13) Lactate Threshold

For over a year I held out that lactate threshold testing would eventually provide a test that would settle many disputes regarding exercise. Most of this hope was based on Brian F. Sharkey's writings. I now understand this belief was in vain. Since then, other publications by George A. Brooks, PhD (SPORTS, Volume 8; Number 1, January 1988 and Sports Science Exchange, Volume 1, Number 2, April 1988), (furnished courtesy of Ted Lambrinedes, PhD) cast weighty doubt that lactate threshold is reliable.

Generally described, lactate threshold is that level of sustained work whereby the blood lactate does not diminish as more of it is produced by the working muscles. Apparently, this threshold is increased with training effect.

Lactate testing is defined in a number of ways; thus, the first problem with it as a standard is definitional. In most disciplines this alone would be adequate grounds to discard it.

Lactate testing is riddled with inconsistencies that are impossible to control in the lab as well as in the field. The results of this test vary significantly dependent upon the time of day, the food ingested and proximity to the test, the site of blood withdrawal, the specific muscles worked and the time lag since the end of the exercise bout. These and other problems make lactate testing hopeless for meaningful standardization. Of course, this realization does not stop the exercise physiologists from using blood lactate testing to gain publicity with its sensationalism. Witness the June 1996 issue of Scientific American.

Hi, again. This time I would like to continue on with my discussion of training for endurance athletes. Last time, I talked a little about VO2 max and mentioned that it is frequently considered to be the prime determinant in endurance performance. Well, this time I would like to discuss another factor which may even be more important than VO2 max in determining performance: the concept of the lactate threshold (LT).

There are a couple of concepts similar to LT which, although not entirely identical, I will consider to be synonymous to LT. These are the anaerobic threshold (AT), ventilatory threshold (VT), and onset of blood lactate accumulation (OBLA). These are not entirely the same concept but, for the sake of this discussion, I will use them interchangeably. Essentially, what these terms refer to is the exercise intensity (or threshold) that you can maintain for a long period of time and are usually expressed as a percentage of VO2 max. Put another way, above LT, you can only continue for a limited time due to the extreme accumulation of lactic acid in the blood which causes pain along with shutting down the energy producing capacity of the muscle.

Let me try to explain the LT with an example. Again, from last time, you may remember that I said VO2 max was frequently considered as the prime determinant for performance. Well, that would be great if you were physically able to exercise at 100% of your VO2 max, which you can't. So, let's take two athletes and do a little comparison. (I will be using extreme values to help illustrate the point).

Let's say athlete 1 has a VO2 max of 70 ml/kg/min which is very good. Athlete 2 has a mere VO2 max of 50 ml/kg/min which is about average. But, for some reason, athlete 2 always seems to win in races against athlete 1. Well, let's say we test the LT (I'll talk about the methods a little later) and find that athlete 1 has a LT at 50% of their VO2 max while athlete 2 has a LT of 90% of their VO2 max (again, LT is the percentage of VO2 max that you can sustain for a long period of time).

So, for these athletes, we find their effective VO2 by multiplying by LT. So, athlete 1 is able to perform at 70 ml/kg/min x 0.5 = 35 ml/kg/min. Athlete 2 can perform at 50 ml/kg/min x 0.9 = 45 ml/kg/min.

So, in the long run, athlete 2 is able to maintain a higher VO2 than athlete 1 which helps to explain why athlete 2 always wins in races. Admittedly, the difference in LT would not generally be this large but I picked these values simply to make a point. Most healthy people have the capacity to utilize about 70-80% of their VO2 for extended periods of time but this percentage can be raised with training.

So, what exactly does the LT (or OBLA, VT, or AT) exactly mean physiologically. Well, as you may know, during high intensity exercise, lactic acid is produced due to the lack of oxygen and the conversion of glycogen to lactate. Well, lactate causes the pH of the muscle to drop (it's an acid) which causes pain and also makes the chemical machinery of the muscle function less than optimally. Even at rest, you are producing some lactate. However, the rate of clearance (Rc) from the tissue is the same as the rate of appearance (Ra) so that there is no net increase in concentration. Well, during low-intensity steady-state exercise, although lactate levels increase, the body is still able to clear it from the tissue quickly enough to avoid buildup

(Rc=Ra). Well, at some critical exercise intensity (i.e. threshhold), the body becomes incapable of clearing the lactate from the tissue quickly enough (Ra>Rc). The end result, lactate accumulation and pain. And, depending on your capacity for pain, exercise generally stops quickly thereafter.

So, LT and OBLA are really referring to that point when lactate begins to accumulate faster than it can be cleared. VT refers to a point during exercise when ventilation (number of breaths/minute) begins to increase from a normal linear progression. This occurs due to a large increase in carbon dioxide levels in the blood. The body uses the base part of bicarbonate to buffer lactic acid and the excess CO2 generated must be blown off with extra breathing. AT is a term that sort of refers to the exercise intensity at which anaerobic (without oxygen) processes take over during exercise as this is generally associated with high lactate levels. AT is somewhat of a misnomer as all exercise use some portion of aerobic and anaerobic processes but it has gained popular acceptance. While LT and OBLA are pretty much identical, the VT generally occurs after the LT has been passed as a certain amount of lactate must build up to cause the overcompensatory effect of breathing to clear the excess CO2.

I'll wrap up the first part right here with a final comment. Some of you may be thinking "Well, that's great, but what do I do to raise my LT?" Well, I'll leave you with one word: intervals.

Hi again. Welcome to the second part in a three part (maybe?) series about the lactate threshhold (LT) and intervals for endurance performance. Before I get into a discussion of intervals and how to develop an interval program, I would like to talk a little bit about how LT is measured.

The most accurate way to measure LT is in the laboratory. But, even there, there are a few different ways to have it measured. The first and probably easiest is by collecting breath data. By performing an incremental exercise test, where the intensity is gradually raised, it is possible to measure a variety of data with a computer including oxygen uptake as well as number of breaths. Well, by graphing the data obtained, you can see a point where breathing rate begins to increase exponentially while exercise intensity is still increasing linearly. This is generally considered to be the LT, or more accurately the Ventilatory threshhold (VT) which as we said before occurs a little after the LT is passed.

A second way is by taking blood at various intervals and measuring lactate levels during the afformentioned exercise test. By looking at when lactate levels begin increasing constantly, the LT (or OBLA) can be determined. The biggest drawback to this is the need to take blood samples during exercise and the difficulties involved with it (i.e. safety, needles, etc).

Well, as with direct VO2 max testing, both methods require significant cost and equipment as well as trained personnel. But, for the majority of people, direct testing may be overkill and unnecessary as it is possible to adequately determine your LT with a minimum of equipment and a couple of helpers.

The easiest way to use LT is just to assume that it falls within 70 - 90% or so of your heart rate reserve. Calculate this by taking 220 - age and subtracting your resting heart rate. Then multiply this value by 0.7 or 0.9 and add your resting heart rate back in. By playing around with where in this range you do your interval training, you can sort of hone in on where you LT is.

A second way to determine LT (which should be used with the above method) is monitoring your breathing frequency during exercise. After warming up, you merely begin to increase the speed/intensity of exercise until you feel your breathing becoming rapid and uncontrollable. This will more or less signify the onset of blood lactate which necessitates extra breathing to dispose of the carbon dioxide generated. If you have access to a pulse monitor (or can accurately take your pulse during exercise), you can determine at what point you are reaching LT. Recall, though, that you are really measuring the ventilatory threshhold (VT) with this type of assessment and that the LT generally occurs before the VT. So, you should back off the intensity a bit to arrive at your LT. Again, assuming you are training correctly, the heart rate at which your breathing becomes uncontrollable should increase indicating that you have raised the percentage of your VO2 max that you can perform at.

A third, and probably more quantitative method is the test Conconi developed by Francisco Conconi and Michele Ferrari for cyclists. Although it is probably easiest for cyclists to perform, other athletes can use it as well. Basically, you will be plotting heart rate versus speed. At some point, the normal linear relationship of heart rate will deviate from speed. The point of deviation is more or less the LT. Ideally, you need a pulse rate monitor and some friends to record pulse and speed. Also, if possible do the test on a track or treadmill or indoors on a wind trainer for cyclists to make speed measurement more accurate. Also, if on a track runners should run behind a pace bicycle to help with speed measurement. For runners, set a 50m section of track and mark the endpoints. You should be timed for this 50m in order to get accurate speed information.

Basically, after a sufficient warmup, you should begin exercise at a moderate pace. After every lap (or 60 or so seconds on the bike), record your pulse and speed and increase speed by 0.5 km/hr for runners or 1 mi/hr for cyclists. Continue doing this until you drop (err,terminate the test). Then graph the data and determine at which point heart rate deviates from speed (there should be a straight line for the majority of the test). Again, the point of deviation is pretty much the LT. The test can be repeated every month or so and, with correct training, the point at which heart rate deviates should go up.

That's it for now. I will conclude next time by discussing intervals: what they do, and how to do them.

Well, I had originally intended to talk about interval training at this point, but (as is usually the case), I will digress a little bit so that the discussion of intervals will (hopefully) make a little more sense. What I'd like to talk about this time is the different energy systems in the body, what they do, what they are good for and how they are trained.

There are three energy systems in the body and each has a different capacity to generate energy during daily activities. However, all three share the same ultimate goal: ***the generation of adenosine triphosphate (ATP).*** ATP is the only form of energy which can be directly utilized in the body and, as such, is ultimately the rate limiting substance in exercise. You can have all of the glycogen or fat in the world inside your body, but if you can't turn it into ATP, it won't do you any good.

Before I get to the descriptions, let me briefly (very briefly) outline what generally happens during exercise. The ATP molecule has a lot of stored potential energy in the form of the chemical bond on the inorganic phosphate. The general structure of ATP is Adenosine-Pi-Pi-Pi where Pi is inorganic phosphate. The bond between the second and third phosphate can be cleaved generating Adenosine diphosphate (ADP), Pi, and energy. The energy is subsequently utilized by the body and the ADP is eventually regenerated back to ATP by the breakdown of another substance which contributes a Pi.

Creatine phosphate (CP) system: The CP system is used only for very fast, intense bouts of activity. The body only has the capacity to use creatine as a substrate for about 5-10 seconds. Basically the CP molecule (a creatine + an inorganic phosphate) is broken down and the phosphate is used to regenerate ADP to ATP which can be used quickly for energy. Then a rest is needed to allow the creatine to reform as CP. which can take upwards of several minutes. This system does not require oxygen to operate (anaerobic) and is very rapid. Thus, this system is only really utilized by strict power athletes (throwers, olympic lifters and very short sprints). It probably has the potential to be improved with training, but doesn't really have a lot of applicability to most athletes (i.e. endurance).

Aerobic glycolysis: This is probably the system that most endurance athletes utilize for the majority of training and racing. It has the greatest potential to generate energy but it requires oxygen to work and is rather slow in working. Thus, it is well suited to sub-maximal, steady state exercise and can generate almost an unlimited amount of ATP from the oxidation of fats and glycogen. However, it is unsuited to high intensity exercise as it is unable to function without adequate oxygen and cannot generate energy quickly enough to meet the body's energy requirements. During aerobic glycolysis, glycogen is broken down primarily to pyruvate as an end product. This pyruvate can be utilized as another source of fuel and recycled into the system. This system is improved by continuous training which increases mitochodrial density and number (which allows the muscle to oxidize fats and sugars more easily). Other adaptations such as increased capillarization (which will increase blood flow and hence oxygen availability) also occur with training.

Anaerobic glycolysis: This is the system that is called into play during high intensity bouts of exercise. When adequate oxygen is not available to the cells to fuel aerobic glycolysis, this system takes over. It can only use glycogen and glucose for fuels (it cannot use fats) but it operates more quickly than aerobic glycolysis although its ability to generate ATP is limited. As opposed to aerobic glycolysis where pyruvate is generated as the end product, anaerobic glycolysis tends to generate our friend lactate during exercise. As previously stated, high lactate levels cause lots of pain and lower the pH of the muscle which shuts down the energy. This system is improved by high intensity training (i.e. intervals). One of the adaptations to interval training is that the Type IIb fibers (which are recruited most during high intensity exercise) actually become somewhat more aerobic. Thus, the point at which lactate begins to heavily accumulate in the blood (lactate threshhold) is higher. Another adaptation is the Type IIb fibers become more able to use lactate as a fuel and recycle it. Basically, the body learns to clear lactate from the blood more quickly which helps offset the increase normally seen with high intensity exercise.

So, why did I bother to go into this discussion? Well, first off, I thought it might be generally helpful to understand exactly what is meant by aerobic and anaerobic glycolysis. Also, when I talk about intervals next time (promise), I will try to tie in how different lengths of intervals may stress the different energy systems differently which will have a bearing on how the interval program is developed.

Ok, well, finally, I would like to talk about interval training. No more digressions this time, just on to the meat of the matter.

Although the difference is really semantical, I would like to differentiate between different types of intervals. After each type of interval's name will be the approximate amount of time for the type of workout. As with weight training, duration of interval and intensity of interval are inversely related so that the harder you go in a given interval the shorter it must be.

1. **Threshhold training:**
   - **Tempo:** continuous training right at the lactate threshold (20-40min)
   - **Cruise intervals:** 2 shorter tempo runs (10-20 minutes each) separated by a period of easy recovery. Threshhold training will help to improve the LT significantly.

2. **Intervals:** intermittent training above the LT and near 100% VO2 max Each interval should be between 2 and 10 minutes with a total amount of on-time of 15-25 minutes. Any more time spent on intervals yields little improvement but greatly increases the chance for injury and overtraining. Long intervals will help train the Type II fibers to clear lactate better due to the high levels of lactate generated.

3. **Repetitions:** these are very high intensity intervals at greater than VO2 max. Due to the high intensity, time is limited to 30-90 seconds max. These are useful for improving form and recruitment patterns for a given sport. Total time per workout is 5-10 minutes. Shorter intervals (sometimes referred to as alactic acid intervals) in the 10-20 second range are limited more by CP stores than by lactic acid buildup and are

useful for improving the CP energy system (see last post).

4. **Fartlek:** Scandanavian for speedplay. This refers to unstructured interval workouts and are very free form. They are a good way to introduce the body to intervals early in the season. They might include easy distance broken up by the occasional hard surge up a hill or sprint.

Depending on the requirements of a particular sport, different lengths of intervals should be performed. This has to do with specificity of adaptation. For example, 100 meter sprinters should emphasize running 100 meter repetitions (or slightly longer) at top speed. Also, practice starting would be a good idea as frequently races can be won or lost in the start. By contrast, tempo intervals would not be as useful for sprinters as it would not be sports specific since no sprinter will ever run more than a few minutes at most continuously.

For cyclists and other endurance athletes, probably some combination of the above workouts would be necessary. During longer races (i.e. a marathon) most of the race will be spent at about the lactate threshhold. However, there will be times when either short surges are needed (10-30 seconds) to catch a competitor or longer surges (several minutes) will be necessary to crank out a really fast mile to work on a lead. Also, having the ability to sprint at the end of a long race might also make the difference between winning and losing. To train for a final sprint, you might do a threshold workout and try to end with some short intervals. The possibilities are endless.

But who else can interval (and other high-intensity training benefit). For the recreational exerciser, interval training is probably not all that necessary unless you want to reach new levels of cardiovascular fitness. However, some recent evidence (which I posted a few months ago) seems to indicate that high intensity training (not necessarily intervals) may actually be as much or more effective than long slow exercise for fat loss due to the sheer number of calories burned. Yes, the percentage of fat burned won't be as high during high intensity exercise but, since the absolute number of calories burned will be higher, the total number of calories from fat will be the same or more. And, high intensity work allows you to get done more quickly. If you're interested, I'll be happy to re-post my article about the "Fat Burning Myth" which gives a bit more detailed info about this.

But, who else?? What about the recreational competitor? Well, again, it's sort of debatable. If you want to really reach new heights with your competing, some sort of interval training will be necessary to improve your speed in your chosen sport. Also, there's one other type of athlete that I think can benefit from intervals: the intermittent sport athlete. By that, I mean, persons who are involved in sports which are stop and go rather than continuous. Some examples would be tennis, basketball, racketball and similar activities. Although many people would consider these to be aerobic, when you think about it, they are really just a series of short, high-intensity bouts of exercise. For example, in racketball, you might play for 10-30 seconds for a given point at a very high intensity. Then you rest a few seconds and repeat. Yes, you do need a good deal of aerobic endurance to last the length of the match, but the individual points are really nothing more than intervals.

Well, I will wrap up this segment here and continue into another part. Next time, I plan to talk about a very important part of interval training which is the rest time between intervals. Finally, I will talk about putting together an interval package within the context of a full training program.

Well, as is usual with my posts, this series just refuses to end. But, hopefully, I can bring it to a close in this post. Last time, I talked about the different types of intervals, what purpose they serve, and briefly how they can be applied to different sports. This time, I would like to talk about the rest interval which is another important aspect of interval training.

Rest interval refers to the time spent between intervals recovering from the pain. There are two different apporaches to rest intervals: active and passive rest. Again the utilization of one over the other will depend on the specific nature of the sport.

Active rest: this has the benefit of keeping blood moving through the legs which will help to clear out the lactic acid and aid in recovery. It is quite simply a brief period of low intensity work to allow the body to recover but movement is never completely stopped.

Passive rest: this really has no particular benefits but it's inclusion may be more sports specific. Basically, after the interval, you get to sit still and hurt (err, recover).

For example, rarely in a cycling or running race do you come to a complete stop. There will be times when you will need to speed up or slow down or whatever during the race though. Thus, doing intervals with passive rest probably wouldn't be that applicable. However, with regards to intermittent sport athletes like football , racketball, and tennis players, etc., after the high intensity bout, you tend to sit still briefly (i.e. huddle, recovering the ball) before going again. Thus, passive rest may be more specific.

Another factor to consider in deciding on rest intervals is on the length of interval. Very generally speaking, the rest interval should be long enough to allow the heart rate to recover to about 120-130 or so. This indicates that the body is ready for another interval. Sometimes, though, you will see the rest period described relative to length of the interval (as in 1:2, 1:3 or whatever). A rest interval of 1:2 would mean that you rest twice as long as the length of the interval before doing the next one (i.e. a 2:00 rest for a 1:00 interval).

However, there are times when you might wish to do intervals with a shorter rest interval than is necessary for total recovery. For example, in cycling races, frequently, a hard surge of several minutes might be followed by a brief respite then another several minute surge. If this type of activity has not been trained, you may not be able to keep up during this period. The drawback to very short rest periods is the huge amount of lactate generated which is very painful. However, this type of training will generate significant adaptations.

Well, as always, this is getting too long, so I'll finish in part 6 with how to use intervals in your workouts.

Ok, so how do you go about integrating intervals into your program. Well,first and foremost, you shouldn't even consider including intervals in your workouts until you've built a sufficient base of six months or more. After this point, you might consider using intervals as a part of your workout. Also, intervals should not be performed year round and should be severely limited (if not omitted) during the off-season. Generally, interval training should begin at the end of the off season, switch into high gear during the months just before competition, and then be curtailed and maintained during racing season when the emphasis should be on racing. I'll talk more about this when I discuss periodization for endurance athletes.

At this point, let me state that there is no set formula for interval workouts. More so than really any other aspect of endurance training, interval workouts are an art rather than a science. So, I can't tell you exactly what will work for you as everyone is different and has different needs and will respond differently. Instead, I'm going to try to give you some suggestions as a starting point and then you can experiment from there.

Personally, I've found that including some very short speed bursts (about 20 seconds) into off-season distance work is one good way to begin acclimating the body to the intensity of intervals. Every fifteen minutes or so during these long workouts, throw in a 20 second burst of speed. The intensity should still remain fairly low but just enough to get your legs moving faster.

Another way to begin intervals is with Fartlek training. As I mentioned before, fartlek refers to the practice of throwing in the occasional speed burst during a workout. For example, during a run in the woods, you might surge up a hill and then run easily for a while and then throw in another little sprint. This type of workout should not be terribly structured (i.e. I'm going to do 4X440 meter repeats with a 1:00 rest interval) and should be fun. They are useful for breaking the body in to interval work.

A third way to introduce the body to intervals is with an interval pyramid. A teacher of mine liked to begin his interval phase by doing 1:00 with a 1:00 active rest, 2:00 with a 2:00 active rest, up to five minutes and then back down to 1:00.

Personally, I've had good success by starting out with relatively short intervals of 1:00 followed by a 1:00 rest doing about 10-20 repetitions. Then as the season progresses, I'll raise the time of the intervals by about 30 seconds per week and bring the number of repetitons down to keep the total on-time between 15 and 25 minutes. I'll eventually get up to 10:00 intervals which are really more of a threshhold interval. Rest time varies as the times increase. When I'm doing short intervals (1-2:00), I generally stick with 1:1 for my rest interval. But, as the intervals increase in length, I have a tendency to keep the total length of each rep (interval + rest time) at 5:00 until I get to 5:00 minute intervals and then 10:00 when the interval is longer than 5:00. Chalk it up to my being anal. However, this doesn't preclude including short intervals though and then I will occasionally throw in some short repetitions on my interval day.

Also, realize that due to the high intensity nature of intervals, you shouldn't do more than two interval workouts (and I prefer one) per week, especially when you begin doing them. Otherwise, you risk overtraining and injury. In animal studies, there was no increase in adaptations between intervals two days per week and six days per week, so it's probably better to go with less rather than more.

Oh, yeah, during an interval workout, you should always begin with a low-intensity workout of 10-15 minutes, perhaps followed by some stretching. Then you can do your intervals. Be sure to include a cool-down after the intervals to help clear some of the lactic acid away. The cool down should also be 10-15 minutes long. Ideally the cool down and warm up should be the same exercise as the intervals (i.e. if you're running intervals, don't warm up on a bike, warm up running).

Whew. Well, at long last, I've managed to finish out this three part series (yeah, right) on the lactate threshhold and interval training. If you have any sports specific questions feel free to send them my way and I'll do my best to help you. Next time, I will talk about developing year long training programs for endurance athletes and discuss periodization as it pertains to them.

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Lactate Threshold - Implications for Training and Performance

Adapted from information by the Physical Conditioning Department of the USOTC Sports Science and Technology Division

Lactic Acid: When energy is required for muscular work, fat and gylcogen (the storage form of glucose) are broken down to produce molecules of ATP which, in turn are used for muscular contraction. Fat and glycogen can also be broken down to produce energy in the absence of oxygen (anaerobically) while fat cannot. The by-product of anaerobic bearkdown of glycogen is lactic acid.

Lactate Threshold (LT): Resting levels of lactate in the muscle and blood are relatively low - approximately 1 mmol/L. As exercise intensity increases, lactate levels remain fairly constant until a point known as lactate threshold (LT) and it occurs when the breakdown of gylcogen becomes predominantly anaerobic and/or the rate of lactic production exceeds the rate of removal. The LT is also indicative of the rate of glycogen usage. The rate of glycogen usage at intensities above the LT is approximately 18 times faster than for the same energy yield then intensities are below LT. For endurance events where glycogen availability may be a limiting factor in performance, the ability to sustain a high workload before LT is reached is advantageous.

Lactate Threshold and Performance: There is a high correlation between distance running performance and the velocity at which LT is reaches. The treadmill velocity corresponding to LT has been found to be one of the best predictors of marathon and 10K running performance as compared to other commonly used measures (such as VO2 max). The LT, when expressed as a percentage of VO2 max, is relatively high in the endurance-trainined athlete. In sedentary individuals, for example, the LT may occur at 50-60% of VO2 max, whereas in endurance-trained athletes it typically occurs at around 70-80% of VO2 max. This is advantageous for the endurance athlete as they can work at a higher pecentage of VO2 max and therefore faster pace, without large increases in lactate levels.

Lactate Threshold and Training: The LT is very responsive to training. While VO2 max will increase minimally in an endurance-trained athlete, LT will show significant improvements with proper training. Measuring your LT several times throughout the year is important for monitoring your progress as well as allowing you to adapt your training as improvements are made.

Generally speaking, the threshold/breakpoint on your graph will occur at a slightly lower lactate level than what you can maintain during a race, thus your LT intensity may represent a minimum intensity for LT or tempo training. Training beyond the LT is also important for performance in certain events as it enables the athlete to sustain intense hours of exercise and to tolerate the high lactate levels which accompany such efforts. However it is important to be aware that very high lactate values resulting from high-intensity workouts may have deleterious effects. The acidosis associated with high lactate levels can cause damage to the muscle cell wall which may take from 24 to 96 hours for recovery. Thus it is important to allow sufficient rest following a high intensity workout.

The best way to train using your LT is to train at heart rates and/or paces which correspond to various lactate levels. For examples of the kind of training you can do using your LT, read the next section Levels of Training.

The Lactate Threshold

In exercise physiology, there have been few topics more frequently investigated, or more vigorously debated than the lactate threshold. It is the details, not the basics that create the big research problems. However, it is the basics that have great application to training and performance. So, we'll stick to those.

What is Lactic Acid and Where Does it Come From?

When you consume carbohydrate, it consists of several different sugar molecules; sucrose, fructose, glucose to name a few. However, by the time the liver does its job, all of this sugar is converted to glucose which can be taken up by all cells. Muscle fibers take up glucose and either use it immediately, or store it in the form of long glucose chains called glycogen. During exercise, glycogen is broken down to glucose which then goes through a sequence of enzymatic reactions that do not require oxygen to proceed. All of these reactions occur out in the cell fluid, or cytosol. They can occur very rapidly and yield some ATP in the process. This pathway is called the anaerobic (no oxygen) glycolysis (glucose breakdown) pathway. Every single glucose molecule must go through this sequence of reactions for useful energy to be withdrawn and converted to ATP, the energy molecule, that fuels muscle contraction, and all other cellular energy dependant functions.

The Metabolic Fork in the Road

There is a critical metabolic fork in the road at the end of this chemical pathway. At this fork, glucose has been converted from one 6 carbon molecule to two, 3 carbon molecules called pyruvic acid, or pyruvate. This pyruvate can either be shuttled into the mitochondria via the enzyme pyruvate dehydrogenase, or be converted to lactic acid via the enzyme lactate dehydrogenase. Entry into the mitochondria exposes the pyruvate to further enzymatic breakdown, oxidation, and a high ATP yield per glucose. Conversion to lactate means a temporary dead end in the energy yielding process, and the potential for contractile fatigue due to decreasing cellular pH if lactic acid accumulation proceeds unchecked. Like a leaf floating in a river, the pyruvate molecule has no "say" in which metabolic direction is taken.

Which Way will MY pyruvate go during exercise?

I am sure you have surmised that that is a critical question with big implications for performance. I will try to answer the question at three levels: a single muscle fiber, an entire muscle that is active during exercise, and the entire exercising body.

The Muscle Cell at Work

In a single contracting muscle fiber. The frequency and duration of contractions will determine ATP demand. ATP demand will be met by metabolizing a combination of two energy sources: fatty acids and glucose molecules (ignoring the small contribution of protein for now). As ATP demand increases, the rate of glucose flux through glycolytic pathway increases. Therefore at high workloads within the single fiber, the rate of pyruvic acid production will be very high. If the muscle fiber has a lot of mitochondria (and therefore more Pyruvate Dehydrogenase), pyruvate will tend to be converted to Acetyl CoA and move into the mitochondria, with relatively little lactate production. Additionally, fatty acid metabolism will account for a higher percentage of the ATP need. Fat metabolism does not produce lactate, ever! If lactate is produced from glucose breakdown, it will tend to diffuse from the area of high concentration inside the muscle cell to lower concentration out of the muscle fiber and into extracellular fluid, then into the capillaries.

The Whole Muscle at Work

Now let's look at an entire muscle, say the vastus lateralis of the quadriceps group during cycling. At a low workload, glycolytic flux is low and the pyruvate produced is primarily shuttled into the mitochondria for oxidative breakdown. Since the workload is low, primarily slow twitch fibers are active. These fibers have high mitochondrial volume. As workload increases, more fibers are recruited and recruited fibers have higher duty cycles. Now ATP demand has increased in the previously active fibers, resulting in higher rates of pyruvic acid production. A greater proportion of this now is converted to lactic acid rather than entering the mitochondria, due to competition between LDH and PDH. Meanwhile, some Fast twitch motor units are starting to be recruited. This will add to the lactate efflux from the muscle due to the lower mitochondrial volume of these fibers. The rate of lactate appearance in the blood stream increases.

The Body at Work

The vastus is just one of several muscles that are very active in cycling. With increasing intensity, increased muscle mass is called on to meet the force production requirements. All of these muscles are contributing more or less lactic acid to the extracellular space and blood volume, depending on their fiber type composition, training status and activity level. However, the body is not just producing lactate, but also consuming it. The heart, the liver, the kidneys and inactive muscles are all locations where lactic acid can be taken up from the blood and either converted back to pyruvic acid and metabolized in the mitochondria or used as a building block to resynthesize glucose (the liver). These sites have low intracellular lactate concentration, so lactic acid diffuses INTO these cells from the circulatory system. If the rate of uptake or dissappearance of lactate equals the rate of production or appearance in the blood, then blood lactate concentration stays constant (or nearly so). When the rate of lactate production exceeds the rate of disappearance, lactic acid accumulates in the blood volume, then we see the ONSET of BLOOD LACTATE ACCUMULATION (OBLA). This is the "Lactate Threshold" (LT).

Performance Implications

Lactic Acid production is not all bad. If we could not produce lactate, our ability to perform brief high intensity exercise would be almost eliminated. However, As I am sure you are aware, lactic acid is the demon of the endurance athlete. Cellular accumulation of the protons (increased acidity) that dissociate from lactate results in inhibition of muscle contraction. Blame those heavy legs on the protons! The bottom line is that exercise intensities above the OBLA point can only be sustained for a few minutes to perhaps one hour depending on how high the workload is above the intensity at OBLA. Exercise at or below this intensity may be sustainable for hours. The causes of fatigue at these sub-LT intensities include carbohydrate depletion and dehydration.

Factors that Influence the Rate of Lactate Accumulation in the body

• **Absolute Exercise Intensity** - for reasons mentioned above.

• **Training Status of Active Muscles** - Higher mitochondrial volume improves capacity for oxidative metabolism at high glycolytic flux rates. Additionally, improved fatty acid oxidation capacity results in decreased glucose utilization at submaximal exercise intensities. Fat metabolism proceeds via a different pathway than glucose, and lactic acid is not produced. High capillary density improves both oxygen delivery to the mitochondria and washout of waste products from the active muscles.

• **Fiber Type Composition** - Slow twitch fibers produce less lactate at a given workload than fast twitch fibers, independent of training status.

• **Distribution of Workload** - A large muscle mass working at a moderate intensity will develop less lactate than a small muscle mass working at a high intensity. For example, the rower must learn to effectively distribute force development among the muscles of the legs back and arms, rather than focusing all of the load on the legs, or the upper body.

• **Rate of Blood Lactate Clearance** - With training, blood flow to organs such as the liver and kidneys decreases less at any given sympathetic stimulation. This results in increaed lactate removal from the circulatory sytem by these organs.

Measuring the Lactate Threshold

We have previously discussed the value of a high maximal oxygen consumption for the endurance athlete. A big VO2 max sets the ceiling for our sustainable work rate. It is a measure of the size of our performance engine. However, the Lactate Threshold greatly influences the actual percentage of that engine power that can be used continuously.

Most of you will never have this measured in a laboratory, but a brief description of a lactate threshold test is still useful, because it will lead us into some specific applications for your racing and training. The test consists of sucessive stages of exercise on a treadmill, bicycle ergometer, swimming flume, rowing machine etc. Initially the exercise intensity is about 50- 60% of the VO2 max. Each stage generally lasts about 5 minutes. Near the end of each stage, heart rate is recorded, oxygen consumption is measured, and a sample of blood is withdrawn, using a needle prick of the finger or earlobe. Using special instrumentation, blood lactate concentration can be determined during the test. After these measurements, the workload is increased and the steps repeated. Through a 6 stage test, we would expect to achieve a distribution of intensities that are below, at, and above the intensity of OBLA or the lactate threshold. The data from a test would generally look simililar to the example below.

Interpreting the Data

For purposes of interpretation, let's say that the athlete above had a maximal heat rate of 182, and a VO2 max of 61 ml/min/kg. These were also determined using a bicycle test. So they are good values for comparison. Looking at the green dots, we see that blood lactate concentration does not begins to increase until during the 4th workload, from a concentration of about 1 mM to 2.5 mM. This is the break point. The subjects VO2 was 45 ml/min/kg at this point. So we determine that his LT occurs at 45/61 or about 74% of VO2 max. If we look at the heart rate at this point, it is 158. Now we have a heart rate at lactate threshold. 158 = about 85% of his max heart rate. This is useful for the athlete. When he is cycling, he can judge his training intensities based on this important value. If he is a time trialist, this would approximate his racing heart rate for the hour long event. It is important to understand that the % of VO2 max and the % of max heart rate at the LT are not necessarily the same %age, as demonstrated in this example.

So, Do I race at My LT Intensity?

This depends on your race duration. If your are rowing 2000 meters, running a 5k race etc, your exercise intensity will be well above the AT. Consequently, the blood lactate measured after these events is extremely high in elite athletes, on the order of 15mM (resting levels are below 1 mM). In races lasting from 30 minutes to 1 hour, well trained athletes also perform at an intensity above LT, but by a smaller margin. It appears that in these events, top performers achieve what might be termed a "maximal lactate steady state". Blood lactate may increase to 8 to 10 mM within minutes, and then stabilize for the race duration. A high but stable lactate concentration may seem to contradict the idea of the LT. But, remember that blood lactate concentration is the consequence of both production and clearance. It seems likely that at these higher lactate concentrations, uptake by non-working muscles is optimized. At any rate, measurements in cyclists, runners and skiers demonstrate the fact that elite performers can sustain work levels substantially above the LT for up to one hour.

Specificity of the Lactate Threshold

It is important to know that the lactate threshold is highly specific to the exercise task. So if this cyclist tries to get on his brand new, previously unused, rowing machine and row at a heart rate of 158, he will quickly become fatigued. Rowing employs different muscles and neuromuscular patterns. Since these muscles are less trained, the cyclist's rowing LT will be considerably lower. This specificity is an important concept to understand when using heart rate as a guide in "cross training activities", as well as for the multi-event athlete.

Effect of Training

For reasons mentioned above, training results in a decrease in lactate production at any given exercise intensity. Untrained individuals usually reach the LT at about 60% of VO2 max. With training, LT can increase from 60% to above 70% or even higher. Elite endurance athletes and top masters athletes typically have LTs at or above 80% of VO2 max. Values approaching 90% have been reported. The lactate threshold is both responsive to training and influenced by genetics.

Your Lactate Threshold (LT) is the point at which your muscles start producing more lactic acid than they can eliminate. We can get a good idea of when this occurs by relating it to an athlete's maximum heart rate. **Most athletes reach their LT when they achieve around 90% of their max HR.** Training at or near your threshold (zone 4) produces a couple of desirable training effects. First, it gets your muscles used to working with the presence of lactic acid. This is called t**olerance**. Secondly, with proper training in this few beats per minute, allowing you to ride harder (faster) before the accumulation of lactic acid begins. This training is vital for all disciplines of bicycle racing. This is where you live during a long time trial, a solo or small group break in a road race, or for the entirety of a cyclocross or mountain bike race.

We start LTs after at least one full 5-week mesocycle of base training. We then enter a 5-week LT mesocycle where we concentrate on this type of workout up to 3 times per week. LTs are continued throughout the season with the frequency depending on the athlete and the discipline. So we begin.

Your first LT workout will probably be 2x10 min. intervals in zone 4 with 10 min recovery between work phases. The following workouts will increase the work phase gradually with specific amounts of recovery prescribed. During the recovery phase your HR should drop to zone 2, but not below. If you let your HR slip down into zone 1 you will find it more difficult to get back into the work phase. Also, during recovery, keep your cadence high around 100 RPM. The work phase begins as soon as you start the effort not when your HR gets to zone 4. Don't sprint up to zone 4; gradually push yourself there over 45 seconds or 1 minute. These workouts can be done inside or out, but make sure you warm up for at least 30 minutes prior to the first work phase and cool down for at least 30 minutes after the last. Outside try to ride a course that has no or few stops for each work phase (possibly a 3.5 mile loop or an out and back). Don't worry if you do have to stop, but keep in mind non-stop is optimal. Here are a couple of ideas to spice up the workouts: Try doing the work phase on a long gradual hill (avoid any steep downhills where your HR can drop too much). Try "criss-crossing" in your zone. Start the work phase, get to zone 4, and continue accelerating gradually over a couple of minutes until you reach the top of the zone. Once you reach the top, ease off slightly and let your HR fall to the bottom of the zone. Repeat this several times until you have reached the end of the work phase.

These workouts should be hard, but they should not destroy you. If you have trouble reaching your zone 4 after about 5 minutes of trying, you are probably too tired, sick, or not prepared for the workout. Stop, ride easy or go home and rest. Let me know as soon as you can if this happens, so we can make adjustments to your schedule.

Lactate Threshold

LT is also known as anaerobic threshold. The LT is the level of effort (usually expressed as a percentage of VO2 max.) at which the body begins to produce more lactate than can be removed. Above this point there is a rapid increase in blood lactate levels. Some physiologists also call it the pulse rate deflection point (Conconi Test). It is also the maximum effort you can maintain for a long periods. Obviously the more you exceed your LT, the more quickly lactic acid will accumulate and impair your performance.

As most cyclists don’t have access to lab facilities, you can estimate your LT with a 30 minute (about 10 mile) time trial. The average heart rate you can maintain is a good approximation of your LT.

The LT will improve with training, and cyclists with a higher LT can work at a higher level of energy expenditure for longer periods, defeating opponents of equal (or even greater) physical strength but with lower LTs. Anaerobic intervals will improve the LT and are designed to be done at heart rates above your personal LT. They can be sustained for only 15 sec to 2 minutes, but will improve your LT fitness.

Recent work has focused on the blood lactate threshold (LT) as a reflection of an individual's level of training. The lactate threshold is that % of VO2 max. at which the cardiovascular system can no longer provide adequate oxygen for all the exercising muscle cells and lactic acid starts to accumulate in those muscle cells (and subsequently in the blood as well). At high levels of activity (below 100% VO2max), it is likely that there are always a few muscle cells (not muscles, but a small number of cells within those muscles) that are relatively deficient in oxygen and thus producing lactic acid. But this lactic acid is quickly metabolized by other cells that are still operating on an aerobic level. At some point, however, the balance between production of lactic acid and its removal by body systems shifts towards accumulation. This point is the LT and it is usually slightly below 100% VO2 max, and it will improve with training (move closer to 100% VO2max). As those with an increased LT not only experience less physical deterioration in muscle cell performance but also use less glycogen for ATP production at any level of performance, an improvement in LT allows the individual to perform at maximal levels for a longer period of time before muscle performance deteriorates because of a lack of adequate energy (glycogen) stores.