How Lactate & Metabolism Influence Performance

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Dr. Andy Galpin
The science and practice of enhancing human performance for sport, play, and life. Welcome to Perform. Hello, friends. I'm Dr. Andy Galpin. I'm a professor of kinesiology in the Center for Sport Performance at Cal State Fullerton. In today's show, we're going to be talking about lactate, or how many of you probably think of it, lactic acid. Now, I know when I say those words, you immediately start thinking about things like exercise and muscle and fatigue, soreness, and reducing exercise performance, and that all is true, kind of. In fact, as we're going to lay out, the overwhelming perceptions and thoughts about what lactate or lactic acid really are and what they're doing are massively false. In fact, I'll spill the beans right now. Lactate is in no form or fashion cause of your muscle fatigue. It actually does quite the opposite. It preserves muscle performance. We'll get into all that stuff later.

Dr. Andy Galpin
In fact, I actually think it highlights why I wanted to have this conversation or do this episode is because it's high time we start really understanding what lactate truly is and how it's functioning in our body. It has classically been thought of as this waste product, something that you don't want around, something that you want to avoid at all costs or manage or mitigate whenever possible. And the reality of it is, it has a number of widespread benefits across your entire physiological landscape. Let me give you a couple examples of what I'm talking about. Lactate is known to stimulate a molecule called PGC1-alpha. This is involved in any metabolically active tissue in any part of your body, and it is directly responsible for mitochondrial biogenesis. This is another way of saying, by increasing and utilizing more lactate, you're going to be increasing and making more mitochondria. This is a known response, and this is obviously a positive thing for overall health and performance.

Dr. Andy Galpin
But it even goes beyond that. Let me give you a couple of other examples you may not realize. For example, did you know lactate targets Leydig cells, which are responsible, of course, for testosterone in your body? It has a number of other benefits, such as BDNF, so brain-derived neurotrophic factor. This works directly on the hippocampus to stimulate neurogenesis, so the growing of new neurons, particularly in your brain. Similar idea with a molecule called VEGF, which is responsible for endothelial cells and then therefore promoting angiogenesis, so the

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growing of new vasculature throughout your entire body. Ghrelin, which is associated with hunger, so lactate actually acts directly on the hypothalamus to regulate ghrelin, and one of the major benefits here is suppression of appetite. I don't need to explain a lot to you there, but very few people can do a high-intensity exercise bout where they generate a lot of lactate and then feel extremely hungry immediately afterwards.

Dr. Andy Galpin
So appetite suppression with high lactate is a pretty easy one to imagine. I'm going to go even further, though, because there's so many more things lactate's doing. Whether we're talking about the liver and the kidneys and increasing what's called gluconeogenesis. So as you'll see later in our conversation, the primary place that we're getting the molecule or precursors for gluconeogenesis is lactate. Another benefit is its ability to act on osteoclasts and therefore play a role in bone remodeling. Now, I could go on and on here, and we're not quite done yet because I want to give you a handful of ones. I'm going to rapid-fire these ones. But lactate, again, has been highly associated with positive adaptations across your brain. It's heavily involved in memory and learning, heart health, dehydration. In fact, any of you that have ever used a Ringer solution, I know exactly what I'm talking about there.

Dr. Andy Galpin
Cancer, sepsis, insulin regulation, traumatic brain injuries, wound healing, post-surgery recovery, arthritis, inflammation, gut microbiome health, and then finally, overall metabolic flexibility. My guess is you had no idea that many things were happening in response to lactate. So in order to understand all these things, what I would love to do is spend a little time today walking you through exactly what lactate really is, how it's created, how it's managed, what role it's truly playing in your overall physiology. And then, of course, at the end, we will do our three I's, which is investigation. How do I measure this stuff? What should I be paying attention to? Two, interpret. How do I know if I'm good, bad, great, terrible, or world record? And then three, intervene. How do I improve my body's ability to produce and clear lactate so that it can perform at its highest level regardless of the task I'm asking my body to perform?

Dr. Andy Galpin
To get us started on this journey, we're going to go all the way back to the beginning when we initially discovered and began to understand the role of lactate in really all of biology, but specifically in human exercise physiology. The story really starts in 1708 when Scheele found lactate in sour milk. Now, the term he gave it actually roughly translates, I think, into milk acid, but it really persisted in this idea of just general food space until nearly 30 years later in 1808 when a scientist, Berzelius, and I have tried to pronounce this at least 200 times. But Berzelius really, and this is a classic story in all exercise physiology cycles, he found that concentrations of lactate were much higher in hunted stags, so a deer-like creature in Europe. And so it's very

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clear at this point that lactate is somehow associated with elevated stress or exercise, and we didn't really know much past that, but it seemed to be in all of physiology at this point.

Dr. Andy Galpin
So we had now crossed over from things like food elements and bacteria into now human physiology. So that was really a big step up in terms of our understanding of the relative importance of it for living creatures. Now, Berzelius went on to do a whole bunch of other stuff in this field, and in fact, he was directly responsible for the name that you all probably recognize as a catalyst. By studying lactate and trying to figure out what's going on, he really came up with this idea that he called ferments. Now, that sounds familiar because it is where we got fermentation from. In fact, you may be starting to make a connection in your brain, which we'll do a little bit more directly later, that really lactate and fermentation are almost one and the same. In a human exercising muscle, we call it anaerobic glycolysis and lactate production. In food elements and in the food industry, we call it fermentation.

Dr. Andy Galpin
Not exactly the same, but very, very close, and I'll maybe explain that a little bit more later. We haven't really moved into the realm yet of exercise physiology. There was no real understanding that this was happening as a byproduct of muscular contractions or anything like that at this time. We were still at the level of understanding what happens when carbohydrates are used with and without oxygen. So in fact, we can be more direct here. When we break down carbohydrates for a fuel source, that's fermentation. You do the same thing with protein, we call that thing putrefaction. Same thing happens with fat, and you call it rancidification. And so matter of fact, you may have never made that connection before, but you ferment carbohydrates, fats go rancid, and proteins are putrefied. So at this point in the story, we're kind of into the mid-1800s. In fact, in 1843, Scheurer was the first to find lactate in the blood.

Dr. Andy Galpin
He actually was autopsying folks that had died from septics and fevers and infections, and things like that, and noticed during these bouts of really high fever. So we now know that, of course, that's really high caloric expenditure, really high need for energy, high temperature, et cetera. You've gone through a lot of metabolism, and lactate concentrations were really high. We hadn't really associated this with muscle yet and certainly hadn't done it with exercise, and we were actually, at this point, thinking it was something that happened to be associated with death. The stags had been dying, folks, these folks had been dying or dead, and that's all we knew at this point. It was another 15 years or so, the late 1850s, when they first started finding this in the blood of actual living people, and this changed everything. In fact, for the next 50 years or so, most of our breakthroughs were from a gentleman named Louis Pasteur.

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Dr. Andy Galpin
You're probably familiar with him, and in fact, all the stuff that we do with milk when we pasteurize it, all this is from Pasteur's original work. And so there was all these associations that were floating around, and then really everything came to fruition with the very classic series of papers in 1907 from a combination of folks. One of them is the authors Hopkins and Fletcher were really the first to identify that lactate was a byproduct of muscle contraction. And then a handful of years go on and two very famous scientists, both of whom won Nobel Prizes, Otto Meyerhof and A.V. Hill, put together what most people, and certainly at the undergraduate or graduate exercise physiology level, now understand as basic lactate metabolism. We are now understanding things like it's coming from carbohydrates, it's coming from muscular contraction. There's an association between more metabolism, more lactate production, and all that fundamental stuff.

Dr. Andy Galpin
And while they certainly got many things wrong, Meyerhof and A.V. Hill are the ones most credited with our basic understanding of the differences between anaerobic and aerobic metabolism, and lactate being a core cog in that discussion. In 1960, lactate analyzers came on board and the field exploded, and one of the more fundamental things that happened was a paper published by Wasserman in 1964, in which he outlined a concept called the anaerobic threshold. Now, what he was basically saying there is, at some point when you're producing energy and you need more of it, you switch from aerobic into anaerobic metabolism, and there's a threshold for everyone at which you can no longer produce energy aerobically, and you have to switch to anaerobic metabolism. If I missed you with all that stuff and you don't really know what those terms are, I promise I'm going to come back and walk you through that all in just one second.

Dr. Andy Galpin
But this concept of the anaerobic threshold from 1964 persisted for a very long time. However, even Wasserman himself, fairly recently in a series of letters, has acknowledged that that was probably not the right concept. And the real rationale here, going all the way back to Meyerhof and A.V. Hill, was the fundamental understanding or thought that lactate was produced as a result of insufficient oxygen in muscle, and that's an incredibly important point here, so I'll say it one more time. The idea at this point was you go through anaerobic metabolism of carbohydrates, and again, if you don't know what those terms are, I will walk you through that in just one second. But you go through that anaerobic metabolism of carbohydrates, and if you have enough oxygen, you'll proceed and handle the carbohydrate just fine. If you don't, that's when you generate lactate. And remember, at this point, lactate was still thought of as a negative thing.

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Dr. Andy Galpin
It was thought of as a cause of fatigue. And so that's really kicked off at that point. It wasn't until 1983 when a young scientist named George Brooks launched an idea called the lactate shuttle hypothesis. Now, it took him almost 17 years to really outline the entire thing, but by the 1990 or so, he had fully explained the lactate shuttle. Since then, the last 20 years, he has just continued to dump more and more research in support of that, such that the field generally recognized it as, while we can continue to call this the lactate shuttle hypothesis, it's very hard to refute at this point. Now, before we go too much further, I'd like to take a quick break and thank our sponsors because they make this show possible. Not only are they on this list because they offer great products and services, but because I actually personally love them and use them myself. Today's episode is brought to you by Momentous.

Dr. Andy Galpin
Momentous makes supplements of the absolute highest quality. For example, we've long known about the numerous health and performance benefits of fish oil. I've personally been taking it for probably 15 years or more. Numerous studies have consistently demonstrated positive impacts of EPA and DHA, the two primary fish oils, on everything from cardiovascular and brain health to exercise performance and joint pain. Now, you can get fish oil anywhere, but personally, I only use Momentous because it's never once given me a fishy aftertaste, and more importantly, every single batch is NSF tested to ensure the lead and mercury levels are undetectable for purity and safety. Their fish oil is pure, potent, and sustainably sourced. Another major benefit is that you won't find any fillers in their fish oil. See, the dirty secret in the industry here is that most companies will add non EPA and DHAs, they're fish oil, to keep their, quote, "fish oil count high," but to keep the active ingredients and therefore costs low.

Dr. Andy Galpin
And it makes you actually feel like when you're purchasing it, you're getting more fish oil at a cheaper price, but you actually have to double or triple your dose to get the same amount of active ingredient, which means you end up spending more money in the long run, or you don't, and you get worse results. If you want to give their fish oil a shot or any other Momentous product, go to livemomentous.com/perform to get 20% off your order. Again, that's livemomentous.com/perform to get 20% off. Today's episode is also brought to us by David. David makes protein bars unlike anything I've ever encountered. They have an amazing 28 grams of protein, only 150 calories, and zero grams of sugar. That's right, 28 grams of protein and 75% of its calories come from protein. This is 50% higher than the next closest protein bar. Honestly, it's the best-tasting protein bar I've ever had in my life by a mile.

Dr. Andy Galpin
Now, I don't usually talk about products before their launch, but these bars by David represent a

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meaningful breakthrough in both macronutrients and taste. And when you guys try it, you will know what I mean. After lots of research and development, these David protein bars are releasing to the public in September of 2024. The macronutrients, one more time, are 28 grams of protein, 150 calories, and zero grams of sugar. And they do this with excellent ingredients. If you're interested in trying these bars for yourself, you can go to davidprotein.com/perform to purchase if possible or be notified when they're available. Again, that's davidprotein.com/perform to purchase if possible or be notified when they are available. So to this point, we've really been dancing around this idea of what lactate is, and I've been trying to argue that it's been misunderstood. And so now at this point, I think you're convinced, and so it's time for me to actually explain to you what it really is and how it's working.

Dr. Andy Galpin
To get us going, the very first thing we need to address is the name. You've heard me continuously refer to it as lactate now and not lactic acid. Lactic acid is almost never existent in the human body. See, what the functional difference is this: when you make a lactate molecule in human physiology at our temperature and pH, it almost immediately disassociates into what's called a lactate anion, so this is actually written as a capital L, little A, negative, and that means it has a negative charge. So it is a lactate anion with a hydrogen plus ion. So one thing you really got to keep in mind, physiology, and in fact, chemistry in general, biochemistry, will regulate charges, and by that I mean that is a positive and a negative charge, dramatically. In fact, this is how all of chemistry works, right? It's positive and negative charges going back and forth, and this is what determines how all molecules function.

Dr. Andy Galpin
And so you don't ever want a situation in your body in which something is floating around with a positive or negative charge. You almost always want to combine it so that they are neutralized. And this is why when you take various supplements, that they have weird things attached to them. Citric acid is a very common one. Salts, a common one. So they can balance charges so that they actually get into your system. They don't get immediately broken down or metabolized or connected with something else you want. So positive and neutral charges are absolutely essential to understanding what's going on here. And so you're never really going to see lactic acid in that form because it would require that hydrogen to be placed on top of it, and that's going to immediately disassociate. Keep this in mind later, as this is going to tell you the entire story of what we're going to talk about. Hydrogen itself is a H+.

Dr. Andy Galpin
That is almost synonymous with proton. So remember, protons, electrons, negative charges, positive charges, right? So if you have a free-floating hydrogen anywhere, that is going to be synonymous with acid. In fact, the term pH, right? So if you have a low pH, you're acidic. A high

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pH is alkaline, so a lot of acid going around. pH, depending on who you want to pick, stands for either potential hydrogen or power of hydrogen. But the point is, pH is simply a measure of how much free hydrogen is around. More free hydrogen, more acid. It's the same thing. So that H+ is acid. So any time I'm walking you through this biochemistry here and you hear me say things like, "This results in a free hydrogen," I might say a free hydrogen, I might say a proton, I might say acid. In your brain, you can hear that all as the same thing. All right? There's no other sources of acid than hydrogen. So the opposite of pH is OH-.

Dr. Andy Galpin
And so an acid is a lot of H. Alkaline is a lot of OH-. You bring those together, you take an acid, you take a base, you put them together, and you make water. That's how the whole system works. Great. Now, lactate itself can come in two basic forms, L-lactate and D-lactate. In humans, we're almost always talking about L-lactate. When we think about D, we're typically thinking about the food industry, so you're talking about sauerkraut and pickles and yogurt, sour milk like we talked about earlier, beer, tomatoes, apples, wine, et cetera. Almost all those have a combination of D- and L-lactate, but they're functionally a little bit different. Recent research is actually coming out on the role of D-lactate in humans, particularly regarding the gut microbiome. And so you can actually see, and you've probably noticed something, there's this connection here between fermentation, fermentable foods, sauerkraut, yogurts, gut microbiome health, and there's a strong relationship there.

Dr. Andy Galpin
In fact, one of the things that's possibly, probably, potentially happening is when we ingest more fiber, we know that this is generally good for gut microbiome health. Potentially, and this is a strong potential, again, the research is very recent here, and there's a ton to learn about the gut microbiome, but that is aiding in the ability to ferment that fiber. That is then producing high-quality results like lactate And so one particular thought that's being espoused right now by Dr. Brooks and others is that maybe D-lactate is a byproduct of some of the bacteria in your gut microbiome, is increasing the amount of lactate in your system, which is a good thing. I told you, go back to the beginning, remember all the positive things lactate is associated with. And so this could be one of the many reasons why a healthy gut microbiome is important for overall health and performance. Again, very early, but very interesting, and the connection seems to make some sense.

Dr. Andy Galpin
We also can take a look at the research. In my group, lead author Greg Grosseckie, we actually have published a review article very recently on the changes in the gut microbiome with acute exercise. There's a lot going on. We have an additional study going on right now on the gut microbiome in female athletes, and there seems to be a pronounced and positive association

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there with the ability to work with lactate in various forms. There are changes in athletes, in the, again, the bacteria associated with lactate production and clearance, and then it goes the other direction as well. So a lot to learn in this area, but there seems to be a very strong connection there with the ability to process, clear, generate, and handle lactate through the gut microbiome, through the blood, as well as in physical activity. So in fact, because of all that, there is some idea right now that D-lactate could be an important biomarker for overall intestinal permeability.

Dr. Andy Galpin
More on that stuff later, but an interesting idea nonetheless. So like I said, while that part of the field is growing and evolving, what's extraordinarily clear is lactate's role in regulating metabolic acidosis. Yeah, that's right. Not contributing or causing, in regulating it, as in stopping it from happening or even reversing it. Now, metabolic acidosis is the increase in acidic level of your blood in response to metabolism. That's most simply its point. But think about it this way. Your body regulates a number of things to keep you alive. How much blood sugar you have, your blood pressure to make sure you're moving blood throughout your system. But over and on top of all of that, the single most important thing for your body to regulate at all times is your pH level. If you become too acidic or too alkaline, all of the enzymes in your body, for the most part, stop working. You'll die very quickly.

Dr. Andy Galpin
It's a huge problem, and so making sure you're not either alkalytic or acidotic, getting too far outside those ranges, is the single top priority of your body at all times. You've got to keep your brain alive, number one, and you've got to make sure your pH is on point. And so when you get this situation where you are slightly acidic, and it's not that much, by the way. The pH regulation in body is very tightly controlled, especially relative to things even like lactate concentrations, which can go up orders of magnitude. You don't change pH very much under any circumstances. So if you were to alter your pH, say at a baseline of somewhere in the neighbor-- we'll just make it 7.1, 7.4 pH, and you were to go down to five, you're dead. So you're going to keep it way tighter than that. Trust me. If your pH was below seven into the sixes, you would be feeling that very much. So metabolic acidosis in that particular case, again, is when the pH or the concentration of acid gets too high.

Dr. Andy Galpin
And so just take, for example, one of the fastest ways that you could deal with that is to get an IV of lactate. This is a very common thing in cases of dehydrations. When folks are really dehydrated, we'll use what's called a Ringer solution. So this is typically a combination of fluids, of course, and then a bunch of salts. So you're talking sodium chloride, sodium lactate, potassium chloride, a whole bunch of electrolytes to balance osmotic pressure, to keep fluids in the system. But really, you're getting a ton of lactate because it can go to the liver, immediately

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be converted into what's called bicarbonate, and bicarbonate could then kind of eat up all the free pH, all the free hydrogens, rather, that are floating around, and, now, careful terminology, and increase your pH, meaning reduce acid level. Higher pH means more alkaline. So don't want to confuse you there. But the point is, you give somebody a bunch of lactate in that form, you're going to make a bunch of bicarbonate, and you're going to alter what's happening at the kidney with urine secretion, and you're going to make yourself more alkaline, back to normal.

Dr. Andy Galpin
And any of you in the medical field that are listening are like, "Yeah, this is very basic medical physiology 101." Lactate will help with metabolic acidosis. But if I really had to boil it down, I would say the three primary roles of lactate in your body is, number one, it is the primary energy source of mitochondrial respiration. Two, it is the primary precursor of gluconeogenesis. And then three, it is a signaling molecule or hormone. In order to understand this, we've got to talk about metabolism and learn how you actually produce cellular energy. Now, in humans, you've got two primary places you can go, fats and carbohydrates, and there are some pros and cons to each. In fact, really the way to think about this is not such as like a one's better than the other one. That's completely misunderstanding the point. They're meant to be complementary. They want to give you options. This is what metabolic flexibility means, the ability to use fat or carbohydrates in the best possible situation.

Dr. Andy Galpin
This allows you to be most efficient as well as most productive, create tons of energy when you need it and not waste any when you don't. But the way in which we create energy from fats and carbohydrates is quite different. And so from the highest onset, fat has to use aerobic metabolism. Keep that in mind. There are no ways in human physiology to anaerobically metabolize fat. Carbohydrates, though, are particularly powerful because they can do both anaerobic and aerobic metabolism. What's that mean? And this is not totally true, but fundamentally, I want you to think about when you hear the word aerobic, associate that with mitochondria. In other words, saying we have to use oxygen, and we have to have the mitochondria in play to go through aerobic metabolism. I don't have to have that for anaerobic. Oxygen can be around to do anaerobic, but it's not required either. And so imagine yourself as a little muscle cell, and you need to create some energy, and you're deciding, what do I use, fat or carbohydrate?

Dr. Andy Galpin
Think about it this way. The benefit of fat as a fuel source is it's basically unlimited. In fact, most people, even fairly lean people, have enough fat on their body to power 30-plus days of continuous exercise. I don't mean working out every day. I mean, start running right now and don't stop for 30 straight days. You probably still will have enough fat supply on your body to stay

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alive. It's effectively unlimited and unending. Why don't you just use all fat for fuel then? Well, the problem is it's way too slow. When you use fat as a fuel source for exercise, it comes effectively from the entire body equally. And so if your hamstring is contracting so that you can run, you're pulling fat from your forearm, from your hamstring, from your back, from your fingers, and anywhere else. It's coming from the entire system, which means it has to be broken down, mobilized, taken into muscle tissue, muscle tissue then has to bring it into the mitochondria, and then we can start producing energy.

Dr. Andy Galpin
The other part about it is, molecule per molecule, fat is less efficient as a fuel source than carbohydrate. And so it's an unending supply, but it's slow and less efficient, which means it's fantastic for times of low energy need. It's great when I'm doing what I'm doing right now, talking, sitting, walking, low levels of exercise. It can be used because I have plenty of time. But any time I need fuel faster or energy faster, I need to switch to carbohydrate. Now, remember, carbohydrates start anaerobically and finish aerobically, which means I can get going right now, and I can be used during really high-intensity exercise when I don't have enough time to bring in and utilize oxygen. And so again, fat is not better or worse than carbohydrate. Carbohydrate is much faster. You get carbohydrate from a couple of places. Most specifically and initially, it's coming from stored carbohydrates in the actual exercising muscle itself.

Dr. Andy Galpin
We call this muscle glycogen. If you need it from somewhere else, it's going to come from your blood. We call this blood glucose. If you need extra supply from that, you can get it from the liver, which stores muscle glycogen. It breaks the glycogen down, puts it in the form of glucose, puts that in your blood, and then you can steal it that way. And so in fact, one of the classic things that happens when you initially start exercising is despite the fact that you are pulling in glucose into your muscle cells, blood glucose levels rise, and that's because of an anticipatory response. The liver starts kicking a bunch into the blood because it knows you're going to take it, and you don't want blood glucose levels to drop because then you're going to pass out because you don't have glucose for your brain. In fact, this is why if you see somebody like at the end of an endurance race pass out, one of the first things that the EMT staff and stuff will do is they'll come over and give them really fast-absorbing sugars, candies, juices, stuff like that, to get blood sugar to come up really fast because they know blood sugar is very low.

Dr. Andy Galpin
Anyways, back to the point. So carbohydrates are fantastic because they are right there. And so at this point, we need to think about what is the actual chemistry of carbohydrates and how does that relate to lactate and actually, really more importantly, why is that then helpful to the brain, to the heart, to the liver, to wound healing, and all the other stuff we talked about earlier. And then,

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of course, why is this actually helping me perform? And one of the things you're going to hear me talk about a little bit later is there's a strong association between better athletic performance when you can produce more lactate, and that's because of what I said at the very beginning here. Remember, it is a potent fuel, it is a strong signal. It's an ability to go to your liver to make more glucose, and it is a hormone. It is a signal. It has many functions there. And in fact, more recent papers describe it as that lactohormone, which is a fun way of saying it can communicate with other cells.

Dr. Andy Galpin
In order to be called a hormone, what this actually functionally means is one cell has the ability to communicate to another one. And so what we'll say for lactate is it has both autocrine, paracrine, and endocrine characteristics. So autocrine meaning it can signal its own cell to do things. Paracrine meaning it can go to neighboring cells, so you're talking other muscle fibers within the same exercising muscle. Or it can actually have an endocrine function, which means it can get in the blood and go to any other tissue. You're going to see this later because it's going to get in the blood, and it's going to go to other muscle. It's going to go to the liver, it's going to go to the kidneys, it's going to go to the brain, it's going to go to the heart, and a bunch of other places. It's going to go to the digestive tract, and it's going to provide them with important signals, as well as be used as a direct fuel source.

Dr. Andy Galpin
Okay, so now going back to where we were at with overall metabolism. When we said it has those three powerful responsibilities, I quickly talked about that third one, right? That's what I mean when I say it's a signaling molecule or mechanism or hormone. The one above that, one I said is the primary precursor for gluconeogenesis. Lactate can go into the blood, get sent then back to your liver and even kidney, and go through what's called the Cori cycle. In this, we can actually take lactate, combine it together, and make glucose. So the way that I call this is it is a precursor to gluconeogenesis. Gluco meaning glucose, neo meaning new, genesis meaning create. So how you can create new glucose molecules out of non-glucose. And so again, all we really have to do, and I'll explain this in a second, is take two lactate molecules, smoosh them together, and I made myself glucose. And so that's an important role as it's in the precursor of gluconeogenesis.

Dr. Andy Galpin
The third one was this being the primary fuel source for mitochondrial respiration. Now again, I apologize. I know I'm throwing lots of different terms around. If you are in chemistry, instead of saying mitochondrial respiration, you probably say aerobic metabolism. They're not exactly interchangeable. As I've discussed earlier, fermentation is not The same as anaerobic glycolysis. Again, functional distinction there. When you're talking about bacteria or food types of things,

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we're going to call it fermentation. When you're talking about an exercising muscle itself, it's now anaerobic glycolysis coming from mitochondria. And so again, trying to not throw you off in terminology, but as you're reading or hearing other things, that's really what we're talking about. And so the ability of lactate to be a primary fuel for mitochondrial respiration is exactly how we started the show. One of the primary things that lactate does is stimulate mitochondrial biogenesis.

Dr. Andy Galpin
It tells your body to make more and make bigger mitochondria. And in fact, it works together in this entire meshing network. And when we generally talk about mitochondria, people kind of think about it as these independent units. But more recent research is suggesting that it is really truly a network effect. You're probably familiar with mitochondria, but it is incredibly important for exercise performance and a number of overall health and longevity metrics. And so people go out of their way to try to stimulate and increase, and have various protocols that they do to enhance mitochondria, and lactate's probably the best one. And so that right there is explaining why you should be paying attention to it if you care about mitochondria. It's the top place to go to increase it or improve its quality. So to get back to the biochemistry of what's happening here. Remember, fat as a fuel is coming from the entire body.

Dr. Andy Galpin
Carbohydrate is coming from the cell that is exercising itself. Fat has to go through aerobic metabolism, which means it has to go into mitochondria. But carbohydrates are going to start anaerobically and finish aerobically, or finish in the mitochondria. So as a very quick reminder, your muscle cells have two functionally different areas. They've got what's called the cytoplasm or cytosol, which is kind of like this jelly-filled thing that's all around the inside of your cells. All your organelle are inside of that. And then in this particular case, you've got mitochondria. Anaerobic metabolism, whether we're talking about creatine or in this case carbohydrate, happens in that cytosol. If you want to then use aerobic metabolism, we've got to now shift into the mitochondria, and this is another reason why aerobic energy from either carbohydrates or fat just takes a little bit longer, because even when we're in the muscle cell, there's that additional step needed to get it into mitochondria to then really go through the metabolic processes there.

Dr. Andy Galpin
All right. Now, last little background before we really get into this story. Remember, fat and carbohydrates are just functionally large chains of carbon. So a fat, in the case of a triglyceride, is a glyceride, which is a carbohydrate. It is a glyceride, three-carbon molecule. Each one of those carbons has a long chain of carbons attached to it that we call a fatty acid. So a triglyceride is three fatty acids attached to a glycerol backbone. Think of it this way. It is a three-carbon carbohydrate with three long chains of fatty acids, and all those long chains of fatty

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acids are carbons. Depending on how many carbons are there, we call it a different fatty acid, stearic acid or linoleic acid or other things like that. If they're perfectly bonded, we call it saturated. If it has one missing bond or two missing bonds, we call it unsaturated or polyunsaturated, et cetera. But we're talking big, long chains of carbon.

Dr. Andy Galpin
So when one molecule of fat comes in to a cell for energy, we have a lot of potential carbons. However, carbohydrates in the case of exercise, remember, it's coming from glucose. That is a six-carbon chain, so it is much smaller. So benefit of fat, unending and way more carbon per molecule. Carbohydrate, way faster, can go anaerobic in the muscle, but only six total carbons. Why this functionally matters. Here is all of metabolism summed up in about five seconds. You break off carbon. You run it through a whole bunch of steps and processes to get rid of that. That releases energy. You use that energy to make a molecule called ATP. You then get rid of carbon, put it in your blood, put it in your lungs, and breathe it out. So you breathe in oxygen, you break up fat or carbohydrates. By breaking those carbon chains, you give off energy. You use that energy to make ATP. The waste product is carbon.

Dr. Andy Galpin
You attach that to the oxygen to make carbon dioxide. You breathe that out. So the net result of all metabolism is three things and three things only, ATP, water, and carbon dioxide.

Dr. Andy Galpin
Now, if you were in my laboratory, I could put a little mask on you, connect you to what's called a metabolic chamber, and I could actually identify how much fat you're using for fuel or carbohydrates you're using for fuel. A little bit of math that goes on there, and we can figure that out because of the different efficiencies between carbohydrate and fat, like I said earlier. But the point is, by simply measuring carbon dioxide, I can measure and identify what you're burning for your fuel. And one of the things that tells us when you start increasing lactate and you pass into these different areas of aerobic or anaerobic metabolism is when the rate of carbon dioxide that you're making or exhaling starts to now be different than your rate of breathing. And I can now tell, "Okay, wait a minute. Those things should be in lockstep." But when they're not, the rate of increase of carbon dioxide is different than the rate of ventilation, I know you've switched ways you're getting energy.

Dr. Andy Galpin
That's the quick version of what's happening there. All right. Now, while you are doing low levels of exercise or even all the way down to sleep, it is advantageous for you to use fat as a fuel source. Again, unlimited supply. I don't have to run it out. I have a limited supply of carbohydrates. I can only store so much in muscle Very, very small amount, typically a couple of teaspoons total of glucose in my blood, and then very small amounts in my liver. Remember, the

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liver is like the football size thing. Relative to how much fat you could potentially have on your body, that's unlimited. And so carbohydrates are always meant to sort of be there for sustained living and high-powered exercise, and fat is your backup tank. It's your reserve, right? Now, when I start going through exercise, the ideal situation would be to spare my glycogen, spare my glucose, spare my carbohydrates. Okay? All the same thing here.

Dr. Andy Galpin
So now, ideally, you would use all fat for fuel. That'd keep you nice and lean, of course, and we wouldn't be wasting our preserves and our concentrations of carbohydrate. But because it's slow, what effectively happens is at rest, we have a value that's called RER or RQ. So this stands for respiratory exchange ratio or respiratory quota. Typically, 0.7, 0.8, something like that in a lot of people, maybe a little bit lower if you're fit. And that suggests that you're burning mostly carbohydrates, but a decent percentage of fat. As you increase exercise intensity, that number will climb. In fact, a score of 1.0 literally means that you are burning 100% carbohydrate. Because I can't break down and utilize fat as a fuel source anaerobically, as soon as I cross that aerobic and the anaerobic space of exercise, I now cross out of my ability to use fat as a fuel. Another way to say that, once exercise intensity gets too high, I can't use fat as a fuel.

Dr. Andy Galpin
And so from there, I'm lowering the percentage of energy that's coming from fat and increasing the percentage of energy that's coming from carbohydrates, such that when I get to truly high-intensity exercise, that number becomes 100 and zero. All my energy from carbs, none of it from fat. The opposite never exists. You can never be in a situation where you're burning 100% fat. In fact, the highest you're going to probably get, maybe 60% fat, maybe 70%, not much higher than that, though. Maybe you could argue maybe 75, but that'd be sort of your peak. And so we are uniquely positioned as humans, and all mammals really, to burn carbohydrates. That is the primary fuel source by a landslide. Basic physiology will tell us that. Doesn't mean we only want to use it. In fact, the idea of metabolic flexibility is I have strong capacity to go back and forth between utilizing fat and utilizing carbohydrates.

Dr. Andy Galpin
Now, a lot of folks in the last couple of years have significantly misinterpreted and misdescribed what metabolic flexibility is. Perhaps we'll do an entire show on that. Maybe we should, how to test it, identify it, improve it, et cetera. But metabolic flexibility does not stand for your ability to maximize fat burning. That is not at all what it is. It is exactly what I just said, the ability to use both effectively. If you hedge towards only fat burning or hedge towards only carbohydrate burning, those are not metabolically flexible. You want to do both. More on that later, perhaps, if you all are interested. So as I get to this high intensity of exercise, in fact, this is one of our metrics we use to identify whether or not you are at a VO2 max is, do you cross a threshold of

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1.1 on your RER, is the typical standard there, which mathematicians are saying, "Well, wait a minute, I thought 1.0 is 100," and it is.

Dr. Andy Galpin
And so anything above that actually represents you hyperventilating, which again tells us kind of where you're at. So I've actually seen, myself pretty typically can get to like 1.35, 1.4. I've seen plenty of athletes get up there, which means you are producing a significant amount of carbon dioxide as a waste product, and you are in significant discomfort as well. And so that's really what's happening, right? We're burning a lot of carbohydrates at high intensity, and the lower the intensity goes, the more fat we're burning as a fuel. Why is that? Well, this is exactly based on the stoichiometry and chemistry of how we can get to energy. So when we use fat as a fuel source, let's say we broke it down from our back of our arm or our face or whatever, and we want to use it to power energy in our hamstring. The fat has to get put into blood. It's got to get transported on a protein. It's got to get into our exercising muscle.

Dr. Andy Galpin
It's got to go through transporters there. It's got to then get transported into mitochondria. That is limited by the amount of carnitine that's there. Some of you may have explored and used carnitine as a supplement. That's exactly why. That's the rate-limiting step. Okay? Now, the more mitochondria I have, the more that I can bring in, and the more carnitine I have on the mitochondria themselves, the more I can bring in. But I have to bring that in. The problem is you have these giant long chains, 16, 18 carbons. They're too big. They can't get into the mitochondria. So what you do is you cut off two at a time, and I know exercise physiologists, I know biochemists, I'm skipping a tremendous number of steps here. But nonetheless, you're going to cut off two carbons at a time. This matters. This matters to lactate. Hang one second, and I'll tell you why. When you cut off those two carbons at a time, that is called beta oxidation.

Dr. Andy Galpin
You've used oxygen to do that, and it's beta because you cut off one, two of the carbons. Those two carbons can then get transported into the mitochondria. Those two carbons together like that are called acetyl-CoA. Very important, acetyl-CoA. That goes into the mitochondria, can run through a thing called Krebs cycle. By doing that, you use these high intermediate exchanges with things like NAD, which we'll come back to, and FAD. You use that to shuttle protons, hydrogen pluses, and electrons around. You send them to a thing called electron transport chain. All that is used to then create a bunch of ATP. As a byproduct of that, you burn off one, two carbons. And so you had a two-carbon molecule go into the Krebs cycle, it comes out as carbon dioxide, ATP, and water. Remember earlier, final product of all metabolism is those three molecules. So now we have taken a fat, taken it into our mitochondria, and run all the carbons out.

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Dr. Andy Galpin
I just continue to cut off two at a time until that entire fatty acid chain is metabolized. Highly effective process, but slow. Limited by my ability to bring in oxygen, get that oxygen into blood, get that oxygen from the blood into my exercising tissue, get that into mitochondria. Now, in another episode, we talked about VO2 max. I believe that's in the cardiac or the heart episode. I went through all those things, AVO2 difference and limiting factors, the central factors to performance. So you can see that episode for more there. But that's effectively the problem. We thought for many years lactate was produced because of an insufficiency of oxygen in that mitochondria. In other words, it's limited by that. We now know that's totally wrong. In fact, the evidence is not only clear, it is beyond reproach. Fuel through your muscle is never limited by oxygen. That's never going to be the limiting step for lactate specifically.

Dr. Andy Galpin
So lactate is created not because we're out of oxygen, but for some other reasons. So that's the quick story of fat metabolism. Understanding that, let's transfer back over to figure out how these carbohydrates are broken down. Doesn't really matter for this story if we're starting with muscle glycogen, if we're getting the glucose from the blood, or if we're getting glucose that was glycogen in the liver, put into blood, and now broken in. Either way, let's just stay with the place of glycogen in the muscle. It's right there. You start going for exercise, I don't have to worry about mobilizing the fat and bringing it in. I don't have to wait for oxygen to come in. I can get bringing in energy right now. And so in this particular case, carbohydrate, the chemical formula is C6H12O6.

Dr. Andy Galpin
What's that mean? Why does that matter? That is six carbons attached to six H2O molecules. Folks, that's what carbohydrate means. It is a carbon that has been hydrated. It is one carbon and one water. In the case of glucose, there are six of them. Now, if you go to fructose or some other forms of sugar or carbohydrate, they have different amounts of carbon. But in this particular case, you have six carbons attached to six waters. That is a carbohydrate. So when that is inside the muscle cell, the cytoplasm, if you will, sitting there, and we've decided to not use phosphocreatine as a fuel source, which is the primary and fastest one, and we want to use carbohydrates, this initial step is what we call anaerobic glycolysis. Again, if you take that and put that into a bacteria, you'd call that fermentation. In your muscle, we call it anaerobic glycolysis. Lysis means to split or to break, and glyc, meaning the glycogen or glucose.

Dr. Andy Galpin
So we're splitting and breaking this thing apart. We're doing it without the use of oxygen, and so it is anaerobic. And so if you can visualize this, any of you watching this, you've got six carbons that are all chained together. Now, instead of breaking two off, like we did in the case of beta

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oxidation of fat, we split the entire molecule in half. So we have two separate three-carbon molecules. We call that pyruvate. So we have not lost any carbon in this exchange, but we have broken a chemical bond. This has given off some energy. This itself gives us two ATP. Give you a little bit of an example. If we go back to earlier, when we take acetyl-CoA and take it to the Krebs cycle, and you get 25 or 28 ATP, in this particular process, we make two. So energy amount that we create from this process of anaerobic glycolysis was very low, but it's not bad either. Okay? We have actually made it with a little bit less oxygen, and we made it really fast because we didn't have to wait.

Dr. Andy Galpin
Here's the downside. This process, as many of the processes, as we'll see later, is limited by this molecule called NAD. Your ability to go through all the metabolism is determined by your ability to regulate pH, meaning enzymes don't work in highly acidic or highly alkaline environments. You won't let things go through if you can't balance positive and negative charges. So what you do with NAD is you shuttle hydrogens back and forth through molecules. Depending on what's happening, it could be going different ways. But you're going to go from a molecule called NAD to a thing called NADH, hydrogen, and an H+. If you want to go the other direction, you ship it back. And so you are limited in a large part by how much NAD you have, because as soon as you run out of NAD, you can't run these processes because you won't be able to handle all the hydrogens that are built up. Critical step. In fact, in a second here, this made me think of something else.

Dr. Andy Galpin
I'll explain to you why that helps you with hangovers really soon. Okay? So that's our process. So by doing that, we've split this glucose into two separate molecules called pyruvate, and by doing that, we've shuttled a couple of NAD, NADHs across each other and made a couple of ATP, and that's all well and dandy. The pyruvate itself is fine. Back to anaerobic threshold, back to how I was taught in exercise physiology. What we initially thought was this is the end of anaerobic glycolysis. We're done at pyruvate. If we had oxygen, we would then take the pyruvate, break off one carbon each, so the three-carbon molecule pyruvate, you cut off one carbon, you make it a two-carbon molecule, and that's acetyl-CoA. That's gone into the mitochondria, and it runs the exact same Krebs cycle or tricarboxylic acid cycle as I described earlier with fat. Identical. Literally the same thing. It is the exact same precursor, it's the exact same substrate, exact same process, exact same amount of ATP created.

Dr. Andy Galpin
Identical, okay? Like I said, carbohydrates start anaerobically and always finish aerobically. Identical to fat at this point. If we run out of oxygen or don't have enough oxygen, that pyruvate is then converted into lactate, okay? That was the original, and that's how I was taught. We now

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know that the end product of that pyruvate is always lactate. And we know this from a lot of different areas of research. The concentration. You typically have something like 10 to 50 to one amount of lactate that you do pyruvate. So it's almost never there, which tells you lactate is very quickly being created out of pyruvate as soon as pyruvate is being created. That number can go up an order of a magnitude during exercise, and so it doesn't make any sense to think that you're stopping at pyruvate. Furthermore, there has been excellent research identifying transporters specific to both pyruvate and lactate that get you into the mitochondria.

Dr. Andy Galpin
And so some pyruvate can be moved into the mitochondria, and a lot of lactate can as well. We also know that those MCT, is the abbreviation for those transporters, are in a number of different cells throughout your body. And so we can move it throughout, and that's one of the reasons why we have this lactate shuttle ability. So here's what we think at this understanding right now, and of course, as research comes on board, we learn more things, we might change our opinion. But according to research right now, the prevailing thought is the end product of anaerobic metabolism is always lactate. The majority of that is going to go into the mitochondria in the working cell. Some portion of it is going to leave muscle. In fact, what happens here is once your ability to process that lactate is exceeded by your lactate production, in other words, you're making more lactate than you can handle in that cell, you begin to transport the lactate out of the cell.

Dr. Andy Galpin
We call that lactate efflux. You put it into the bloodstream, and you ship it to a number of different areas. The first place you ship it to are neighboring muscle fibers that are not working or have a greater ability to process lactate. Now, think about it this way. Anaerobic metabolism is more common in your fast-twitch fibers. Aerobic metabolism is more common in slow-twitch fibers. The amount of an enzyme called lactate dehydrogenase, which is the enzyme that switches you back and forth between lactate and pyruvate, is about 50% higher in slow-twitch fibers. And so we're creating it in fast-twitch fibers and likely shipping it into slow-twitch fibers. So those slow-twitch fibers got a pre-digested, half-broken-down sugar molecule. It's an insanely effective fuel source. It didn't have to do anything, didn't have to increase its acid concentration, didn't have to run through any of its NAD, and it got a pre-digested, if you will, fuel source.

Dr. Andy Galpin
At the same time, the fast-twitch fiber benefits from being able to run through metabolism faster and not having to deal with the waste products. So it's a win-win-win-win-win. If those muscles don't want it, it can go, again, as I said earlier, in the blood and can go to the kidney or liver for the gluconeogenesis. It can go to the heart, which absolutely loves lactate as a fuel source. In fact, the heart is the biggest consumer of lactate of any organ in the body. It's actually the

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preferred fuel source over glucose, especially during ischemic or any time oxygen concentrations get low in the heart. It loves it. It can go to the brain, and the astrocytes, actually, which are these star-like cells that are all across the central nervous system, they prefer lactate as a fuel over glucose or anything else. In fact, this is also why you see things like ketones and other non-carbohydrate fuel sources, because we know we need that as fuel for astrocytes, and lactate is basically, again, pre-digested carbohydrates.

Dr. Andy Galpin
So it is adored across the entire physiological system as a lovely fuel source. So not only is it grabbing on and holding on and making you less acidic, it is a phenomenal signaling mechanism as well as a direct fuel source for almost every tissue in your body. I'd like to take a quick break and thank our sponsors. Today's episode is brought to you by AG1. AG1 is a foundational nutrition greens supplement. That means AG1 provides a variety of vitamins, minerals, probiotics, prebiotics, and adaptogens in an easy-to-drink greens powder. Initially, I was very skeptical of AG1, as I am with all supplement companies, frankly. But after months of discussions with their lead nutrition scientists and the team at AG1, I've been impressed by their commitment to sourcing the highest quality ingredients and rigorous testing to ensure that every single batch is free of banned substances, allergens, heavy metals, microbes, pesticides, herbicides, residual solvents, and mycotoxins.

Dr. Andy Galpin
It's even earned the prestigious NSF Certified for Sport third-party testing approval. Now, AG1 is not a replacement for eating whole foods, but it is a great way to fill in the gaps, and it's been a big help pushing some of my clients just in the right direction for eating more high-quality foods, because it helps them with cravings, digestion, and many other benefits. Now, not everyone needs to consume greens powders. But if you're going to do so, you better make sure it actually includes the ingredients that it claims to, and that those ingredients are of the best sourcing. If you'd like to try AG1, you can go to drinkag1.com/perform to receive five free travel packs plus a year's supply of vitamin D3 plus K2. Again, that's drinkag1.com/perform to receive five free travel packs plus a year's supply of vitamin D3 plus K2. Today's episode is also brought to you by Renaissance Periodization.

Dr. Andy Galpin
If you want to put on muscle through science-backed training programs, look no further than Renaissance Periodization. RP, as we call it in the industry, guides users through effective and easy-to-follow lifting programs, all through their hypertrophy app. These programs are designed by the absolute best in the industry, including one of my absolute favorite sports scientists and professional bodybuilder, Dr. Mike Israetel. You may recognize that name because I've referenced him and his work countless times over the years. So whether you're looking to put on

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muscle, gain strength, or both, these programs will help you achieve your goals and have produced results in literally thousands of men and women. Renaissance Periodization also has a diet app that is backed by the latest science and innovation in the fields of nutrition and takes the complexity out of dieting, helping you achieve your ideal body composition.

Dr. Andy Galpin
If you'd like to try Renaissance Periodization, go to rpstrength.com/perform to save up to $50 off of your subscription. Again, that's rpstrength.com/perform to save up to $50 off your subscription. Okay, at this point, we've covered how lactate is created and what it's doing and the different roles it's having in our body. I want to move on to some other things, but before I do that, I got to go back to a promise I made earlier, which is talking about alcohol. Now, if you pay attention to beer or wine or spirits of any kind, you probably are recognizing fermentation. So if I were to take barley or hops and introduce some yeast or bacteria to them and ferment them, if I did that long enough, I would create ethanol. Well, that's basically what I just described to you in your muscle anyways. It's a very similar process. In fact, there's a high exchange here. Remember earlier when I was talking about the gut microbiome being able to create all kinds of awesome stuff with lactate, ferment fibers and stuff like that?

Dr. Andy Galpin
Your body actually is thought to produce around three grams or so a day of your own ethanol through that exact same process. It takes the carbohydrates, it does the same thing that your favorite producers do when they make your beer or your bourbon or whatever the case is, and your gut just does the exact same thing. However, you're able to clear it really fast, so don't worry, no one can smell the ethanol on your breath because of your gut microbiome. Babies do the same thing, by the way. It's happening in fetuses and all that stuff. So it's a normal part of our physiology. And so there is this very strong tie between these things. Now, what you can actually do is kind of go in reverse. And so ethanol typically is associated with even things like methane. This is associated with fermentation and foul-smelling gases. In fact, if that process is happening too much in your stomach, then you can have some pretty significant GI distress.

Dr. Andy Galpin
This is one of the reasons why carbohydrates are the primary cause of flatulence and overall gas. But nonetheless, what's really happening is you've got your ethanol alcohol. You've created it yourself, or you've brought it in. That's ethanol. ETO, if you're in my lab, you'll see all the bottles with ETOH on them. That stands for ethanol. We use that to clean surfaces and a bunch of different things in our action. But if you were to have this in the form of an alcoholic drink or whatever, your body would bring this in, and it runs almost identical to the pyruvate metabolism that I just talked about. So you can take ethanol, and the very first thing you're going to do is convert that into a thing called acetaldehyde. Now, that is highly toxic and primarily responsible

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for hangovers. And so one of the things that's happening is when you bring in that ethanol again, you're immediately digesting it as quickly as you can in your liver.

Dr. Andy Galpin
When you do that, because it has to go through the liver for the most part, because this is metabolism, now you can think about that this as basic carbohydrate metabolism. Now, when you increase carbohydrate metabolism, you tend to decrease fat metabolism and the opposite, right? So these are kind of working back and forth. So unlike earlier when we talked about the lactate shuttle, and I said, "Hey, you should stop thinking about lactate as this negative byproduct," you also need to really stop thinking about aerobic and anaerobic metabolism as a tug of war. It's not good or bad. It is more like a chain on a bicycle, such that the chain is the lactate, and turning of one gear turns the other one. This is a fundamental rethinking of how we understand metabolism and energy production. Anaerobic and aerobic metabolism are not at each other's throats. They are productive, and lactate is the signaling mechanism from one to the other one.

Dr. Andy Galpin
It is the precursor for mitochondrial biogenesis. It is a precursor for gluconeogenesis. It is a signaling mechanism. It is this, as George Brooks called it in one of his more recent papers, it is the phoenix rising again. It is a restored understanding that this is a collective cooperative relationship between aerobic and anaerobic. It is not a tug of war. That is the absolutely wrong way to think about it. So when we're in the liver here, and we're handling this carbohydrate metabolism, because the need to go through carbohydrate and anaerobic glycolysis is so high, it shuts down fat utilization. Why this is problematic is this is why high amounts of alcohol consumption is associated with fatty acid development in the liver. This is exactly what happens. You're supposed to be metabolizing the fat there, but you can't because you're too busy processing the alcohol, and so that fat then becomes stored.

Dr. Andy Galpin
You shifted the burden. It's also why alcohol intake is associated with overall fat storage, because again, you're downregulating fat storage everywhere because you're upregulating the need to do the ethanol in your liver. That fat then gets stored everywhere else. Now, as long as your calories are equated, it's a little bit different, but alcohol typically comes in caloric excess, and so then you've got extra calories that need to be burned, but you can't burn fat, so they get stored. So that ethanol then, like I said, is supposed to be converted into acetaldehyde. Acetaldehyde is very easy to then convert into acetate, which is then converted directly into acetyl-CoA. So you're right back to where you started. The ability to cruise back and forth between pyruvate, acetaldehyde, and all the way up to ethanol is fairly quick, to be totally honest with you. And so you can cruise back and forth between those things, and so whether you're a

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bacteria or in your own system, whether you're creating yourself, you can create some acetate yourself.

Dr. Andy Galpin
You can go backwards up and down that chain. But really, you're talking one step away. And so ethanol, again, acetaldehyde, tons of that going through metabolism. That concentration gets really high, and you get super hungover. So what do you do about it? Well, this is one of the reasons why getting a big sweat in the next day or going for a run or working out tends to help some of the symptoms. Not all of them. There are many symptoms associated with a hangover, but one of the things that you're doing is you're increasing the demand for acetyl-CoA. Doesn't matter if you're going aerobic or anaerobic, because remember, acetyl-CoA comes from the breakdown of fat or carbohydrates, anaerobically or aerobically, it's got to get there. And so you've increased your demand for acetyl-CoA. So instead of leaving things in the form of acetaldehyde, which again is really problematic, you force it to be converted into acetyl-CoA because you've increased the demand for that.

Dr. Andy Galpin
And so you can kind of think about it as like the old college, "Man, I got to go burn out all the alcohol to get out of my system." That's not exactly what's happening, but it's also not super far off either. You're really just using it as a fuel source. Now, alcohol as a fuel source for exercise performance is not a good thing. This is a very, very slow and rate limiter process. In fact, this is being limited heavily by NAD concentrations. You're going to run out of them, and so that process gets backed up very quickly. You can do a handful of things to potentially try to escalate that or keep that going faster, but the reality of it is your liver is only so big. It can certainly take a beating. It is one of the most regenerative tissues in all the body. But that said, you're going to only metabolize alcohol. In fact, some of you have probably heard of some people metabolize alcohol much faster than others, and that's specifically because the acetaldehyde dehydrogenase molecule, the more that you have, the faster you metabolize alcohol, the slower, the lower.

Dr. Andy Galpin
This is the red face flush and all those other things associated with low alcohol metabolism. So alcohol metabolism, fermentation, anaerobic exercise, carbohydrates, starches, all this stuff, very similar. Fermented foods, all this stuff can really come back to, in some part, lactate. Okay, so to get us back on track here, up to this point, we've talked about what lactate really is and its role in physiology and then more specifically, exercise physiology. But if you're a curious mind, you may be thinking to yourself a handful of things. "Wait a minute. So I'm confused at this point. Is more lactate good or bad? You keep saying it's good, Andy, but I haven't quite made that connection. And if so, how is it really good? What is it doing?" Maybe go a step further. "If it's

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good, is more better? And what does more mean? More in the cell, more getting out of the cell, more in blood? What really is going on here?

Dr. Andy Galpin
And so can you really just, Andy, can you bring it all together for me and help me truly understand the role of lactate, what it's doing for my body, and why it's positively affecting all these other organs outside of exercising muscle?" Let's start off by just answering the question of, well, is more lactate better? That's a little bit tricky to answer. So remember, lactate is created in exercising muscle, and then at some point when that rate of production exceeds how much the mitochondria can handle, it starts getting pushed into blood. Now, in order for me to know how much lactate is actually going on in your muscle, I have to go in and take a biopsy, so that's really tricky. The easier way to understand that is to measure it in blood. And so we can look at things like onset of blood lactate concentrations, how much lactate's in your plasma or whole blood overall, and different things like that.

Dr. Andy Galpin
And kind of depending on which metric you look at, you're going to get different values, different terminology, and so again, admittedly, that stuff can be a little bit tricky. I want to try to simplify it as much as I can for you right now and give you just the overview of what I think the field is saying rather than all those individual details, because it will get unnecessarily tricky at this point. Well, there's research suggesting that higher-level athletes, those that have greater performance in endurance-based events, actually are able to handle more lactate. At the same time, there are plenty of anecdotes for folks like Michael Phelps, who supposedly sustained extremely low concentrations of lactate. I guess this really highlights a couple things. One, we don't really fully understand exercise biochemistry yet. There's clearly some gaps in our understanding of what's really happening.

Dr. Andy Galpin
The second thing is that we probably have multiple avenues to physical success. You can imagine some individuals doing well because they can handle a lot more lactate. Others may be doing particularly well because they don't produce that much, and so they don't have to deal with that. I think it's pretty clear both of those avenues are potential for success, again, particularly in endurance events. At the same time, look at the research on lactate supplementation. Now, we know very effectively that sodium bicarbonate and other forms of supplementation that reduce acid buildup in tissue are quite effective. This comes in a number of varieties, so you can take a look at things like beta-alanine supplementation. This increases carnosine concentrations in muscle tissue and effectively acts as an acid buffer. So it keeps it lower, and so your muscular endurance, whether short-term or even moderate-term exercise events, tends to increase.

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Dr. Andy Galpin
And it's not perfect, but there's a lot of research behind that. Similarly, you have things like sodium bicarbonate. This is a different mechanism, but same idea. You're bringing in bicarbonate. As I talked about earlier, it's able to then absorb some of the free-floating hydrogen protons, which brings your muscle pH up, right? Less acidic, more alkaline. So then when you start producing excess hydrogen ions from exercise, you're at a higher set point, and so then again, the pH or acid-induced fatigue is slowed down. Again, a lot of research on that. The problem with sodium bicarbonate is sometimes can create GI distress and some other issues, and so a way around that is a handful of different lotions or creams. Momentous, for example, makes a thing called PR Lotion, which is a sodium bicarbonate thing that you can apply directly on muscle to, again, have the same effects of that. Lots of different ways around it.

Dr. Andy Galpin
Momentous is one product, but there's plenty of other ones on the market as well. And so we know that works, but what about then if you just take lactate? We know lactate is another potential buffering mechanism. We know what it can do. It can hold onto those hydrogen protons for us, help with NAD recirculation, et cetera. So will this allow me to continue to go through glycolysis since I continue to feed back NAD to that system, which we know requires it to proceed? Well, it's one of those disappointing aspects of science. It should work. Makes all the sense in the world, but it doesn't look like it does. The evidence that's available today suggests minimal or no effect, really, of lactate supplements on exercise performance. So if that's what you're looking for, I would encourage you going through either the sodium bicarbonate, either the powder supplementation pill or the lotion, or something like a beta-alanine to buffer and improve performance.

Dr. Andy Galpin
At the same time, there is much more room for hope in application of lactate supplements for other outcomes. In fact, I know of multiple trials led by the legendary George Brooks, who I've mentioned multiple times. George, again, as I mentioned, is still active in this field. Actually, he took on one of my master's students, Jose Arevalo, a number of years ago, who should be finishing his PhD up there. But they've done numerous trials looking at applications of lactate immediately after traumatic brain injuries, concussions, and other treatments. And so there's a lot of things to be excited about, about lactate, but from an exercise performance perspective, where we focus most of our time in this show, doesn't really seem to be super effective. That said, there's not a tremendous amount of research. Probably more is needed or warranted, so if more comes on board and we get a different answer, I'll be sure to update you when that time comes.

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Dr. Andy Galpin
I'd like to take a quick break and thank our sponsors. Today's episode is brought to you by Continuum. Continuum is a membership-only wellness club designed to help high performers reach their fitness and performance goals. Continuum just opened its flagship club in Manhattan, quickly making it one of the most sought-after memberships in the city. Its location in Greenwich Village is incredible. In fact, it's stunning. It's a 25,000 square foot space with state-of-the-art equipment, a beautiful design, and everything you could possibly want in this unique mix of a gym, wellness center, and social club. Continuum members start with a thorough Olympic-grade assessment that results in a biometrically-driven, AI-assisted wellness program that updates in real time and incorporates everything from personal training and physical therapy to hyperbaric and IV therapies. By bringing together true fitness experts, best-in-class technology, and proven wellness services and amenities, Continuum delivers the most comprehensive solution to performance.

Dr. Andy Galpin
I've been involved with Continuum, working as their head of performance science, since their founding, and I've been incredibly impressed by what the team there has built. If you're interested in joining Continuum, their team has agreed to give a select number of you, the listeners here, a fully waved onboarding, which includes VO2 max testing, DEXA scans, blood panels, sleep analysis, and more, all at their fabulous New York City flagship location. To learn more, visit continuum.club/perform. Again, that's continuum, with two Us, .club/perform. I realize at this point now I've talked about lactate and convinced you it is not a cause of muscle fatigue, but I haven't explained to you what is. So I didn't really plan to get onto this in this episode, and matter of fact, we may do an entire show on just fatigue management sometime down the road, perhaps in season two or three. We'll see. But I got to give you a teaser here, and really to reiterate, it's not lactate that causes the fatigue, but pH can be a legitimate issue.

Dr. Andy Galpin
In our cardiac episodes and some of the other ones that we've done in this season on endurance, I have talked about when you-- Exercise fatigue is a global event. There are what we call central reasons for fatigue, so this is the central nervous system, this is the heart and cardiovascular system, and ability to move oxygen throughout the body, et cetera. And there are peripheral issues, more specific to muscle uptake and oxygen. As I said at the very beginning, it is clear at this point, lack of oxygen in muscle is not the cause of lactate production. That part is extraordinarily clear. I think it's also fair at this point, while people are debating still whether or not fatigue is central or peripherally driven, I think it's hard, in my opinion, to make a reasonable argument that it's not a combination of both. There are excellent review papers on this that cover dozens of different explanations.

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Dr. Andy Galpin
I would love to be able to explain to you in one or two words what the real culprit is. That's just not the case. Easy examples. If you change and alter pH with exercise, I'm almost exclusively talking about more acidic. Could be more alkaline, it would have really the same effect, but really, it's acidic. You've made that pyruvate. You've then tried to convert that into lactate, or you have successfully converted it into lactate. Either way, you still have hydrogen floating around. When you take ATP and you split it into ADP, that goes through a process called hydrolysis. This still results in hydrogen production. And so no matter how you slice it, if you're contracting muscle, you're going to generate hydrogen. That's going to make the environment more acidic. Enzymes, all of the enzymes involved in aerobic, anaerobic, phosphocreatine, muscle contraction, all of those are going to have a problem in excessive acidic environments.

Dr. Andy Galpin
Same thing with temperature changes. We see alterations in things like calcium signaling. So calcium is one of the important minerals required for muscle contraction. That gets altered during muscle fatigue. The little environment organelle inside your muscle called sarcoplasmic reticulum, so it holds and stores your calcium and releases it, becomes problematic. There are issues with magnesium. Magnesium then starts taking the place where calcium should be there and inhibiting it. So we see single muscle fiber contract out problems. We see oxygen transportation problems. We see other issues associated with ATP pumps and sodium potassium pumps being dysregulated and changed and altered. So really the most fair and honest way to explain to you why you're getting fatigued Well, I know it's not because of lactate buildup. That's true. And it's definitely not because of lactic acid. And for that matter, lactic acid is not even close to being responsible for your muscles being sore the next day.

Dr. Andy Galpin
That has nothing to do with the equation. It's definitely not involved. However, you can still globally say acid buildup. That's a reasonable thing to say. It is more complicated than that, but it is also true at the same time. It's just probably most appropriate to say while there is an increase in acid buildup during muscular fatigue, it's not lactate. Lactate's actually probably saving you from acid buildup. If that wasn't there, you'd have even more acidity. But still, you see how those two things are going to be highly associated. Let's go back to the very beginning, hunted stags. Imagine you're running through a forest. Being hunted or not, doesn't matter, but you're exercising, sprinting through there. You're creating more metabolic waste, more pH, more acid, rather. You're feeling more fatigued. At the same time, you're having a higher lactate efflux. Even if that is a positive thing for you, those two things, increasing fatigue and increasing lactate, are going to be associated.

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Dr. Andy Galpin
And that's why for almost 200 years of lactate research, we have associated fatigue with lactate buildup. So they do go hand-in-hand, but that is a classic example of correlation, not causation. Now that we have a better understanding of what lactate really is, it's time for us to discuss our three I's, such as how do I investigate? In other words, how do I measure my lactate or my lactate threshold? Number two, how do I interpret it? How much lactate should I have at rest, and what should my lactate threshold be, and what's the highest lactate we've ever seen? And then three, finally, how do I intervene? In other words, how do I improve my lactate concentrations, again, at rest as well as during exercise? And then how will that actually relate to my improvements in sport performance? Let's get started with the very beginning, and that is investigate. So with a couple ways to think about this, I slid in a term there, I realize I've said it a few times, but maybe not fully described, and that is lactate threshold.

Dr. Andy Galpin
Okay, you can measure lactate concentrations in your blood. That's the normal way to do it. A biopsy is probably not realistic for many of you, and honestly, not necessary. But I do want to acknowledge a couple of things. There are a lot of low-cost lactate analyzers available on the market. When I was a student, you basically had to be in an exercise physiology lab. Now these are consumer available for $20 to $30 or $40. There is also research on these different devices and their accuracy, and they're not all the same. I wish I had a gold standard one. I could say, "Go buy this one. It is the best." Unfortunately, that's not the case. Honestly, they measure them a little bit differently. The techniques used, the part of your blood that's used is a little bit different, and so these values can be fairly squirrely. I would strongly encourage you to pick one, and pick one of the ones from the research that is known to be reliable, and then use that for all of your metrics moving forward.

Dr. Andy Galpin
If you switch machines out and change standardizations and procedures, you're going to get slightly different results. I will give you one little insider tip here behind the scenes. If you're going to use something like a small finger stick or an earlobe stick, which is the most common ways to do it, that first drop of blood that comes out, I would wipe it away and not use it. It tends to give you really funky numbers. It's going to tell you the lactate that is right there on that spot rather than circulating in the tissue. So we always take the first couple drops, wipe them off, and then use the second ones. You'll get much more reliable numbers. If not, you will see your lactate all over the place, and you'll be like, "What the heck is going on? I don't believe anything these people say about exercise physiology because these lactate numbers are totally screwed." So that's going to tell you how much lactate you have.

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Dr. Andy Galpin
The other thing you probably want to pay attention to is what's called lactate threshold. There are at least 25 different methods I have found in the literature for measuring lactate threshold. There is clearly no succinct, completely agreed-upon method. Many of them are good. In fact, all 25 of those have been validated, but they are not measuring the same thing. This gets extraordinarily complicated. You thought that the biochemistry got complicated earlier. This is potentially worse, and that's not all measuring the same thing. Generally, the field has moved past anaerobic threshold. You may have heard of that before. For the reasons I've described, we don't really talk about that one. However, there is lactate threshold, and in fact, there's multiple stages of lactate threshold. There's stage one and stage two. There's ventilatory threshold, and that is very similar, but it's not the same thing.

Dr. Andy Galpin
There are things like critical power, your maximum velocity at lactate threshold, your ability to sustain just under lactate threshold, and a ton of different things to pay attention to here. So what are you actually measuring is the first question. Then secondarily, again, there are dozens of different free, low-cost, and all the way up to clinical research-grade methods to assess lactate threshold. I'm not going to go through all of them for you. Rather, I want to arm you with the tool of saying, if you care about learning something like your lactate threshold, that's great, but really pay attention to what your needs are. So what sport are you in? Are you a distance runner? Are you a rower? Are you a more anaerobic sport athlete? What are you using? And try to pick the test that is best for you and your situation. And what do you care most about? Ventilatory threshold, anaerobic threshold.

Dr. Andy Galpin
Do you want to know your race pace? That's probably the most common reason people get a lactate threshold test done, is they want to know what pace to run at during their races, or how fast they need to run to be in zone one or two or three or four, how much time they should spend at each exercise intensity, and things like that. And so it is extremely context-dependent going through lactate threshold. I will give you a couple of examples here, but I did need to make sure you understood depending upon where you look, you can see wildly different numbers, wildly different protocols, and dozens of different free or in-laboratory assessment methods for lactate threshold With that entire preamble aside, even me trying to describe to you what I mean by lactate threshold, it's different for each one of these definitions. Quick example. The general idea here is we're trying to figure out how fast can you run or how hard can you row or cycle or whatever you're doing before we see a different change in our slope of lactate.

Dr. Andy Galpin
What do I mean? Imagine you're sitting there at rest, and you're producing a very marginal but

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small amount of lactate. And now we start jogging, and then we slowly, over the course of, say, 10 to 30 minutes, increase our speed of jogging. Okay? As I increase my speed, I'll increase my fatigue. I'll get more tired. But that's not a linear increase. It becomes exponential. It is linear at the bottom, and then at some point, we have this sharp uptick in fatigue. Now, that is what we're trying to identify as our lactate threshold. What we're saying is, if I know that, and let me give you some numbers here. Let's say you can run at 20 miles per hour. That's pretty darn fast. It's not the fastest ever, but that's pretty fast, and we'll make numbers easy. All right. Imagine you and I both run at 20 miles per hour. And let's imagine, just make it even easier, we have the same VO2 max. So we both have a VO2 max of 100.

Dr. Andy Galpin
That would be very, very, very high, but I'm trying to make math nice and easy for you. So you and I can both run 20 miles per hour, and our VO2 max is 100. Who's going to win the race? Well, if we look at classic exercise physiology literature, there are three main predictors of endurance performance. And again, I really want you to think about marathon running, just as an easy example here. Your VO2 max, your efficiency, and your lactate threshold. What I'm effectively saying is if you and I both have the same VO2 max and the same maximum running speed, but you are slightly more efficient than I am, you will have more energy to run that race. So even though we can run as fast as each other, you'll be able to run at a higher percentage of your max speed before you get tired. This is classic Jack Daniels, not the whiskey, the famous running coach. Has a ton of work in this area. In fact, a lot of people call him the greatest running coach of all time.

Dr. Andy Galpin
I'm not a runner, so I don't know. But he really laid this stuff out and said, "All right. If it's not those two things, it's your lactate threshold." So if both of us can run at 20 miles per hour, but you can run at 16 before your lactate really starts to increase, and I can run at 15. That means in the race, I have to run the race at 14.9, because if I go at 15, all of a sudden, I have this massive increase in lactate. And you get to go at 15.9. You get to run a whole mile an hour faster than me, even though our maximum speed is the same and our VO2 max is the same. So lactate threshold is that way of saying, what's the threshold? How much work can I do? How many watts can I put out on my bike before I have this, again, excessive increase in lactate buildup? Why that matters? Not that lactate is causing fatigue, but that is clearly an association in which you have overwhelmed mitochondria.

Dr. Andy Galpin
That's what it's telling you. Mitochondria can no longer keep up with lactate build, and so now an efflux happens, and this efflux happens really, really fast. Easy examples to think about. Go on and do some exercise at 80% of your heart rate. Then do it at 85%. Then do it at 90%. You're

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going to feel slight increases in fatigue. Go from 95% to 100%. That 5% increase, 95% to 100%, will feel way worse than if you'd have gone from 50% to 55%. In fact, you will feel very little differences in fatigue from 50% to 60% or 65%. But a 10% increase going from 90 to 100 is way more fatiguing than going from 50 to 60. Hopefully, that makes sense. And so fatigue is not linear like that. What with lactate threshold, we're trying to identify where do these breaking points, or what a lot of times we'll call them is deflection points, happen. Well, again, this is where lactate threshold gets complicated because people define these things differently.

Dr. Andy Galpin
Depending on the method you use, and again, there's over 25 of them. There are excellent studies over the last 30 years where you can take the exact same report from the lab, hand it to different exercise physiologists, and get different lactate thresholds based on calculation. Not only because of subjective decisions, which can happen in the visual method, but also just which calculation you're using, which equation you're using, which method you're using. So a lot of the times, and I'll get to this in one second, but just so we're right here, a lot of the times people can say things like this. All right. The visual method, the most classic method of lactate threshold identification is you do a 30 to 60-minute test, and you slightly increase fatigue over time. And what you're going to see is this slope of VO2, so how much oxygen are you using, go up. But again, that slope will have a big curve, and there'll be these inflection or deflection points.

Dr. Andy Galpin
Those points are then marked as lactate threshold. At the very beginning, you tend to see an early one, and then there's a second one later. So some people say there's lactate threshold one and lactate threshold two. Others will say, "I don't care about the first one. I only care about the second one." It doesn't matter. It tends to be lactate, we would've covered this in one second, but we'll do it now, I guess, since we're here. At rest, your lactate is typically something like one millimolar, maybe down to 0.5 millimolar, in that neighborhood. And a lot of people will then say lactate threshold happens at two millimolar. Now, you may be familiar with that because that is generally what people say as the threshold for being in zone two training, and that's exactly why. One of the major reasons people are excited about zone two training is you're actually saying we are specifically staying below that threshold, which means we are not going to overwhelm mitochondria.

Dr. Andy Galpin
We're going to train them and work them, but we're not going to let them off the hook because if we go too high We've bypassed that system. We're now having to deal with so much lactate efflux that we're using different fuels of energy production. So we're going to stay right below that threshold to make sure we put the most pressure possible on mitochondria. This should enhance your ability to use fat as a fuel source. This should enhance mitochondrial biogenesis and a

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bunch of other positive benefits associated with that type of training. Others are then going to say no, lactate threshold happens at four millimolars. It's a different thing, but there is a very clear distinction between two and four. And so in fact, probably the most common way to establish lactate threshold in science is to just arbitrarily say what speed, in the case of running, or wattage, in the case of cycling, are you at when you hit four millimolars of lactate.

Dr. Andy Galpin
And so rather than defining it by the slope of that oxygen increase, and I know this is a little bit technical and wordy for some folks, a lot of times you can just arbitrarily say it is four millimolar, and where you're at when you cross that threshold is your lactate threshold. Scientifically, you will see equal accuracy between both of those methods. Now, if you don't have the ability to analyze lactate directly, there are a number of different ways to estimate it. I mentioned Jack Daniels earlier. He has by far the most popular version called a VDOT. This is a little bit of a play. He actually initially, I think he called it the pseudo VO2 max, and he had this really cool conversion equation. This book's very, very old. But it's really cool in that it allows you to say, all right, if you know your race pace, so whether you've done a 400-meter dash, 800-meter dash, either way up to a marathon, half marathon, 5Ks, 10Ks, any one of these races, you can actually look up your race score in it.

Dr. Andy Galpin
He's got all kinds of tables. These are available all over the Internet, and then you can look and predict your performance in any of those other races based on your VDOT. Which is really pretty cool, actually. And so you get an idea of how much time you should be spending in each training zone, according at least to Dr. Jack. But that is a nice way to do it. Is it perfect? No. Is it scientifically validated? Yeah. So pretty cool tool there. If you want to know more about your race pace, if you have the data from one, you can predict it and many others. If you want, you can go to the show notes and pull up the papers and these exact tables and look up your scores. But I'll give you a couple just since we're here to have a little bit of fun. Let's take a mile. Most people know their mile time, and you probably think back to high school. In fact, you should go run one right now and see where you're at.

Dr. Andy Galpin
I always think like once a year, you should go run a mile and see where you're at. Okay, so let's just pick a random score here. Let's say you ran a mile in seven minutes and 38 seconds. According to this table then, you should be able to run a 10K in 53 minutes or so, a half marathon in an hour and 58 minutes, and a full marathon in four hours and four minutes. If you've ever done any of those events, that smells pretty good, right? You're running a seven and a half minute, eight-minute mile. Recreational runners that go run a marathon probably going to do a four-hour marathon. Those numbers again are pretty good. If we want to have a little more

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fun for those of you faster out there, let's say you have a VO2 max of 70 milliliters per kilogram per minute-ish. More specifically, technically a VDOT of 70, but those are somewhat interchangeable here. This should mean you should be able to do a one-mile race in four minutes and 19 seconds, which is cruising.

Dr. Andy Galpin
Not elite, elite, but pretty elite for most people. Also, a 70 milliliter per kilogram per minute VO2 max is pretty elite, so that makes sense. Your 10K time would be 31 minutes, your half marathon would be one hour and eight minutes, and your full marathon would be two hours and 23 minutes. Again, feels pretty darn good. Let's go even further all the way down. Let's just keep that same person just to do a couple more ones. If you wanted to do kind of interval pacing, you'd run a 400-meter dash in 71 seconds, which again feels about right, and a 200-meter dash in 32 seconds. And so there again, you can look up any one of these, and there's a bunch of them. If you want to look up your marathon pace, your easy running pace, your threshold pace, your interval pace, your repetition pace, they're all available in these, geez, I don't know, 30, 40, 50-year-old charts at this point. I can just tell you anecdotally, spending many, many years in exercise physiology labs with a lot of endurance athletes, though I'm not one myself, and these numbers are pretty good.

Dr. Andy Galpin
I've yet to find anybody who's significantly off on them. You'll have some people who are just a little bit unique, but they're pretty darn good and pretty impressive to figure all this stuff out without the advanced technologies we have now. I know we got a little bit off track there, but to wrap up the investigation, if you want to know your lactate levels, a lactate analyzer is really the only way to do it, but really pay attention, get a high-quality one, and use the same one over and over. If you want to know your lactate threshold, you have dozens of ways to do it. The gold standard is to go into a laboratory. At this point, it's somewhere usually between $100 and $200 or so to find a lab that has a metabolic cart. Now, not all offer a lactate threshold test, but if they do, that's probably what you're going to be looking at. They tend to last something like 30 to 60 minutes. You're going to have to run for a long time, and it's a lot different than a VO2 max test.

Dr. Andy Galpin
So if you specifically want a lactate threshold test, you need to ask for that. Not nearly as many labs offer that as a VO2 max test. In the VO2 max test, some will take your lactate, but that's not a true lactate threshold test. That's a very different thing. Usually what we're looking at here is something like four to five-minute stages where we slightly increase the velocity on the treadmill or something like that, and we're going to take a finger or ear stick and plot out your lactate every four minutes for, like I said, 30 to 60 minutes. So that is kind of the gold standard if you really want to know. If not, there are tons of ways. There's a Conconi test, there are 30-minute

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run tests, there are two-mile tests, there's Jack Daniels tables, and a bunch of other ways you can just take a heart rate monitor at most, at least a stopwatch, go run a test, come back with your numbers, plug it in, and get a good sense of your lactate threshold.

Dr. Andy Galpin
Hopefully, though, in a few years, we'll have a better answer for this. I know of at least four companies at this point who are working on continuous lactate monitors. These come in the form of watches as well as an eyepiece, like a contact lens that can do that. That technology's already available for things like glucose monitoring, and I know that many companies, again, are working on this for lactate. I don't know exactly when they'll be on the market, but I would imagine potentially by the time you're even listening to this, they're available, if not, pretty soon after that. I don't know the accuracy or validity of them. Of course, that will come in time. But it's reasonable to think it's not a particularly hard thing to measure. It is needed in so many different areas, even things like acute medicine and trauma, heart failure, heart attacks, other issues like that. So I am pretty optimistic that within a few years, there will be really high-quality, continuous lactate analyzers available to the masses.

Dr. Andy Galpin
I mentioned this just a second ago, but it's worth repeating. In terms of interpreting these data, at rest, something like one millimolar of lactate is pretty normal, maybe even down to 0.5. What I can tell you, and this is just anecdote, this is Andy's personal coaching belief, you will not find extensive data to support this, we know lactate at baseline is a reflection of what's happening in your mitochondria. And since you're not going through much physical activity, there shouldn't be much. Now, we don't want it to be zero because the lactate is beneficial. It is good. But I think my interpretation of it is this gives you tremendous insight about your metabolic flexibility. If somebody has a resting lactate of 1.5, or even honestly into like 1.2, 1.3, I have seen this oftentimes associated with either short-term overtraining or overreaching, excessive stress, psychological or physiological, other things going on in their blood work with hydration, number of cortisol dysregulation, and things like that.

Dr. Andy Galpin
Also could indicate a bias towards carbohydrate metabolism. So this is actually something that is a little bit sneaky. I don't want you to overinterpret yourself there. There is actually some data on what happens. I know that at least there's some case studies on individual athletes throughout the entire year of the season, and when they're doing more lower intensity endurance work, resting lactate levels come down, and when they shift over to more power and speed and peak performance, they start to go up. This makes sense. We know that physiological adaptations happen in the muscle when you bias towards different forms of energy production. It's a good thing, right? And so that's actually one of the things I pay attention to as an idea of to say, "Okay,

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is this person struggling with fat utilization?" I should be able to use a lot of fat as a fuel source at rest, and so therefore, lactate production should be fairly minimal.

Dr. Andy Galpin
And so something to keep in mind. Like I said, once you get to two or so, you probably feel different. So if you're at that stage, you may actually have something else going on that's medical, diabetes or metabolic acidosis or something like that. I don't know. Again, I'm not a doctor. Don't use me for medical advice. But the point is, somewhere around one or so is normal. At maximal exercise, you will see people get as high as 20 to 25. I don't know what the highest number I've ever really seen is. I know of some folks in medical situations, like having metabolic acidosis that's associated with diabetes, especially at altitude. Highest number I've seen in the literature is like 47 millimolar. I know of a group of actually endurance athletes who supposedly maintained 10 millimolar for an hour straight, which again, folks, some people will be peaking at 10. Michael Phelps supposedly only got to eight even during world record swim performances, right?

Dr. Andy Galpin
Fatiguing, not the sprint ones. And so a lot of high-level athletes, 10, 12 is enough. Some can get up to 20, 25. And in that particular case, that person was up to 47, which is extraordinarily high. I don't know what the real numbers are for that, but that gives you a little bit of context of where you're at at rest as well as maximal exercise. In terms of lactate threshold, typically happens around 70% or so of your VO2 max or maximum heart rate for recreationally or lightly trained individuals. As you become more physically fit and you're able to handle that efflux better for a number of different reasons, you're either better at creating lactate or you're better at clearing it, then that number actually gets higher. It's not uncommon to see folks high 70s, 80s, even up to 85%. We don't have a ton of data on male versus female, but the sum that is available suggests it's slightly higher in women than it is in men.

Dr. Andy Galpin
But I wouldn't say that is a complete slam dunk in the science. You will often also see this number to vary between highly successful individuals. Like I said earlier, endurance events can have success in many different ways. So you can have a higher VO2 max. You can have a higher running economy or cycling or swimming economy. Or you can have a higher lactate threshold. But at the same token, that also means you can be really good with a lower lactate threshold. So there's a lot of paths to victory in sports, and endurance is no different. So anything in that stratosphere of kind of 80, 85% would be normal for a moderate to decently trained endurance athlete. Fun fact while we're on this point, remember the heart itself needs metabolism. So it is going through energy production. It is then therefore generating lactate as a byproduct of its own endogenous energy production, so the energy needed for the heart to

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contract.

Dr. Andy Galpin
Now, if you give a given second, typically when your heart is contracting, that takes around 200 milliseconds, and around 800 of the milliseconds then are left where the heart is not contracting. So it's filling back up with blood. It's thought then that during that contraction time, you're producing lactate. During the relaxation time, which is, again, four times as long, it's clearing the lactate. But once heart rate gets really, really high, and that goes from a four to one relax to contract ratio, to three to one, to two to one, to one to one, or even more than that, the heart doesn't actually have enough time to clear all of its own endogenous lactate production, which is one of the reasons why you become fatigued. Which brings us to our final I, intervene. A handful of ways you want to think about this. Number one, you want to make sure you're metabolically flexible so that we're not creating too much lactate at rest and not too little as well.

Dr. Andy Galpin
We talked about possible supplementation directly of lactate, and that doesn't seem to be panning out at this particular point. Maybe more hope for gels and creams, but as a direct supplement, doesn't seem to be super effective. Nutritionally, well, you might think about carbohydrates are important and the primary place at which lactate's created, so then should I have lower carbohydrates, or should I have more carbohydrates? At this point, I don't think there's any specific rationale to think as long as metabolic flexibility is appropriate, that increasing or decreasing carbohydrates is going to play a significant role in your quality of lactate management. Will it change production? Look, anytime you have more carbohydrates, especially directly prior to exercise, you're going to bias carbohydrate metabolism, which is a way of saying you will shift more of your energy coming from carbohydrates because more is acutely available.

Dr. Andy Galpin
So will that shift and alter lactate production? Potentially. But is that making a meaningful impact on human performance? Well, outside of the benefits of having carbohydrates in your system, it's unclear at this point. In terms of training then, all we really have to think about is what's going to advance and increase mitochondrial health, quantity, and size. And the reality of it is you have a ton of options here. We talked about this a lot in our other episodes on the heart and VO2 max, and so I'll keep it brief here. You can head over there for more detail, but you have different options. What about low-intensity exercise? What about zone two? Well, let's run the whole gamut here. Starting off with low-intensity exercise. We know that zone one or zone two can enhance mitochondrial quality. This is almost by definition staying at two millimoles or lower. So that's absolutely a strategy.

Dr. Andy Galpin
In fact, many distance and endurance coaches are going to spend a lot, if not most of their time

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in that area, and for probably very good reasons. If that also increases capillarization and we're able to then get out lactate of the muscle and get it spread across to the other tissue, the heart, the liver, the kidneys, the brain, then that's going to be effective. What about more moderate continuous exercises? In the research, we generally abbreviate this as MICT, so moderate intensity continuous training. Well, that works too. Now you're probably in the neighborhood of two to four millimolars, something like that, and you're going to be doing it for a longer duration. Is it having the exact same effects? No. But has it been shown many, many times to enhance mitochondrial quality, fuel utilization, and waste removal? Absolutely. Continuing past that, what about higher intensity stuff? Really now we're talking about a couple of things.

Dr. Andy Galpin
High intensity intervals is a good way to do it, and you can do these in long or short. The short version would be something like 20 to 90 seconds of a burst, followed by one to one or up to three to one rest. So this could be as short as 30 seconds of rest, up to even three minutes or more of rest. Also incredibly effective. We know this increases VO2 max and certainly lactate threshold as well as overall economy. So another possible strategy. The longer duration intervals would be more like two, three, four, up to five minutes with an equal or larger amount of rest. This is a classic, most well-described one, four minutes of all-out work matched by four minutes of rest. Important to realize when I say things like that, four minutes of all-out work, I really don't truly mean that. You can't be at 100% of your VO2 max for four minutes. Typically, high intensity interval training is really honestly somewhere between 85% to 90%, maybe up to 95%.

Dr. Andy Galpin
And so good, but a slightly different mechanism. The highest on the end here then past that is what we usually call SIT or sprint interval training, and now this is truly at 100 if not higher or super maximal all-out exercise. The duration here is far shorter, sometimes as low as even 10 to 15 second bursts matched by a lot of rest, but now you got to repeat this many, many times. So instead of doing things like 30 seconds on, 30 seconds off for, say, four attempts or five attempts, or even your longer duration ones for, again, three or four, you're doing many more, maybe up to 20 repetitions, if not more than that, of these short bursts. If you look at the research and the studies, even the meta-analyses that have directly compared MICTs, moderate intensity stuff with low intensity stuff, maybe even high intensity intervals and SITs, and there's lots of different combinations in the research here, you're going to find slight differences, I'll acknowledge that, but all of them work.

Dr. Andy Galpin
Do they have unique components to it? I think so. I don't think we have a ton of information to explicitly say that with confidence, because again, they all generally work. Now, sometimes in some studies, in some meta-analyses, some work slightly better than others for different

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aspects. And so to me, the clear answer is you should probably have all of it in your program. There should be plenty of time at low intensity, steady state, sub two millimolar. Some time, though probably not a ton, but some time in two to four millimolar range, continuous submaximal stuff. A decent amount of time in these higher 85% to 95% high intensity interval ranges, and then some small amount of time in these super maximal. But the final point here is this Remember, fatigue exists on a non-linear curve. And so if you can imagine all four of these paradigms on that curve, if I'm in zone one or two and I double my work, I go twice as fast, I only have a small increase in fatigue as long as I'm still in that zone.

Dr. Andy Galpin
Going from 40% to 55% is not much more fatiguing. But as I go and I cross MICT, and I get into the high-intensity intervals, now 2, 3, 4, 5% increases have huge increases in fatigue. And now I get all the way up to super maximal. I have large increases in fatigue for very small increases in performance. To me, that suggests you should probably spend small amounts of time in the top end of the range, some amount of time in the middle, and then a lot or most of your time in the low end of the range. The rationale not being low intensity is more effective, it clearly is not. I need to repeat that. Low intensity is not more effective at improving VO2 max. It is not more effective at fat loss, which we've talked about in other episodes. It is not more effective at improving mitochondria. It is, however, more recoverable. At the same time, it takes a long time, and so the benefit of going at moderate and high and even really high intensities is they're really, really short.

Dr. Andy Galpin
I don't need to be running for 45 or 60 minutes. And they are providing unique and potentially more adaptations. I just can't spend all my time doing that because I won't have the recovery necessary to keep it up for long enough to really get sustained adaptations. So in my opinion, whether you're in this for sport performance, you want to run a marathon, you want to row in a race, you want to do an Ironman, or whether you're in this for life, you just want to improve your VO2 max, you want to enhance your metabolic flexibility, improve your overall mitochondrial health, have more energy throughout the day, more global recovery, be better at utilizing all forms of fuel. The answer at the end of the day is still the same. You probably want to train over that full spectrum, making sure we lower or at least keep our lactate production at baseline, moderate to low, enhancing our lactate threshold, enhancing our total ability to produce, to generate, and to handle and clear lactate once it's there, appreciating all the benefit it's doing for our memory, for our brain health, for our cognition, for our heart, for our liver, for our wound healing, for our immune system, for our digestive system, and everything else that lactate is doing to make us a healthier, happier, and better-performing human.

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Dr. Andy Galpin
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Dr. Andy Galpin
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