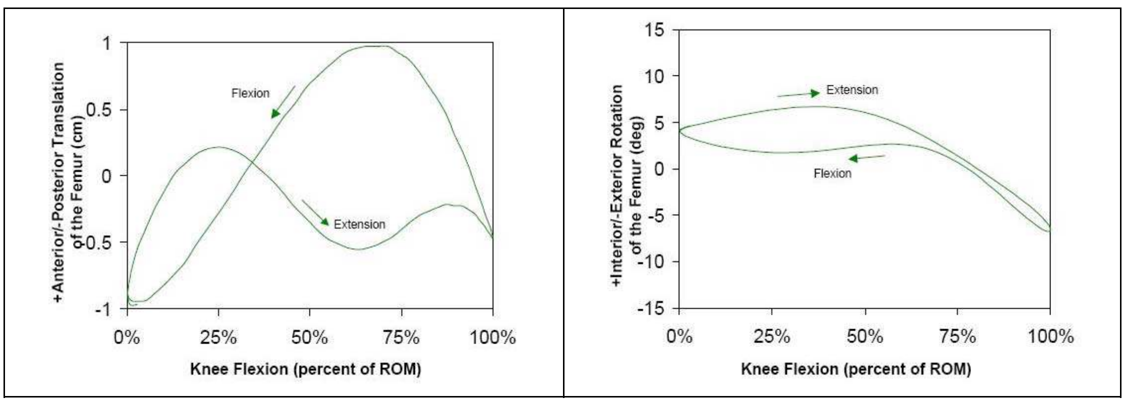

Figure 67. As the knee flexes and extends (bends and straightens) during cycling, the tibia and femur move forward and backward (left), and twist (right) relative to each other. From Chaudhari.

Although aesthetically appealing, vertically aligning the hip, knee, and foot is a physical impossibility for many riders. For example, in a rider with narrow hips the distance between the femoral heads might be 6 inches and the distance between the second toes while pedaling might be 10 inches, or more, if the rider is duck-footed.

In this case, the "wedge proponents" suggest that the knees should track directly over the feet with medial wedges.

Since the muscles of the buttocks and thigh are the main propulsive leg muscles, other dissenting authorities feel that a pedaling style with the knees angled diagonally from the top tube down toward the pedals is better for all riders for power production and aerodynamics. A traditional and classic adage is that riders should pedal to "scrape the paint off the top tube."

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58 Chaudhari, AM, et al. *Dynamic changes in anterior/posterior translation and internal/external rotation of the knee during cycling.* American Society of Biomechanics. Annual meeting. Poster. (2001). Linked and accessed Jan 8, 2008. Abstract. (2001). Linked and accessed Jan 8, 2008.

For narrow-hipped riders, these dissenting authorities would vote for tracking the knees below the hips, rather than over the feet.

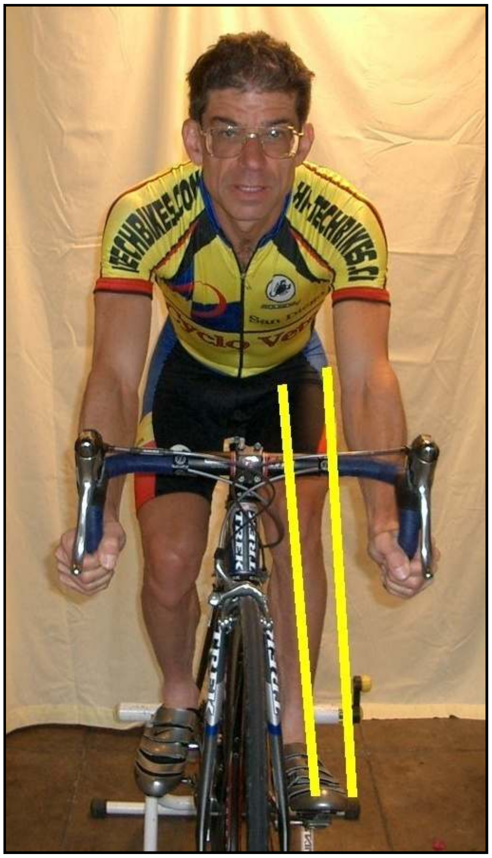

Figure 68. Whether the anatomical landmarks used are the femoral head, mid patella, and second toe (left yellow line); or lateral thigh, knee, and foot (right yellow line); riders with narrow hips cannot have all three structures vertically aligned.

This is not practically possible either, because as the leg reaches the bottom of the stroke, the knee must move away from the bicycle frame.

Some riders pedal in an ellipse. After they finish pushing down with a knees-in style, they move their knee outward as they beginning lifting their leg. They then move their knee inward again as they begin the power phase to push down.

Although somewhat ungainly, this style may work for these riders because in externally rotating their hips they can more effectively use their hip flexors and unweight their pedals with this motion. Other riders pedal this way because of hip problems, including arthritis.

Since changes in power production are unproven with changes in alignment pedaling style, and since many riders have spent tens if not hundreds of thousands of miles adapting to their style.... Unless there are overuse or other biomechanical problems that suggest a change, my approach is to leave riders alone.

Knees-Out Style

Bow-legged or knees-out from the top tube pedaling is rarely an advantageous style.

Most riders who pedal this way are either obese or have hip or knee problems. Riders who bow only one leg may do so if that leg is longer than the other one is, or if they have hip or knee problems.

Riders who pedal knees out are usually more comfortable if this style is reduced or corrected to a vertical style.

The best way to reduce or correct this style of pedaling is to increase stance width (see below).

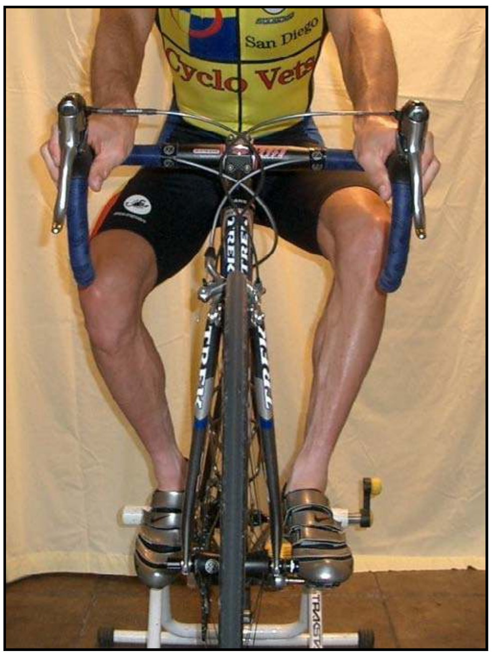

Figure 69. Exaggeration of knees-out pedaling style.

Lateral wedges may also align the knees more in a vertical plane while pedaling. This approach may be helpful if the rider has forefoot valgus—the big toe lower than the little toe. Forefoot valgus is uncommon, occurring in less than 10% of the population.

Lateral wedges are likely to hurt, rather than help, riders whose knees-out style is joint- or obesity-related.

Q-Factor—Stance Width

In bicycling, Q-factor refers to stance width. Bicycle Q-factor relates to bottom bracket axle width, crankarm offset, pedal spindle length, and cleat position.

Pedals have different length spindles, or distances from the crankarm to the center of the pedal platform.

The same manufacturer may produce pedals with different spindle lengths. Bowlegged riders generally need pedals with long spindles.

Cornering clearance is improved as the Q-factor decreases.

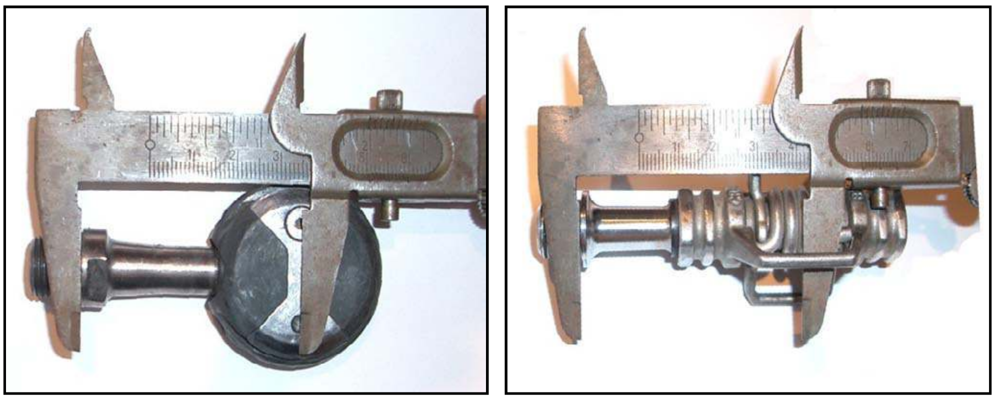

Figure 70. Pedal spindle length. Left: Speedplay X-1 titanium pedal top. 50 mm from crank face to center of pedal. Right: Crank Bros Egg Beater. 57 mm from crank face top center of pedal.

Placing the cleat inward, toward the bike, also widens the stance.

Longer bottom brackets or crankarms with more offset may also increase stance width. Note: Mountain bikes and tandems often have longer bottom brackets than road bicycles. Bicycles with triple chainrings often have longer bottom brackets than bikes with double chainrings.

Pedal/stance spacers (see Figure 74 on page 101) that increase the distance to the crank reduce the tendency to pedal bow-legged.

Pedal/stance spacers usually help knees-out riders. Washers 2 mm thick are usually safe. Spacing more than 2 mm may not leave enough threads on the pedal to safely engage the crank.

Pedal axle extenders are an alternative.

A 20-mm spacer, threaded male at one end and female at the other, is commercially available under the brand name Kneesavers. Unfortunately, this amount of spacing overcorrects knee-out style for many riders. 25-mm and 30-mm extenders are also available.

Increasing the distance between the feet with pedal/stance spacers can be especially helpful for obese riders who frequently pedal with their knees splayed out during the downstroke power phase of the pedal stroke.

Windswept Style

Riders pedal with one knee toward the top tube and one knee away from the top tube. Check for a leg-length discrepancy or spinal twist (scoliosis).

Riders are generally more comfortable with a pedal/stance washer on the side on which the knee moves away from the top tube. This also improves alignment on this side.

Alignment on the knees-in side can usually be improved, if desired, with a medial wedge.

Waterfalling

Too much unsupported pressure on the outside of the foot results in waterfalling.

In this situation, the outside of the shoe falls over the sole; or the outside of the shoe and sole falls outward over the cleat and pedal.

This may occur when a heavy or powerful rider positions the cleat inward (so that the shoe is farther from the crank) and breaks down the shoe material.

Riders commonly set their cleats inward when using pedals with short spindles or pedals with small Q-factors to avoid hitting the crankarm with their shoe.

Riders with a knees-out pedaling style—for example riders with wide pelvises or overweight riders—waterfall their shoes more often than those with a knees-in style.

Waterfalling may be improved by using pedals with longer axles, increasing the Q-factor for pedals that have this feature, or using pedal/stance spacers.

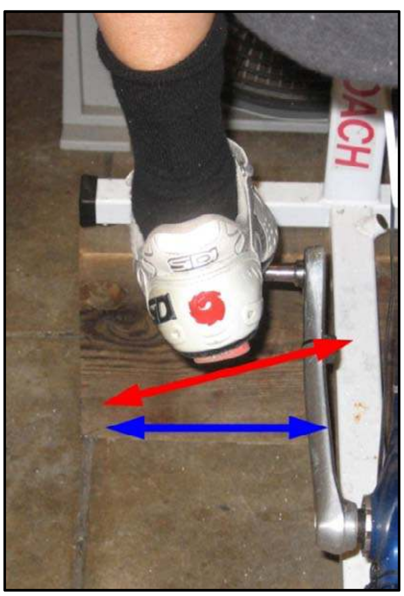

Figure 71. Waterfalling shoes. The outsides of the shoes fall over their soles. The plane of the sole (red-arrowed line) is not horizontal (blue-arrowed line).

Predicting Pedaling Style

Wedge requirements to improve knee-over-foot vertical alignment can be predicted based on forefoot alignment. (Whether such alignment *should* be corrected is debatable.)

Forefoot alignment can be measured with standard or specific forefoot goniometers.[59]

A 1-mm wedge will correct roughly 5° of forefoot varus (twist).

Figure 72. Specific forefoot goniometer. Courtesy LeMond Fitness.

59 http://www.physiotherapy.asn.au/AJP/48-1/02MarGlasoe.pdf.

Part 6: Wedges, Shims, Pedal Spacers & Extenders, Orthotics, & Custom Shoes

Wedges and Shims

If performing bike fits for many riders, a variety of shoe-pedal wedges and pedal/stance spacers will be useful.

As discussed throughout this book, these devices can be useful to help correct leg-length discrepancy, to cant the foot, and to increase stance width in knees-out (bow-legged) pedaling riders.

Commercial wedges are readily available for standard 3-hole, Speedplay, and SPD-type cleats. Alternatively, washers can be used. When wedges are alternated with the thicker side toward and away from the crank (medially and laterally) they function as shims.

Longer cleat-fixing bolts may be required.

Some bike fitters wedge most riders, believing the common forefoot varus is responsible for a knees-in pedaling style that should be corrected. As discussed on page 92, this opinion is far from universal.

Although some coaches and other cycling experts quote a 1997 study by Van Zyl showing that medial wedges help patellofemoral pain, this same study showed that raising the seat height a couple of millimeters was equally effective.[60]

A more recent study by Gregersen found theoretical reasons why medial wedges might prevent or treat patellofemoral pain.[61]

Figure 73. Look-style shims. The four held shims are 4 mm thicker on the side away from the fingers.

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60 Van Zyl, E, Schwellnus, M, and Noakes, TD. *Correcting lower limb kinematics decreases patellofemoral pain (PFP) in cyclists*. Medicine & Science in Sports & Exercise 29 (197, 1123). (1997).

61 Gregersen, CS, et al. *How changing the inversion/eversion foot angle affects the nondriving intersegmental knee moments and the relative activation of the vastii muscles in cycling*. Journal of Biomechanical Engineering. 128 (3). 391-398. (2006). Linked and accessed Feb. 4, 2008.

Wedges Cause Problems

One of the most common problems I see in riders I fit are the inappropriate, ill-advised, or ill-luck use of wedges.

- Riders with problems sometimes try wedges on their own or based on the recommendation of a bike store employee who sells the product but gives no assistance in its correct use. If a rider with iliotibial band syndrome tries a wedge and places the thick part medially, rather than laterally, the wedge is more likely to hurt than help.
- In at least half of the riders I fit who come to me with wedges already installed by other fitters, I remove the wedges. However, in fairness to those other fitters: I am a problem fitter: I fit riders who have not been helped sufficiently by others. I know the numerator, not the denominator. What I do not know is how many riders who have been fit with wedges do *not* come to see me because their problem was improved with wedges.

Pedal/Stance Spacers and Extenders

Pedal/stance spacers are 9/16 inch (14 mm) inside-diameter washers. These can be found at specialty hardware stores, through LeMond Fitness, and from manufacturers who produce washers for their carbon cranks, such as Full Speed Ahead.

Split lock washers push the pedal out and do not allow for the usual self-tightening action of pedaling. Avoid them.

Be cautious about using washers. Washers reduce the number of pedal threads engaged in the crank, and therefore make a fastening failure more likely. Even without the use of washers, fastener failure is an occasional problem. Avoid using washers that are more than 2 mm thick:

Figure 74. Pedal/stance spacer. This aluminum washer has a 14-mm inside diameter, a 22-mm outside diameter and is 2 mm thick.

Figure 75. Pedal axle extender. This steel extender effectively lengthens the axle 20 mm.

Specialty pedal axle extenders, often 20 mm to 30 mm long, are available through a number of suppliers, for example, High Sierra Cycle Center and Kneesavers.

Orthotics

These shoe inserts help support the foot and direct weight and energy forces. Orthotics may provide support, cant (angle) the foot, or provide a space or shim to help correct a small leg-length discrepancy. They are used for a variety of foot, ankle, knee, hip, back, and other biomechanical problems. Cycling orthotics are longer than running orthotics—they should support the metatarsal heads.

Cycling orthotics are used less commonly than running orthotics because the cycling shoe provides good support to the foot and cycling is mostly a forefoot sport. Running, in contrast, often requires motion control or cushioning of the mid or rear foot.

As discussed above, inexpensive wedges cant forefoot misalignments. Relatively expensive orthotics help cant midfoot problems.

Orthotics may be modest over-the-counter products, perhaps better termed footbeds, used interchangeably by different individuals and different sports, or sport-specific custom-molded products costing hundreds of dollars.

Orthotics may help those in whom anatomic variation is otherwise difficult to correct by adjustment of the bicycle.

Orthotics may be helpful in realigning the structures of the leg. They tend to be most useful for problems closer to the foot and less useful for such problems as back and neck ache.

Who is Most Likely to Need an Orthotic?

Those who walk with an abnormal pressure pattern are most likely to be helped with orthotics.

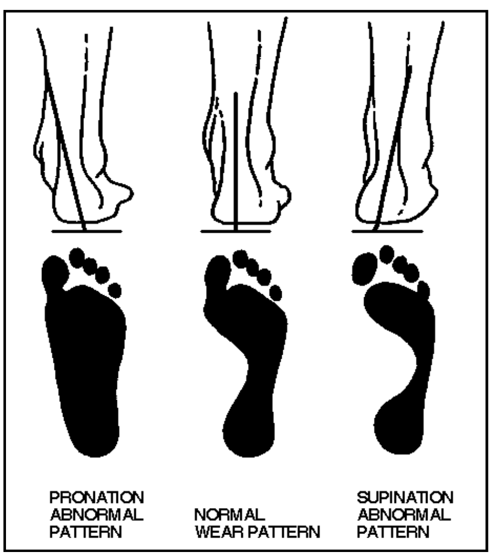


Figure 76. Midfoot patterns.

If you have chronic foot, knee, hip, or leg pain or problems, and your patterns are abnormal, it is possible an orthotic may help.

If your pattern is abnormal and you have no problems, there is no reason to get orthotics. For those who have needed orthotics, studies have shown no difference in power when they cycle with orthotics. Orthotics may help pain or other medical problems but do not otherwise improve performance.

Custom Shoes

Specialty shoe manufactures build footbeds or orthotics into custom-made cycling shoes. These products may be lighter, more aerodynamic, with lower stack heights, and smaller or larger Q-factors than standard shoes.

Part 7: Pedal Stance Width, Stack Height, & Dropped Pedals

Pedal Stance Width

Pedals differ in their stance width or Q-factor. Some have an adjustable Q-factor in the pedal. Some cleats can be adjusted side-to-side (cleat Q-factor). Some manufacturers make the same pedal platform with different lengths of spindle (axle).

Figure 77. The Speedplay pedal has an adjustable cleat Q-factor. It adjusts 4 mm to each side of center for a total of 8 mm.

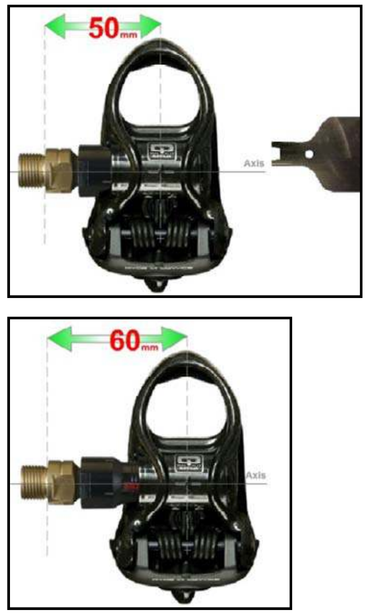


Figure 78. The center of the Look CX6 pedal may be between 50 mm and 60 mm from the crankarm. It has an adjustable pedal Q-factor of 10 mm.

Although riders may adjust cleats to one extreme or another to optimize stance width, in a perfect world the center of shoe pressure should be centered over the pedal. In a perfect world, stance distance would be accomplished through bicycle frame design, bottom-bracket length, crank offset, and pedal-spindle length rather than moving the shoe side-to-side on the pedal.

Cleat Width

Heavy or powerful road riders may prefer wider cleats. When narrow cleats such as SPDs wear, they toggle (rock) side to side more than wider cleats.

Pedal	Pedal Q-Factor. Crank-Center (mm)	Cleat Q-Factor. Play (mm) from Center	Pedal Stack Height (mm) (Pedal and Cleat Thickness)
Campy Record	51	±3.5	20.5
/Chorus	51	±3.5	20.5
Crank Bros. Egg Beater	57	0	
Look PP206	50	±3	22
CX6, CX6 Ti	Adjustable 50 to 60	±3	21.3
CX7 Cant adjustable	Adjustable 50 to 60	±3	21.3
Ritchey	53		
Shimano DA	53	±1.5	13.7
Ultegra	53	±1.5	13.7
SPDR540	54	±1.5	12
M-series	59		
Speedplay X/1 Ti	51	±4	11.5
X/2 X/3 Steel	53	±4	11.5
Zeros		±4	11.5
Frogs			
Time EQ	56	0	
Impact, Impact Mag	Adjustable 2.5mm		12.2
Source	Direct measurement		Manufacturer's websites

Table 10. Pedals. Selected biomechanical factors. For a discussion about pedal float, see page 54.

Pedal Stack Height

Limited studies are available concerning the effects of ankle elevation above the pedal axis.

Pedal platform height and cleat thickness (stack height), shoe sole thickness, and elevation of the ankle joint above the foot sole (ankling) contribute to ankle elevation.

Typically, pedal platform height, cleat thickness, and shoe sole thickness contribute about 2 cm to ankle elevation.

Figure 79. Pedal stack height—the distance from the shoe sole to the center of the pedal axle—depends upon cleat thickness, pedal thickness, and how the cleat and pedal fit into one another. Left, Speedplay: 11.5 mm. Right, Look PP296: 22.0 mm.

Dropped Pedals

Cyclists rarely consider changing the pedal height, although this is possible.

Shims under the cleat raise the pedal height. When placed on both shoes, they increase ankle elevation above the pedal axis. No studies have shown this to be useful. When placed on one shoe, they can help treat leg-length discrepancy.

Specially designed pedals or drop pedal systems lower the pedal height. When placed on both cranks, they lower ankle elevation above the pedal axis. No studies have shown this to be useful, though claims of improved performance are made. When a drop pedal system is used with one shoe, it can help treat leg-length discrepancy.

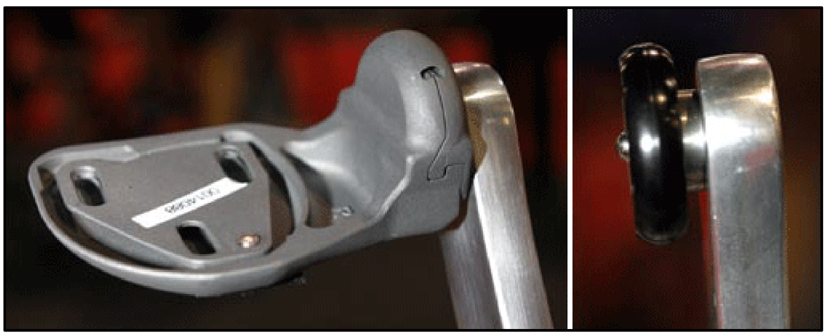


Figure 80. The SMp pedal allows the pedal to be lowered as much as 1-1/2 inches below its usual height. The manufacture claims the pedal is 3% to 4% more efficient.[62]

Figure 81. Drop pedal system lowers ankle elevation above the pedal axis. When used on one crank, a drop pedal can help treat leg-length discrepancy. System from High-Sierra Cycling Center.

62 SidedMountpedal website. Linked and accessed Jan 14, 2008.

Discussion

Lowering the pedal platform will allow a lower seat height and center of gravity. This might be expected to improve aerodynamics.

Lowering the pedal platform worsens pedal clearance to the road, potentially causing a crash when pedaling around corners. It might also worsen front wheel/toe overlap, again potentially causing a crash.

Intuition might lead one to think that the lower the foot, the better in terms of pedaling economy (metabolic cost).

However, that is not what the research of Hull and Gonzalez shows.[63]

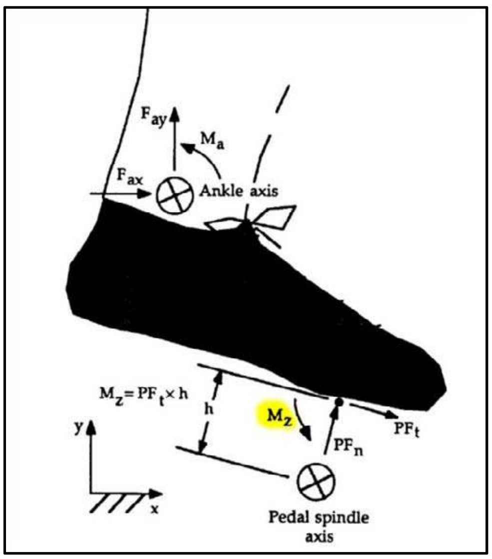


Figure 82. Foot moment of force (torque), M_Z, (highlighted) ensures a net zero moment of force about the pedal spindle axis when the pedal platform does not coincide with this axis. From Hull and Gonzales.

Hull and Gonzalez developed a joint moment-of-force-based cost function of pedaling. They showed that the necessary zero foot moment of force about the pedal axis translates to a preferred platform height of 2 cm at a cadence of 90 rpm.

However, the authors themselves note that:

- The validity of their cost-function model is uncertain.
- The sensitivity of the cost function is low. Heights in the range of 0 to 2.5 cm increase the cost function by only 0.15%.
- Pedaling rates below 90 rpm favor a platform lower than 2 cm.
- Pedaling rates above 90 rpm favor a platform higher than 2 cm.

63 Hull, ML and Gonzalez, HK. *The effect of pedal platform height on cycling biomechanics*. International Journal of Sport Biomechanics. 6. 1-17. (1990).

Position-Related

Part 8: Handling & Overlap Problems

The table below summarizes some common handling and overlap bicycle-fitting problems. (Overlap problems are those where a bike part and a body part bump into each other.) For position-related aches and pains, see *Part 9* on page 110.

Problem	Possible Causes	Solutions
Lack control on descents	Too much weight forward	Slide aft on saddle Move saddle aft Shorten reach
Loss of rear-wheel traction	Too much weight forward	Slide aft on saddle Move saddle aft Shorten reach
Front-end shimmy	Too much weight aft (Loose headset or other front-end mechanical problem common)	Slide forward on saddle Move saddle forward Lengthen reach
Loss of front-wheel traction	Too much weight aft	Slide forward on saddle Move saddle forward Lengthen reach
Scooting forward on saddle	Reach too long Saddle nose tipped too far down	Shorten reach Raise saddle nose
Scooting backward on saddle	Reach too short Saddle nose tipped too far up Seat too forward	Lengthen reach Lower saddle nose Move seat aft
Hard to reach brake levers from handlebar drops	Overall reach too long Handlebar reach too long Brake levers too big	Shorten reach Shorten handlebar reach Use specialty bar for small hands Use specialty smaller brake levers
Wrists hit handlebar tops when sprinting in drops	Too long handlebar top	Choose handlebar with curved top Choose shorter handlebar
Knees hit handlebar tops when standing	Too short stem	Longer stem
Knees hit stem or headset when sprinting out of the saddle	Too short top tube (bike reach) Too long stem	Longer top tube Shorten stem

Knees hit chest when riding in drops	Handlebar too low	Raise handlebar
		  Raise stem
		  Use stem with greater rise
		Shorter stem

Knees hit elbows when riding in drops	Reach too short	Longer stem
		Lower handlebar
		  Lower stem
		  Use stem with less or negative rise

Heels hit cranks when pedaling	Duck-footed	Use pedal with greater Q-factor Use 2-mm pedal/stance spacer Use cranks with less offset
Toes hit front wheel when turning	Poor small-bike design Too long cranks Feet too forward	Bike with 650c wheels Custom bike Shorten cranks Adjust cleats to move feet aft
General lack of comfort or stability	Almost anything!	Reread this book!

Position-Related

Part 9: Aches & Pains

Poor or suboptimal bicycle position can be associated with overuse injuries. Overuse injuries may be *caused* by bad bike fit.

Injuries, caused by non-bicycle triggers may be *worsened* by bad bike fit.

Even good bicycle fits have adjustability, and modification may be necessary when aches or pains develop.

The table below summarizes bicycle fit solutions for common ailments. Many of these problems have non bicycle-fit causes. The general biomechanical principle is often to reduce, equalize, or redistribute the stretch or pressure on the affected structure.

When attempts at bicycle-fit solutions do not improve injuries, or when problems are more than subjective (symptoms)—that is problems are objective (signs: redness, swelling, grating)—consultation with a cycling-aware medical professional is wise.

For a more complete discussion of these issues, see *Bicycling Medicine,* published by Simon & Schuster, 1998.

Problem Location	Causes	Solutions
Neck and Shoulder ***Scapula***	Exercise load too high Volume Intensity	Reduce miles, readapt slowly Consciously relax and stretch on and off bike Reduce hard efforts involving upper back muscles
	Position too low, craning Torso angle too small Reach too great	Ride more upright. Ride on hoods or tops Reduce reach Raise or shorten stem Increase stem rise or flip level threadless stem Narrower handlebars Shorter top tube Vary position Check seat fore-aft Avoid tilting saddle nose down
	Jarring	Pad saddle, gloves, handlebars, or grips Wider tires, lower pressure Crossed, not radial spokes; reduce spoke tension Seatpost with offset, suspension seatpost Mountain bike on road Butted tubes, raked fork, suspension frame
	Arm-length discrepancy See page 90	Offset brake hoods or aerobars
	Heavy helmet	Lightweight helmet
Lower Back	Exercise load too high Big gears	Reduce miles, readapt slowly Increase cadence. Keep rpm >70
	Climbing	Reduce climbing, readapt slowly Shift climbing positions Relax back muscles; stretch on bike Take climbing breaks on long climbs

	Too stretched out
	  Torso angle too small
	  Reach too great
		Ride more upright. Ride on hoods or tops
		Reduce reach
		  Raise or shorten stem
		  Increase stem rise or flip level threadless stem
		  Narrower handlebars
		  Shorter top tube

	Jarring	Pad saddle, gloves, handlebars, or grips Wider tires, lower pressure Crossed, not radial spokes; reduce spoke tension Seatpost with offset, suspension seatpost Mountain bike on road Butted tubes, raked fork, suspension frame
	Leg-length discrepancy See page 87	Set seat height for longer leg Shim shorter leg
	Tight hamstrings	Stretch and strengthen
	Poor core strength	Stretch and strengthen back and abdominals
Buttocks **Saddle Sores**	Volume, too high Intensity, too easy	Reduce miles, readapt slowly Increase intensity
	Bad saddle shape for anatomy	Fit anatomy
	Volume, too high Intensity, too easy	Reduce miles, readapt slowly Increase intensity
	Weight loss	Increase padding
	Pressure and jarring	Pad saddle, gloves, handlebars, or grips Wider tires, lower pressure Crossed, not radial spokes; reduce spoke tension Seatpost with offset, suspension seatpost Mountain bike on road Butted tubes, raked fork, suspension frame

	Friction and shearing	Layer
		  Saddle cover or pad,
		  Two pairs of shorts

	Seat position	Any minor change may help
		  A slight nose-down or nose-up position may help
		Check weight distribution not too far back
		  Slightly fore or aft may help
		Vary position
		  Move around frequently
		  Stand up

	Seat too high	Lower saddle
	Leg-length discrepancy	Set seat height for longer leg. Shim shorter leg
	Spinal twist or arm-length discrepancy	Stagger brake hood position

Elbows	Wrists bent toward pinky	Rotate brake hoods upward
	Twisting motions	Reposition twist gear and brake lever devices
Wrists **Thumb side**	Wrists bent toward pinky	Rotate brake hoods upward
Hand Numbness **(Cyclist's Palsy)**	Too much riding	Reduce, readapt slowly
	Jarring	Pad saddle, gloves, handlebars, or grips Wider tires, lower pressure Crossed, not radial spokes; reduce spoke tension Seatpost with offset, suspension seatpost Mountain bike on road Butted tubes, raked fork, suspension frame
	Hand position	Reposition frequently Relax hands, wrists, and upper body Improve brake hood position Tasks (e.g. drinking) with both hands
	Pressure too high	Avoid placing pressure on heel of hand Vary position Check seat not too forward Use shorter stem Avoid tilting saddle down Use shorter top tube
	Too far forward	Check seat fore-aft position
Knee		
Front (Anterior)	Seat too low	Raise seat
	Seat too forward	Move seat back
	Climbing too much	Reduce climbing
	Big gears, low rpm	Increase cadence. Keep rpm >70
	Cranks too long	Shorten cranks
Inside (Medial)	Seat too low	Raise seat
	Cleats—toes point out	Modify cleat position—toe in Consider floating pedals
	Floating pedals	Limit float to 5°
	Toggling cleats	Replace cleats
	Exiting clipless pedals	Lubricate pedals or cleats Lower release tension Alternate or use other leg to unclip at stops
	Feet too far apart	Decrease stance width: Modify cleat position—closer Shorten bottom bracket axle Cranks with less offset Pedals with smaller Q-factor
	Lateral wedge or Canted shoe	Remove wedge Remove lateral cant or change shoe

Knee		
Outside (Lateral)	Seat too high (more common)	Lower seat to as much as 35° knee flexion
	Seat too low (knees-out style)	Raise seat to as much as 30° knee flexion
	Cleats—toes point in	Modify cleat—toe out Consider floating pedals
	Floating pedals	Limit float to 6°
	Toggling cleats	Replace cleats
	Feet too close	Increase stance width: Modify cleat position—apart Shim pedal on crank 2 mm Longer bottom bracket axle Cranks with more offset Pedals with larger Q-factor
	Medial wedge or Canted shoe	Remove wedge Remove medial cant or change shoe
Back (Posterior)	Saddle too high	Lower saddle
	Saddle too far back	Move saddle forward
	Floating pedals	Limit float to 6°
	Toggling cleats	Replace cleats
	Tight hamstrings	Improve flexibility
	Weak hamstrings	Increase strength
Ankle **Achilles**	Climbing Big gears, low rpm	Reduce climbing Increase cadence. Keep rpm >70
	Saddle too high	Lower saddle
	Cleat too far forward	Move cleat rearward
	Cold-weather riding	Keep Achilles, calf, and foot warm
Foot Pain or **Numbness**	Tight shoes	Increase size Loosen straps with climbing or heat Foot rest breaks
	Too much pressure on ball	Move cleat back Use pedals with larger cleat platform Try softer plastic rather than stiffer carbon-soled shoes
	Big gears, low rpm	Increase cadence. Keep rpm >70

Table 11. Bicycle-position related problems, causes, and treatments. Many of the problems listed above have causes other than bicycle position. For a fuller discussion, see *Bicycling Medicine*, published by Simon & Schuster, 1998.

Notes

Pressure and Jarring

Steps that reduce pressure and jarring help no matter where the pressure- or jarring-related problems occur, although the closer they are to the area affected, the more likely they are to work. Consider that on a tandem a suspension stoker (rear rider) seatpost helps not only the stoker but the captain (front rider) as well. Consider that cross-spoked front wheels help not only hand-related pressure and jarring problems, but saddles sores as well.

To reduce pressure and jarring, consider:

- Padded saddle, gloves, handlebar tape, and grips
- Neoprene saddle cover, such as QR Mr. Flitie
- Wider tires, lower tire pressure
  25 mm road tires at 100 psi provide more comfort and only marginally-reduced performance compared with 21 mm or 23 mm tires at 120 psi.
- Crossed, not radial spokes; reduce spoke tension
- Seatpost with offset
- Suspension seat post
- Mountain bike on road
- Raked, not straight-bladed, fork
- Butted tubes
- Suspension frame

Stance Width

To increase stance width (bicycle Q-factor) consider:

- Modify cleat position—apart
- Shim pedal on crank 2 mm
- Longer bottom bracket axle
- Cranks with more offset
- Pedals with larger Q-factor

Part 10: Arnie's Differences

My approach often results in nearly the same position as a traditional fit. Nearly, though, is often not the same.

Here is a summary of the differences in the way I fit bicycle riders vs. traditional methods.

- I generally position the cleat as far back as standard shoes and cleats allow. This works out to the same or up to 1 cm further back than traditional.
- I position the cleat to orient the cycling shoes the way the rider walks, rather than the conventional straight ahead.
- I set seat height by knee angles, not by traditional leg-length or inseam formulas.
- I rotate the handlebars so that the tips point down from the traditional horizontal, generally toward the midpoint of the seat stays.
- I think about reach, and its many components, in terms of torso angle.
  I measure reach to the brake lever, not the handlebar.
- I set handlebar height higher than is traditional, especially for recreational riders and climbers.
- I set the seat with the nose level or pointed slightly down, rather than traditional level or slightly up.

Part 11: Almost Final Words

Many riders can learn to properly adjust their bicycles to establish good bicycle fit.

By simply observing a rider pedaling on the road, an experienced coach can eyeball and evaluate bicycle position for most riders.

A more precise fit can be accomplished on a stationary trainer.

Performance riders (racers) may benefit from an annual fit “check-up.”

Riders with biomechanical, overuse injury or other special situations may benefit from a more comprehensive position fit on a stationary trainer that may include medical history, general orthopedic physical examination, biometric measurements, and video gait and pedaling analysis.

Figured Your Bike Position?

Write down your bike measurements: Seat height. Saddle nose behind bottom bracket. Saddle nose to handlebar. Reach. Bar width. Stem height.

Place some electrical tape on your seatpost where it exits your frame. Use a magic marker to mark your saddle position on its rails.

Record your basic bicycle geometry: Frame size, top tube length, seat tube angle.

It will then be easier and faster to reestablish your position if a part slips, you get a new part, you reassemble your bicycle after traveling, you get a new bike, or you set up another bike.

You may also want to record your biomechanical measurements. These measurements are discussed throughout this book and specifically in the section on anatomical considerations on page 85.

The table below may be useful to record these values.

My Bike Measurements		**My Measurements**	
Frame Size c-c		Height	
Top Tube Length c-c		Inseam	
Seat Tube Angle		Leg Length	
Crankarm Length		Shoulder Width	
Seat Height		Arm Length	
Knee Extension R/L		Hand Size	
Saddle Angle			
Foot Fore-Aft		Bow-Leg/Knock-Knee	
Nose Behind BB		Tibial Torsion (Duck/Pigeon)	
Stem Length		Pronator/Supinator	
Handlebar/Stem Height		Foot Size R/L	
Reach: Seat Nose to Handlebar		Forefoot Varus/Valgus	
Reach: Seat Nose to Brake hood			
Handlebar Width c-c		Orthotic/Footbed	
Handlebar Drop		Shim	
Handlebar Drop Angle		Cant	
Brake Levers			
Cleat Rotation		Flexibility	
Other		Other	

Table 12. Bicycle measurement and biomechanical data sheet.

Appendix A: Mini-Anatomy Glossary

Angles and Leg Length

Hip Angle—The angle formed by the shoulder (greater tubercle of the humerus), hip (greater trochanter of the femur), and knee (lateral condyle of the femur).

The hip angle is (1) the sum of the torso angle and the femur angle, and results from (2) hip and back flexion.

Torso Angle—The angle formed by the shoulder (greater tubercle of the humerus), hip (greater trochanter of the femur), and a horizontal. Standard measurement is on a level bicycle with the rider positioned with the hands on the hoods.

Femur Angle—The angle formed by a horizontal, hip (greater trochanter of the femur) and knee (lateral condyle of the femur).

Pelvic Tilt—The incline of the pelvis. If the pelvis is considered to be a bowl, anterior pelvic tilt is the forward tipping of the bowl and posterior pelvic tilt is the backward tipping of the bowl. Cyclists commonly ride with 20° to 25° of anterior pelvic tilt.[64]

Leg Length—Anatomical and bicycle fit dimension.

(1) Anatomic: from the anterior superior iliac spine (ASIS) to the medial malleolus (ankle bone).

(2) Bicycle fit: Greater trochanteric. Standing, from the greater trochanter to the floor.

(3) Bicycle fit: Inseam. Standing, from the crotch to the floor.

For a discussion about leg length discrepancy, see page 87.

Figure 83. Hip angle (in this example, 94°), is the sum of the torso angle (38°) and the femur angle (56°).

64 Sauer et al showed that males have about 21° and females about 24° of pelvic tilt. Sauer, JL et al. *Influence of gender, power, and hand position on pelvic motion during seated cycling*. Medicine & Science in Sports & Exercise. 39 (12). 2204-2211. (2007). Linked and accessed Jan 27, 2008.

Directions, Movements, and Planes

Anterior—Towards the front of the body (or the front-most portion or structure).

Posterior—Towards the rear of the body (or the rear-most portion or structure).

Medial—Toward to the centerline of the body.

Lateral—Away from the centerline of the body.

Abduction—Movement away from the midline or centerline.

Adduction—Movement towards the midline or centerline.

Flexion—Bending movement that decreases the angle between parts.

Extension—Bending movement that increases the angle between parts.

Valgus—Bent (or bending, or force) inwards. Knock-knees = genu valgum.

Varus—Bent (or bending, or force) outwards. Bow-legs = genu varum.

Sagittal Plane—Plane splitting the body into left and right sides. Most bicycling movements have been traditionally studied in the sagittal plane.

Coronal (Frontal) Plane—Plane splitting the body into front and rear sides.

Transverse (Axial) Plane—Plane splitting the body into top and bottom sides.

Bones and Landmarks, Pelvis and Leg

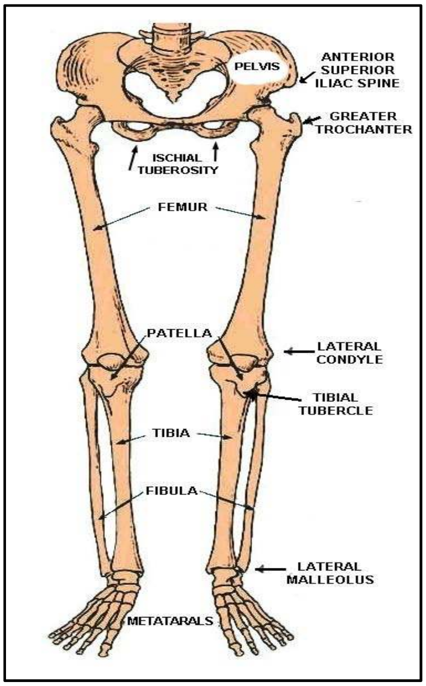


Figure 84. Selected lower limb bones and landmarks. For the shoulders, see Figure 35 on page 60.

ASIS—The anterior superior iliac spine, a landmark on the anterior pelvis.

Femur—The thigh bone. The largest bone in the body; runs from the hip to the knee.

Fibula—The minor bone running from the knee to the ankle.

Greater Trochanter Femur—A landmark at the junction of the neck and upper body of the femur.

Greater Tubercle Humerus—A landmark at the lateral head of the humerus.

Humerus—Upper arm bone.

Ischial Tuberosity—The sit bone.

Patella—The kneecap. Part of the knee's extensor mechanism. Serves as a pulley for the quadriceps muscles. The patella slides in a groove in the femur. Tracking of the patella is related to the Q-angle: the quadriceps-pull angle. The Q-angle is the angle formed by a line drawn from the ASIS to the central patella and a second line drawn from the central patella to the tibial tubercle.

Pelvis—Bony structure at the base of the spine. Each os coxae (hipbone) comprises three bones: the ilium, ischium, and the pubis. The ilium is the largest and upper most part, the ischium is the posterior-inferior (back-lower) part, and the pubis is the anterior (front) part of the hipbone. The two hipbones are joined anteriorly at the symphysis pubis and posteriorly to the sacrum.

Tibial Tubercle (Tibial Tuberosity)—The bony knob just below the patella. An attachment point of the patellar tendon.

Tibia—The shinbone. The major bone running from the knee to the ankle.

Muscles, Hip and Leg

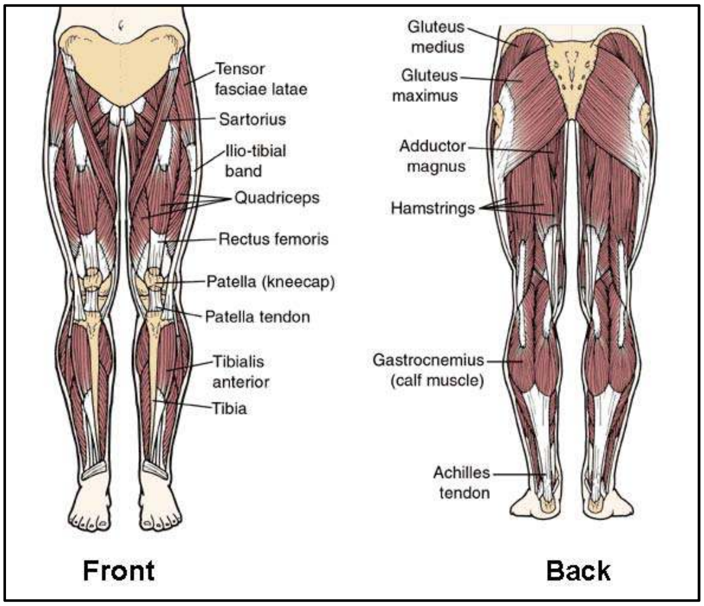


Figure 85. Selected lower limb muscles.

Gastrocnemius—Calf muscle that extends the ankle. Minor role: flex the knee.

Gluteals—Buttock muscles that extend the hip. Minor role: outwardly rotate hip and extend the trunk. Comprised of the gluteus maximus, gluteus minimus, and gluteus medius. The gluteus maximus is the largest and most powerful.

Hamstrings—Upper leg (posterior thigh) muscles that flex the knee. Minor role: extend the hip. Comprised of the biceps femoris on the lateral side of the leg, and the semitendinosus and semimembranosus on the medial side.

Sitting in a chair, you can easily feel the two sets of hamstring tendons.

Hip Flexors—Group of muscles that flex the femur onto the pelvis. The muscles contribute to flexing the lower back onto the pelvis when the pelvis is fixed, or flexing the pelvis onto the lower back when the lower back is fixed.

The hip flexors include: Tensor fasciae latae, sartorius, pectineus, adductor longus, adductor brevis, rectus femoris (part of the quadriceps), and the iliopsoas.

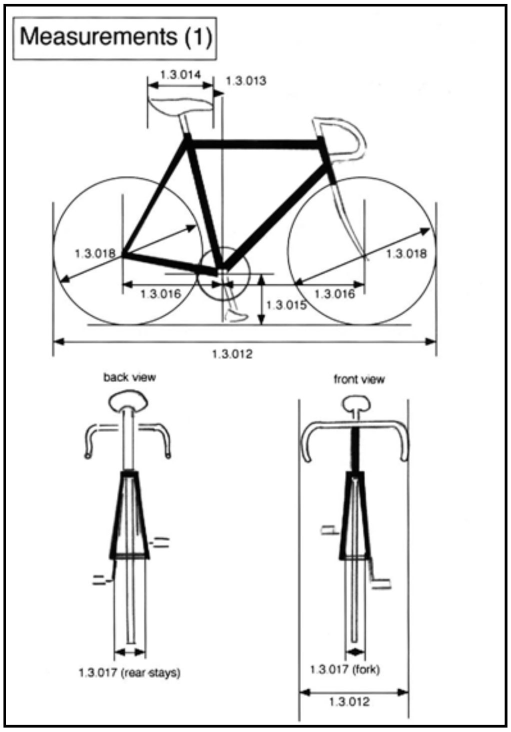
Quadriceps—Upper leg (anterior thigh) muscles that extend the knee. Minor role: flex the hip. The largest, most powerful group of muscles. The quadriceps, more fully named the quadriceps femoris group, comprised of the vastus lateralis, vastus intermedius, rectus femoris, and vastus medialis. The anterior thigh sartorius muscle is not part of the quadriceps group.

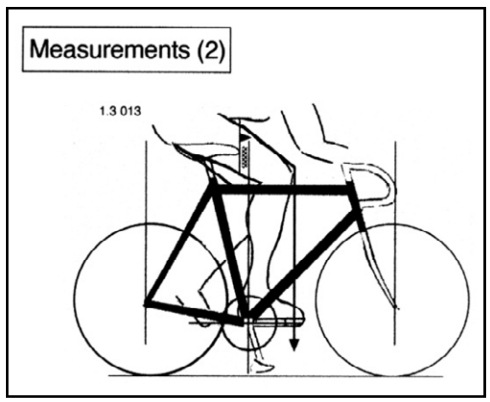
Soleus—Lower leg (posterior) muscle that plantar flexes the ankle. Underneath the gastrocnemius.

Appendix B: UCI Bike/Fit Rules

The following are UCI (Union Cycliste Internationale) rules, with their numbering and diagrams, abridged, from their website.[65] I have **bolded** the rules racers most commonly need to know.

1.3.011 Measurements (see diagram «Measurements (1)»)





1.3.012 A bicycle shall not measure more that 185 cm in length and 50 cm in width overall.

1.3.013 The **peak of the saddle** shall be a **minimum of 5 cm to the rear of a vertical plane passing through the bottom bracket spindle** (1). This restriction shall not be applied to the bicycle ridden by a rider in a track sprint event, keirin, 500 meters or 1-kilometer time trials. In no circumstances shall the peak of the saddle extend in front of a vertical line passing through the bottom bracket spindle.
The **distances may be reduced** where that is necessary for **morphological** reasons. The commissaires' panel may check to see whether, when pedaling, the point of the **rider's knee** when at its foremost position passes beyond a **vertical line** passing through the **pedal spindle** (see diagram «Measurements (2)»).

1.3.014 The saddle support shall be horizontal. The length of the saddle shall be between 24 and 30 cm.

1.3.015 The distance between the bottom bracket spindle and the ground shall be between 24 and 30 cm.

1.3.016 The distance between the vertical passing through the bottom bracket spindle and the front wheel spindle shall be between 54 and 65 cm.
The distance between the vertical passing through the bottom bracket spindle and the rear wheel spindle shall be between 35 and 50 cm.

65 Linked and accessed Jan 30, 2008.

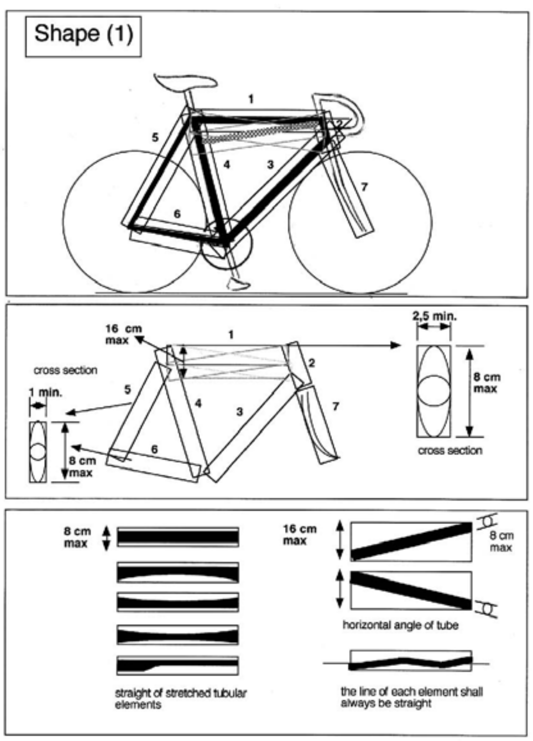
1.3.017 The distance between the internal extremities of the front forks shall not exceed 10.5 cm; the distance between the internal extremities of the rear triangle shall not exceed 13.5 cm.

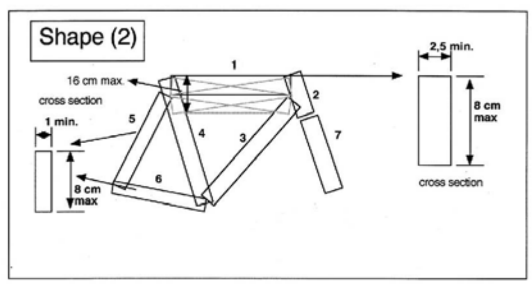
1.3.018 Wheels of the bicycle may vary in diameter between 55 cm and 70 cm, including the tire.
For massed start competitions, wheels shall have at least 12 spokes; spokes can be round, flattened or oval, as far as no dimension of their sections exceeds 10 mm. In order to be granted approval wheels must have passed a rupture test as prescribed by the UCI.
A traditional wheel is deemed to be a wheel with at least 16 metal spokes; the spokes may be round, flat or oval, provided that no dimension of their cross sections exceeds 2.4 mm; the section of the rim must not exceed 2.5 cm on each side.

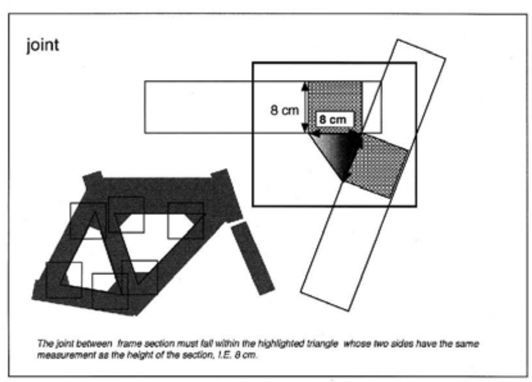
1.3.019 Weight. The weight of the bicycle cannot be less than 6.8 kilograms.

1.3.020 Configuration. For road competitions other than time trials, the frame of the bicycle shall be built around a main triangle. It shall be constructed of straight or tapered tubular elements (which may be round, oval, flattened, teardrop shaped or otherwise in cross-section) such that the form of each element encloses a straight line. The elements of the frame shall be laid out such that the joining points shall follow the following pattern: the top tube (1) connects the top of the head tube (2) to the top of the seat tube (4); the seat tube (from which the seat post shall extend) shall connect to the bottom bracket shell; the down tube (3) shall connect the bottom bracket shell to the bottom of the head tube. The rear triangles shall be formed by the chain stays (6), the seat stays (5) and the seat tube (4) with the seat stays anchored to the seat tube at points falling within the limits laid down for the slope of the top tube.
The maximum height of the elements shall be 8 cm and the minimum width 2.5 cm. The minimum width shall be reduced to 1 cm for the chain stays (6) and the seat stays (5). The minimum thickness of the elements of the front fork shall be 1 cm; these may be straight or curved (7). (See diagram «Shape (1)»).
The top tube may slope, provided that this element fits within a horizontal template defined by a maximum height of 16 cm and a minimum thickness of 2.5 cm.

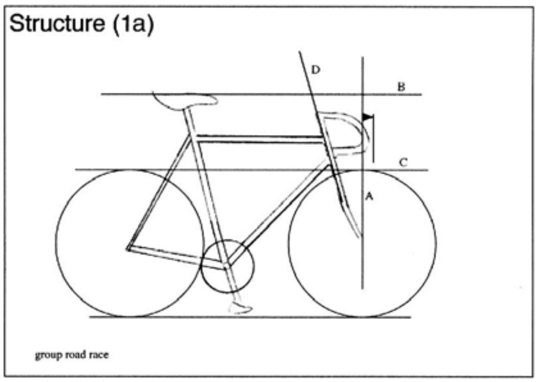
1.3.021 For road time trials and for track competitions, the elements, including the bottom bracket shell, shall fit within a template of the «triangular form» defined in article 1.3.020. (See diagram «Shape (2)»).

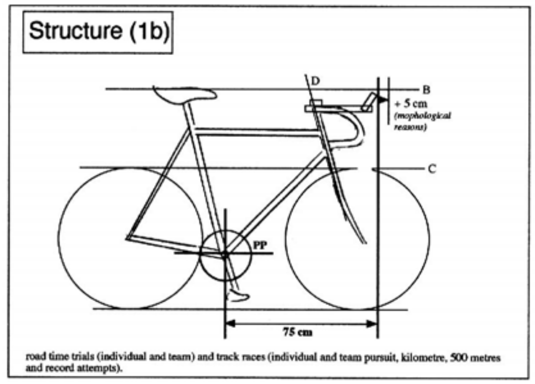






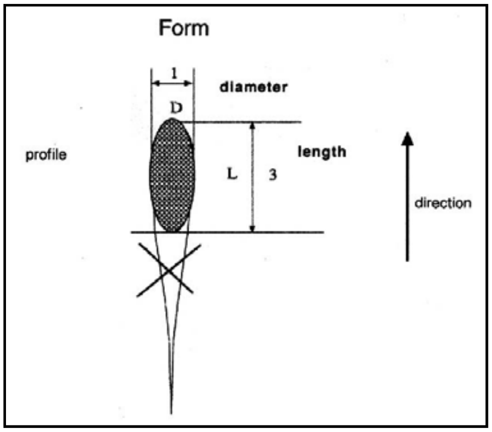
1.3.022 Structure In competitions other than those covered by article 1.3.023, only the traditional type of handlebars (see diagram «structure 1») may be used. The point of support for the **hands** must be positioned in an area defined as follows: above, by the **horizontal** plane of the point of support of the **saddle** (B); below, by the horizontal line passing through the highest point of the two wheels (these being of equal diameter) (C); at the rear by the axis of the steerer tube (D) and at the front by a vertical line passing through the front wheel spindle with a 5 cm tolerance (see diagram «Structure (1A)»). The distance referred to in point (A) is not applicable to the bicycle of a rider who takes part in a sprint, keirin or Olympic sprint race, but must not exceed 10 cm in relation to the vertical line passing through the front wheel spindle.
The brake controls attached to the handlebars shall consist of two supports with levers. It must be possible to operate the brakes by pulling on the levers with the hands on the lever supports. Any extension to or reconfiguration of the supports to enable an alternative use is prohibited. A combined system of brake and gear controls is authorized.

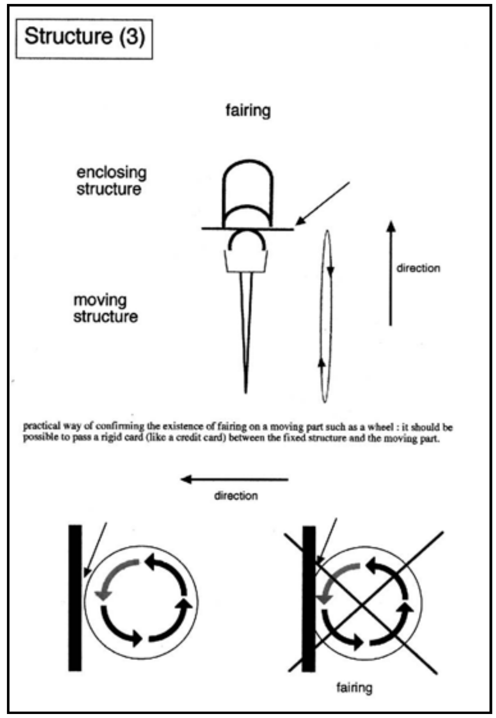




1.3.023 For road time trial competitions and for the following track competitions: individual and team pursuit, kilometer and 500 m, an extension may be added to the steering system. The **distance between the vertical line passing through the bottom bracket axle and the extremity of the handlebar may not exceed 75 cm**, with the other limits set in article 1.3.022 (B,C,D) remaining unchanged. A support for the elbows or forearms is permitted (see diagram «Structure (1B)»).
For road time trial competitions, controls or levers fixed to the handlebar extension may extend beyond the 75 cm limit as long as they do not constitute a change of use, particularly that of providing an alternative hand position beyond the 75 cm mark.
For the track and road competitions covered by the first paragraph, the distance of 75 cm may be **increased to 80 cm** to the extent that this is required for **morphological** reasons. The commissaires' panel may carry out the following test: ensuring that **the angle between the forearm and upper arm does not exceed 120°** when the rider is in a racing position.

1.3.024 Any device, added or blended into the structure, that is destined to decrease, or which has the effect of decreasing, resistance to air penetration or artificially to accelerate propulsion, such as a protective screen, fuselage form of fairing or the like, shall be prohibited.
A fuselage form shall be defined as an extension or streamlining of a section. This shall be tolerated as long as the ratio between the length L and the diameter D does not exceed 3.
A fairing shall be defined as the use or adaptation of a component of the bicycle in such a fashion that it encloses a moving part of the bicycle such as the wheels or the chainset. Therefore, it should be possible to **pass** a rigid card (like a **credit card**) **between** the **fixed** structure **and** the **moving part**.


Form
1
diameter
D
profile
L
3
length
direction


Structure (3)
fairing
enclosing structure
moving structure
direction
practical way of confirming the existence of fairing on a moving part such as a wheel : it should be possible to pass a rigid card (like a credit card) between the fixed structure and the moving part.
direction
fairing

Appendix C: ABC Publications

The following publications are available through arniebakercycling.com:

Books

Bicycling Medicine

For more detailed information about how bicycle fit is modified due to biomechanical or overuse injuries, or other medical problems.

HIT—High-Intensity Training for Cyclists

Smart Cycling

Slide Shows

Aerodynamics

Climbing

Saddle Soreness

Time Trialing

Handouts

Climbing & Descending

Forefoot Problems

Time Trialing

High-Intensity Training Tips

Isolated Leg Training

Saddle Soreness