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A Solution to Running Cramps Induced by Electrolyte Imbalance

Millions of people run, some recreationally, and some professionally. No matter what speed or distance runners run, cramps are possible. Anatomically and physiologically, cramps are a very likely possibility for most. Given what it takes for a muscle to contract, the number of muscles involved in running, and the likelihood for the environment to be depleted of the necessary nutrients, getting cramps is no surprise. Cramps are easily avoided, though. By replacing electrolytes in the muscle, cramps are less likely to occur. Unfortunately, during long distance runs, replacing electrolytes in the most popular ways is rather inconvenient. Through a proposed electrolyte pump, similar to an insulin pump, electrolytes could be replaced constantly during long runs and significantly reduce the chance of running cramps.

Skeletal muscle is one of three types of muscle found in the body. It is the only type of muscle that is voluntary, meaning that the muscle is able to be moved by a conscious decision. All movements of the skeletal muscle are controlled by the nervous system. There is a specific sequence of events (called the Sliding Filament Theory) that occur that lead to a muscle contraction, and that sequence must always begin with an action potential, or electrical impulse, down the axon of the motor neuron. Eventually, that electrical impulse will arrive at the neuromuscular junction, which is a very distinct connection between the motor neuron and the muscle fibers. The motor neuron and the muscle fibers do not come in direct contact with each other, but are rather connected by a fluid filled junction called the synaptic cleft. This synaptic cleft is where the action potential of the motor neuron is transferred to the muscle fibers. A neurotransmitter called acetylcholine sits at the very end of the motor neuron (the part closest to the muscle fibers) and once the action potential reaches this end of the neuron, the acetylcholine is dispelled from the neuron through exocytosis. The acetylcholine then travels across the synaptic cleft and binds to receptors on the sarcolemma, or outer covering, of the muscle fiber. When the acetylcholine binds to these receptors, the permeability of the sarcolemma changes and thus allows more sodium ions into the sarcoplasm of the muscle fiber. The influx of sodium ions cause the inside of the muscle fiber to be a tad more positively charged than the outside, depolarizing the muscle fiber. The depolarization, or action potential, travels along the sarcolemma and down the transverse tubules into the sarcoplasmic reticulum. The transverse tubules and sarcoplasmic reticulum wrap each muscle fiber. When this action potentials reaches a specific part of the sarcoplasmic reticulum that stores calcium ions (called lateral cisternae), the calcium ions are released. Sarcomeres, small sections of skeletal muscles, receive the calcium that is released by the lateral cisternae. Actin, a myofibril within muscle fibers, has structures called troponin sitting along the

length of it. The calcium ions attach to troponin. This causes a rotation of the actin. This rotation makes the calcium-troponin complex more accessible to the myosin heads. Myosin is a second myofibril in muscle fibers. These myosin heads, once attached to the calcium-troponin complexes, pull actin filaments toward each other and over the myosin itself. This pull of the actin toward each other and over the myosin is what cause the muscle to become shorter, and thus contract. ^{1,2}

The muscles that are used in running specifically are primarily the quadriceps femoris, the hamstring, the gluteus maximus, the iliopsoas, and the calf muscle. The quadriceps femoris is a group of muscles that flexes, or contracts as seen in the Sliding Filament Theory, the hip. This muscle is also responsible for extending the knee. The hamstring encompasses four different muscles that flex the knee, serving as an antagonist to the quadriceps femoris. The gluteus maximus works in conjunction with the quadriceps femoris by being in charge of extending the hip. Because of this, we are able to stand erect. The iliopsoas is a pair of muscles that supports hip flexion. Finally, the calf muscle is to flex both the knee and the ankle. All of these muscles are able to do what they do for the runner because of the Sliding Filament Theory and the contracting and the extension that that Theory involves. ³

With training, running can become an enjoyable and simple exercise, but when muscles cramp, running can suddenly turn to a very painful and tough thing to do. Generally, cramps occur due to a lack to ATP, an electrolyte imbalance, low blood glucose levels, and low pH, heat, or medicine. Large amounts of ATP are produced through cellular respiration, but in order for cellular respiration to take place, there must be glucose available to start the process in glycolysis and oxygen to continue the process into the krebs cycle and electron transport. The muscle cells only have enough energy (glycogen and oxygen) to fuel about 40 seconds of exercise aerobically. After that 40 seconds, ATP is produced through anaerobic respiration. This anaerobic respiration leads to lactic acid production. Because this is an acid, the pH of the muscle is lowered. This lactic acid can build up and the pH can drop too low, causing the muscle to cramp. As time passes, such as over long distance runs, more and more lactic acid builds and more electrolytes are depleted, causing more and more potential for cramping.² Electrolytes are minerals like sodium, magnesium, calcium, and potassium that help maintain the voltage in muscle cells.⁴ This voltage is seen in the Sliding Filament Theory when acetylcholine attaches to the receptors on the sarcolemma, thus allowing the cell to be more permeable to sodium. Calcium, also an electrolyte, is seen in this Theory when calcium floods the sarcoplasm and attaches to the troponin complex. When there is an imbalance of the electrolytes, usually a result of too little fluid in the body or great loss of electrolytes in sweat, muscles tend to tighten and shorten, leading to a muscle cramp.⁴ For runners, it is safe to say that most cramps occur in

the calf muscle. This can be assumed because the calf muscle is responsible for both ankle and knee flexion. The running motion is most dependent upon these movements. An electrolyte imbalance, a low pH, etc. in the primary running muscles are what cause the most problems for runners specifically.

Thankfully, there are ways to prevent muscles cramps. One of the biggest ways that muscle cramps can be prevented is through electrolyte replacement. Returning sodium, potassium, calcium, and magnesium to the muscle will help it to run more efficiently and decrease chances of cramping.⁴ Traditionally, salt water, bananas, sports drinks, broccoli, etc. have been advertised as great ways to replace these minerals in the body.⁵ These methods are not to be discredited. They have been extremely successful in everything from weekly workouts to professional athletes, but these methods are not always the most convenient when running long distances, such as a marathon or triathlon. Trying to keep pace for a race does not lend itself to trying to drink fluids or eat and digest solid foods. A more convenient and practical way that electrolytes could be replaced are through a pump that attaches to the body similar to an insulin pump that diabetics use to get insulin throughout the day and after meals. Granted, insulin pumps are much more crucial to a diabetic's body and well-being than a convenient electrolyte replacement pump is to a runner during a race, but such a device could prove very beneficial.

An insulin pump works fairly simply. It is a small device about the size of a cell phone that is carried in a pocket or clipped onto a belt. From the pump itself runs a very tiny tube that connects on the opposite end to a even smaller tube called the cannula. The cannula is essentially a needle that goes through the skin and is about the length of one fingernail. The insulin that the pump is programmed to deliver flows through these two tubes and into the blood stream. Because diabetics cannot produce insulin on their own, the pump is responsible for delivering insulin throughout the day to the diabetic. The diabetic receives a basal dose of insulin, or a constant flow of insulin throughout the day, and then also a bolus, which is a dose of insulin with a meal. Both the basal dose and the bolus are custom amounts of insulin to the diabetic. This pump makes life much more stress free for the diabetic because they no longer have to worry about getting shots of insulin at the appropriate times every day. This way, they can live a more simple, care-free, and efficient life.⁶

A pump that replaces electrolytes could would work the exact same way, maybe even more simply because it would not have to be worn constantly. A few tests could be done on the runner to see what volume of electrolytes their muscles use in a certain amount of time, and how much average time passes before the runner gets a cramp. This information coupled with how often the runner goes on long distance runs and how often they are willing to wear the pump, a plan can be set out for the runner for wearing the

electrolyte replacement pump. Tubing of the same sort could be used to deliver the electrolytes into the blood stream as in an insulin pump and could also be worn like one. The pump would realistically only have to be worn on race day, so that as the runner could guarantee that with the plan devised as a result of personal testing, no cramps would spring up during the race.

The electrolyte pump, though its purpose and mechanisms are simple, has both pros and cons. The true disadvantage to the electrolyte pump would be the cost. To give a rough comparison (assuming that this cost will *not* be covered by insurance), an insulin pump costs \$6,000. Running the pump costs about \$250 per month (i.e. Tubing, insulin, etc.)⁷ To be fair, electrolytes are much more accessible and easily made than insulin, and the pump would not be worn constantly. This means that the cost of monthly upkeep of the pump might be under \$100 and the pump itself, well, if run similarly to an insulin pump, might not be that much cheaper. Also, because the pump would need to be personalized, taking into account one runner's use of electrolytes, the tests to determine the correct flow of electrolytes during a run could cost a decent sum. Obviously the money adds up, meaning that a pump that replaces electrolytes to prevent cramps may only be practical and pay off for those runners who travel extremely long distances on foot at least a couple times a month. Another issue with an electrolyte pump is that the amount of electrolytes being replaced, and the levels throughout the race, would have to be monitored. Too much of even one electrolyte could be dangerous and cause other issues in one's body. Electrolyte levels would have to be tested for just as blood sugar levels are tested in diabetes.

On the upside, an electrolyte replacement pump would have no reason not to be successful. The groundwork has already been laid by the insulin pump and electrolyte research for the making of sports drinks, etc. All that is left to be completed is the conversion into a pump and the customization of each one. The runners who could afford it (which may become more and more over time as technology advances) would run cramp free as long as the dosage that they pump delivered into the blood stream (and thus the muscles) was accurate. Surely runners (especially those from materialistic countries such as America) would pay for success, efficiency, and personalization.

Convenience, efficiency, and success run wild in technology today, An electrolyte pump that returns electrolytes to the muscles during long distance runs would fit perfectly with the market. Cramps are a serious disease by any means, but they are a concern and a difficulty for both recreational and professional runners. Cramps can occur due to many reasons and in a numerous amounts of muscles involved in running, but can be simply solved. When conventional methods do not lend themselves to the situation at hand, an electrolyte pump that constantly supplies electrolytes is the solution.

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