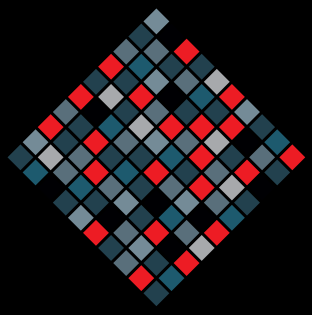
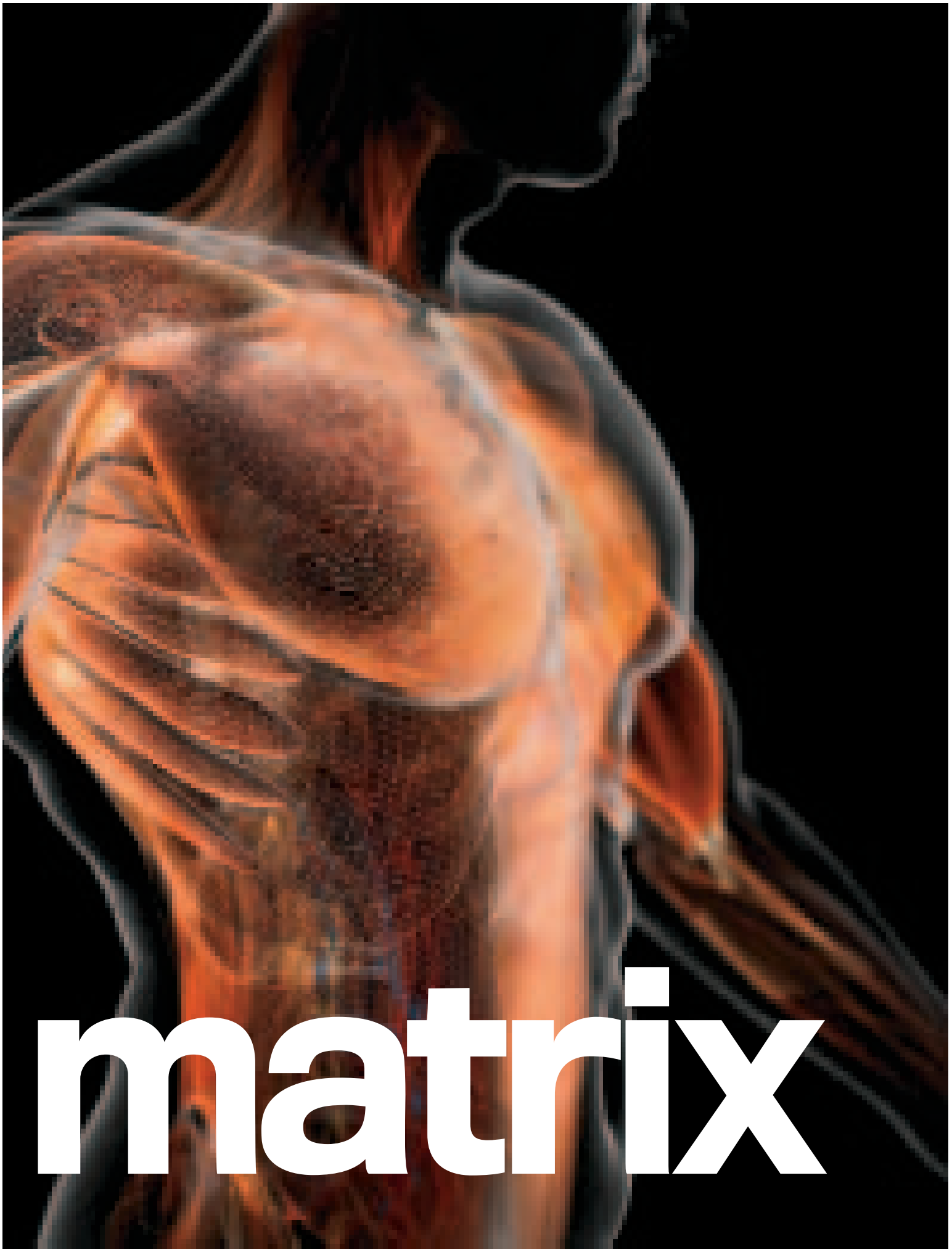
BY MICHAEL BEHAR
ILLUSTRATION BY BRYAN CHRISTIE



Want huge biceps, six-pack abs, and perfect pecs? Then it's time to rethink everything you think you know about muscle building. Because new evidence suggests that it's not actually your muscles but your connective tissue—the muscle "matrix" that holds your muscles together—that triggers strength and size. The good news? You can exercise it, too.

HARNESS THE POWER OF YOUR muscle


matrix

Picture a medieval torture rack for Smurfs.

The device, called a uniaxial tensile tester, is about the size of a shoebox. With long tweezers, a doctoral researcher at the UC Davis Functional Molecular Biology Lab plucks a freshly grown, two-week-old anterior cruciate ligament, or ACL, from an incubator and clamps the ends to anchors on the tensile tester. A USB cable then hooks it to a laptop, allowing the researcher to tweak how hard and fast the tendon gets yanked, and for how long—hours, sometimes days.

While the thought may be horrifying to anyone who's experienced the searing pain of snapping an ACL—it connects your femur and tibia, and is prone to blow out if you play basketball, football, soccer, or ski—thousands of ACLs, cultivated from samples donated by knee-surgery patients, have been torn, twisted, and pulverized with this miniature device. The man behind the mayhem is the lab's director, Keith Baar, Ph.D., a renowned scientist in the emerging field of molecular exercise physiology. Baar is leading a team of researchers attempting to fathom the complex relationship between your muscles and the connective tissue that holds them together.

Your connective tissue consists of tendons, ligaments, and what's known as the "extracellular matrix," a scaffold-like network of fibers that permeates muscle. Scientists have long known that lifting heavy weights produces bigger, stronger muscles—it activates genes and proteins that instruct cells to build more muscle fibers. During that exercise, it was always thought, your connective tissue was limited to a simple mechanical function: transfer force from muscles to bones, or for ligaments, bones to bones. (Picture train couplings between railcars.)

But recent discoveries are revealing that connective tissue does a whole lot more. As it turns out, it plays a crucial role in muscle building, a process called hypertrophy. On top of that, it appears that your connective tissue can be improved with specific exercises and nutrient supplements to profoundly impact athletic performance and strength, and prevent injuries.

"The reality is, if you want to be strong, you need to have not only big muscles, but also really good connective tissue," says Baar. And any exercise routine that overlooks it, he warns, would be like a workout that only targets, say, the left half of your body.

Collagen evangelist. *Keith Baar preaches the benefits of robust connective tissue (which builds stronger muscles) to NBA, MLB, and pro cycling athletes.*

THE MYTH-BUSTER OF MUSCLE BUILDING

On a sunny August afternoon in California, I walk with Baar across the UC Davis campus to his lab, where things are bustling. A student is hunched over a laptop, squinting at data from an experiment designed to pinpoint which genes instruct muscles to bulk up from weightlifting; another is gloved in latex, handling pea-sized artificial bones made from calcium paste. Baar, 44, svelte in his crisp blue oxford and pressed gray slacks, sports a golden summer tan. "I've been training for the Vancouver Marathon, hoping to qualify for Boston," he says. Baar hardly ever sits. In his office is a chest-high desk designed for working upright. "Every hour I stand it burns 100 calories—that's equal to running six miles by the end of the day."

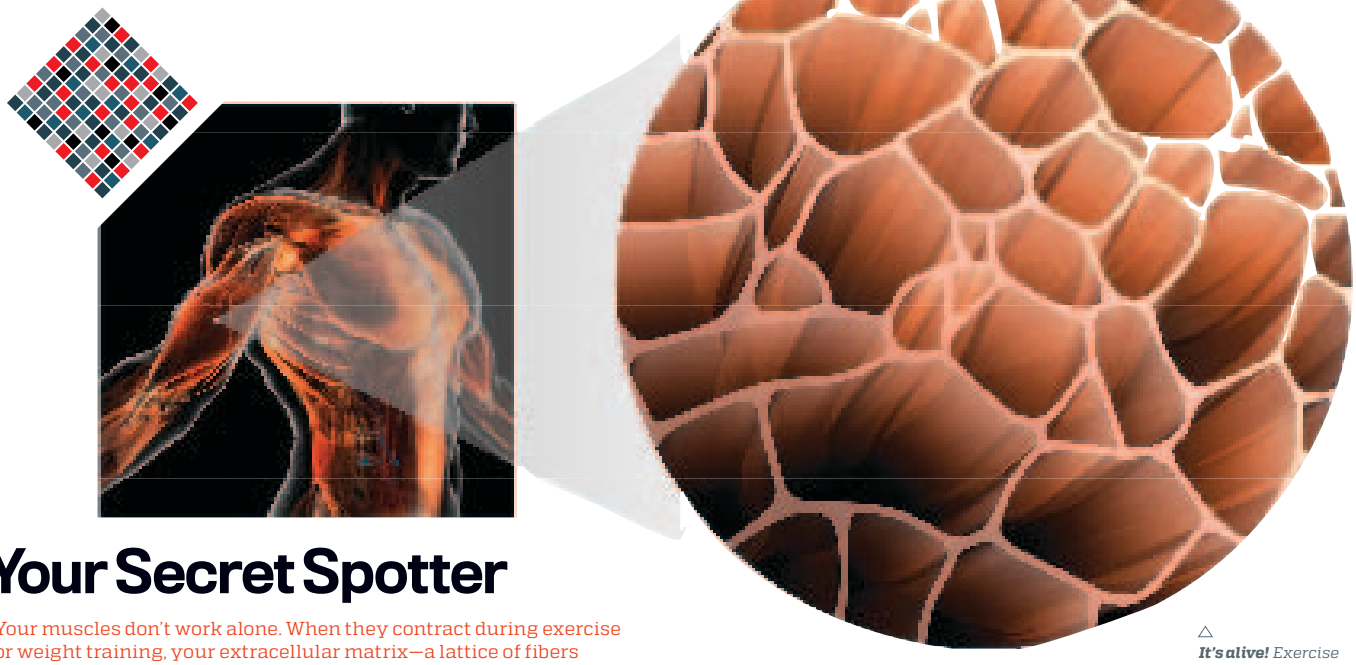
In his early career, Baar was the strength and conditioning coach for the University of Michigan football team. Today he preaches the benefits of connective-tissue health to trainers with USA Track & Field, British Cycling, Major League Baseball, and the National Basketball Association. His research, along with that of a handful of contemporaries around the world, is using new technologies to learn about the genes and proteins that come into play during exercise, chiefly within muscles.

"Twenty years ago, it was extremely expensive to look at all this stuff," explains Andrew Philp, Ph.D., a professor of physiology at the University of Birmingham in the U.K., who's collaborated with Baar on numerous projects. "Only a couple of labs in the world were doing it." Today, however, once prohibitively pricey tools—machines that analyze scads of genes simultaneously, or isolate single strands of DNA—are accessible to almost anyone doing basic research.

Because of that, "we now know there are thousands of genes relevant to exercise," says Richard Lieber, Ph.D., senior research VP at the Rehabilitation Institute of Chicago, who pioneered techniques for recording gene activity in muscles. Imaging systems have vastly improved, too: With MRIs and PET scans, muscles can be observed relaxing and contracting in real time, even in humans. "We can really visualize what's going on," says Michael Kjær, Ph.D., a professor of sports medicine at the University of Copenhagen and one of the world's foremost experts on muscles.

So, what's all this science telling us?

In part, it's corroborating conventional



Your Secret Spotter

Your muscles don't work alone. When they contract during exercise or weight training, your extracellular matrix—a lattice of fibers made of collagen and amino acids that permeates your muscle—bears up to 80% of the force. In other words, when you lift a barbell, the load gets spread across a honeycomb-shaped network that works like suspension cables holding up a bridge. Ultimately, a stronger matrix means stronger muscles.

△ ***It's alive!*** *Exercise tears down and rebuilds the muscle matrix—which signals muscles to grow, researchers believe.*

wisdom with hard data. For example, bodybuilders have religiously ingested protein and omega-3s immediately after a vigorous workout without really knowing why. Now research has confirmed that this practice can boost new muscle growth by up to 60%.

Breakthroughs are also shattering some stubborn misconceptions. For instance, lactic acid buildup isn't the only thing that makes muscles hurt. Inflammation also contributes to soreness after exercising—and soreness, it turns out, stimulates hypertrophy. The upshot: No pain really does mean no gain.

"Pain is healthy," says Kjær—so much so, in fact, that he warns against taking ibuprofen to alleviate post-workout soreness because it can negate the gains attained from exercise.

But of all the recent breakthroughs, none is more surprising than what molecular exercise physiologists are learning about connective tissue and its crucial role in muscle building. It works like this: Human cells "communicate" with each other by releasing biochemical compounds. When you endurance-train, for instance, these compounds, principally calcium, signal your muscle cells to ratchet up your mitochondria, which then increases your capacity for oxygen and allow you to run faster, for longer. A similar signaling process occurs whenever you lift weights.

But throughout these processes, "we always thought connective tissue was inert," says Baar. In the mid-2000s, when Kjær—the first to establish a link between robust connective tissue and healthy muscles—and others began recording cell signaling in tendons, they expected silence. Instead they heard a cacophony. And that changed everything.

LIFELINE TO MUSCLE GROWTH

"Connective tissue is alive and has the ability to renew itself!" Kjær whoops enthusiastically into the phone when I call him at his office in Copenhagen. It's as if he's just witnessed a corpse rising from a grave. In a sense he has. Back in 1998, when Kjær, an endocrinologist, began a sports medicine professorship at the University of Copenhagen, "people considered connective tissue not necessarily dead, but not very dynamic either," he says. "It worked or it was broken, and you couldn't adapt it very much with training."

The scientific consensus—and the conviction of pretty much anyone who'd ever done a bench press—was that weight training rendered so-called "micro-tears" in the cells, or myofibers, that muscles are made of; rip them apart, the thinking went, and they responded by beefing up. Meanwhile, the connective tissue that linked the moving parts—bone and muscle—was thought to have negligible influence on muscle size and strength. "But I didn't really buy this," says Kjær. "There had to be more to it."

Indeed there was. In a series of experiments in 2007, Kjær managed to debunk the enduring notion that micro-tears occur during resistance training by showing that, during exercise, much of what's torn down and later rebuilt in muscles is the connective tissue—specifically the extracellular matrix—and not the muscle itself. Biopsies on test subjects also confirmed that the culprit in muscle soreness was not, in fact, lactic acid or micro-tears in myofibers. "It was the connective tissue that was damaged," says Kjær.

Most surprising of all, Kjær found that a kind of "post-exercise renewal cycle" goes on in connective tissue. His work, along with findings by others, suggests it's this renewal cycle that signals muscles to hypertrophy—that is, to grow bigger. And that's why it's important not to ignore your connective tissue.

FEEDING THE MUSCLE-BUILDING MONSTER

Connective tissue consists almost entirely of collagen, a type of protein. But collagen doesn't act alone. Ropelike amino acids called "crosslinks"—which Kjær compares with the suspension cables on the Golden Gate Bridge—bind the collagen molecules together. This has profound ramifications in the extracellular

PHOTOGRAPH BY SAM KAPLAN

GET-BIG FUEL: EATING TO BUILD MUSCLE

MOST GUYS THINK they've cracked the dietary code for larger, stronger muscles: protein with a side of protein. Well, new research—especially on the connective tissue that holds your muscles together and connects them to bone—suggests it's not that simple. Not only is all protein not created equal, but not all carbs are evil, liquid egg whites are an unnecessary evil, oysters are amazingly good for you, and one fish held in high, healthy esteem may actually be terrible for you. ¶ With help from Brian St. Pierre, M.S., R.D., a nutrition coach for Precision Nutrition, we offer the nine new guidelines for stocking a muscle-building fridge and eating away. (Just remember to keep working out.)

BY SEAN HYSON, C.S.C.S.

FOR STRONG, POWERFUL MUSCLES

RULE NO. 1

Fish Carefully

Low in calories and price, tilapia is one of the best-selling fish in the country. But it's usually farmed, and that may pose health risks—a recent Wake Forest University study found that farmed tilapia contains high levels of omega-6 fats, which trigger inflammation in the body. Instead, opt for salmon. Rich in protein and anti-inflammatory omega-3 fats—four grams per ½ fillet—it also provides high levels of more than a dozen different vitamins and minerals, including vitamin D and vitamin B12.

RULE NO. 2

Eat Beyond the Breast

Skinless chicken breast meat is a staple among bodybuilders, but according to St. Pierre, most guys don't realize that the whole bird is fair game. "It's a great source of protein, goes with just about any other kind of food, and is reasonably priced." Just keep in mind: The skin and dark meat contain fat, so adjust your portions accordingly.

RULE NO. 3

Not All Beef Is Created Equal

Sure, top sirloin may be on the expensive side, but you get what you pay for (at least, in terms of health). It has a lot more protein (26 grams in a three-ounce serving) and far less fat than lesser, cheaper, more popular cuts such as chuck or round. But don't worry: The good stuff retains "enough fat to keep it juicy and tasty, but not so much that it outweighs the protein," says St. Pierre.

RULE NO. 4

Save Your Yolks

Stop buying liquid egg whites—now. You're wasting your time. "Whole eggs are some of the most nutritionally dense foods on the planet," says St. Pierre, who argues that the real thing is far better for you than the watered-down stuff that comes in a milk carton. "Real eggs are loaded with brain-boosting choline, and zeaxanthin for eye health." The saturated fat and cholesterol they contain doesn't affect cholesterol levels in your blood.

RULE NO. 5

Forget the Full Paleo, Embrace the Potato

Miles of research suggest that a low-carb diet won't build muscle for long. The energy you need to train and recover from training comes from carbohydrates, and one large potato contains 63 grams' worth—and seven grams of fiber. We recommend sweet potatoes, which are nutritionally dense and jammed with potassium, a mineral essential for muscle health.

RULE NO. 6

Eat Oats for Breakfast

Pre-workout drinks and caffeine have their place, but eating the right carbs can provide consistent, lasting energy throughout the day with no crashing. "One cup of oats provides 166 calories, four grams of fiber, six grams of protein, and eight vitamins and minerals," says St. Pierre. "And it's a slow-digesting carb," meaning it won't cause a big spike in blood sugar and send your energy crashing later.

RULE NO. 7

Always Have Nuts to Snack On

Avoiding fats entirely to save calories is costing you on a chemical level. "Consuming adequate fats is critical for maintaining testosterone levels," says St. Pierre. And the more testosterone you have, the greater your potential to be big and strong. One serving of nuts or nut butter offers 16 grams of healthy fat, "as well as a powerful assortment of phytonutrients and antioxidants to boost your health and recovery."

FOR HEALTHY CONNECTIVE TISSUE

RULE NO. 8

Get Jiggly With It

Jell-O is great for building muscles. (Yes, you read that correctly. And no, we don't think you're 12.) It's composed of gelatin, which is made directly from the connective tissue of animals (the slow-boiled tendons, ligaments, and sometimes bones of cows and pigs). Eating it will boost your own tendons and ligaments.

RULE NO. 9

Mollusks for Muscles

Oysters are a major source of copper, which not only helps build collagen for your connective tissue but also spurs production of lysyl oxidase, which in turn stimulates production of collagen and elastin.

Food Styling by Brett Kurzweil/Art Department

matrix. Without those connections, the muscle would simply fall apart.

When your muscles contract, the crosslinks in the matrix tissue bear up to 80% of the force. In other words, the extracellular matrix–under a microscope it looks like honeycomb–spreads the load and, therefore, helps you engage more of your muscles during exercise. It's only logical, then, that any training you can do to build a healthier muscle matrix will improve your overall performance. But what would this kind of training look like?

In 2008, Baar and Jennifer Paxton, Ph.D., a professor of tissue engineering at the University of Edinburgh's Center for Integrative Physiology, set forth to find out. Their team rigged up ACLs on a tensile tester–the Smurf torture device–capable of tugging 11 ligaments simultaneously. Over three years, they churned through more than 1,000 ACLs. They stretched them for different durations–a minute, five minutes, 10 minutes, a week. They stretched them unloaded (bearing no weight), then loaded. They stretched them fast and slow. They varied the recovery intervals from 30 minutes to 24 hours. After each round, they crushed the ACLs into a powder, then tested to see whether new connective tissue had been produced, and if so, how much.

After years of peering through microscopes and crunching numbers, Baar and Paxton made an astounding discovery: The amount of weight lifted has no impact on connective tissue. In fact, only two variables–duration and recovery–make any difference at all. Baar explains it like this: "Whether you're lifting a huge load or a little load, your tendons respond the same. The only thing that seems to have an effect is time. Your cells stop responding after about five minutes. It's like speaking to your kids: If you talk to them for longer than a couple of minutes, they stop processing what you're saying. We found it took six hours for the cells to reset back to normal."

He continues, "This tells us that if we want to maximally improve our connective tissue, we have to do five minutes of activity, wait six hours, then do five minutes again." Practically speaking, you could jump rope for five minutes and then take the afternoon off. The same is true for lifting: light five-minute stints on all your muscle groups gives your connective tissue a rejuvenating thrashing. You can also do Pilates, HIIT, CrossFit, or even basic calisthenics. But whatever method you choose, always use light resistance. If you feel the burn, says Baar, you're doing too much.

These repetitive motions will ramp up the collagen in both your extracellular matrix and your tendons, the latter becoming thicker and stiffer. And a stiffer tendon is a good thing, like a bungee cord attached to a kettlebell–a firmer bungee can exert more force on the kettlebell than a stretchy one. "It's like a spring," says Baar. "The stiffer the spring, the more energy you get back."

Baar and Paxton's research yielded the world's first basic training protocol for connective tissue: five minutes on, six hours off. But whether it would actually work had yet to be proven.

△ ***Knee deep.*** *A researcher in the UC Davis Functional Molecular Biology Lab converts proteins harvested from human ACL ligaments into a gel for scientific analysis.*

THE MUSCLE MATRIX HITS THE BIG LEAGUES

On July 21, 2004, Grady Sizemore played his first Major League Baseball game, as center fielder for the Cleveland Indians. During his subsequent eight seasons, he played in three MLB All-Star games and won the Gold Glove twice. In 2006, at just 23, he'd scored more runs than any other player that year, and become the youngest player to rack up more than 90 extra-base hits in a single season.

Then he got injured. Repeatedly. Over a four-year-span, Sizemore underwent seven surgeries–two hernia, one back, an elbow, and three knees. He sat out every game from 2012 to 2014. For his knee surgeries, Sizemore headed to The Steadman Clinic in Vail, CO, known for its progressive techniques and world-renowned orthopedic doctors and physical therapists, including Luke O'Brien, P.T., of the clinic's rehabilitation program. By chance, O'Brien was introduced to Baar.

Baar told O'Brien that connective tissue and muscle worked systemically–that an injury to one was like an injury to both. Sizemore had

THE PRESCRIPTION FOR STRONG CONNECTIVE TISSUE? A FIVE-MINUTE ROUTINE OF LOW-INTENSITY MOVEMENTS FOLLOWED BY SIX HOURS OF REST.

surgery to his knee to repair a bone bruise. But O'Brien now understood that ignoring the supporting tendons would create an inherent weakness–a defective cog in the musculoskeletal machinery–and the player could wind up injured again. "We didn't treat Grady specifically for a tendon problem," O'Brien points out. "But the whole process of [rehabbing his knee] allowed the cells enough recovery time to reset, and then reloading him, and doing it a few times during the day, we were doing exactly what Keith had demonstrated."

The 32-year-old Sizemore recovered. He did a stint with the Boston Red Sox, did a stretch in the minors, then got called back up to play with the Philadelphia Phillies in July 2014. And his seemingly miraculous comeback was largely due to the attention given to his connective tissue. In the six years since Baar and Paxton developed their training protocol for connective tissue–five minutes on, six hours off–Baar has added another component: Speed.

AFTER HIS SEEMINGLY MIRACULOUS COMEBACK, SIZEMORE WAS CALLED UP TO PLAY FOR THE PHILLIES.

After snapping many more ACLs in his lab, he says, he noticed that "when you move slowly, you train more of your muscle. If you work faster, with a lighter weight, you get a stimulus for the connective tissue." He's already putting this new insight to use. During a scrimmage in August, NBA forward Paul George, who plays for the Indiana Pacers, severely fractured the tibia and fibula in his right leg–the splintered bones tore straight through his skin. George's trainers at the Gatorade Sports Science Institute called Baar. "They asked for advice on how to get him back playing as quickly as possible," Baar says.

His advice: rapid, low-intensity movements–think: CrossFit for wimps–to bolster George's connective tissue during his downtime.

OYSTERS, JELL-O, AND A HUNGRY MUSCLE MATRIX

Meanwhile, back in his lab, Baar shows me ACLs marinating in various nutritional liquids. He's curious which foods might supercharge connective tissue. After a thorough soaking, the ACLs are stretched on the tensile tester until they break. Subsequent analyses inform Baar whether certain compounds influence the formation of collagen and crosslinks.

"Gelatin is a big one," he says. "It's pure collagen, made from animal bones." More accurately, it's manufactured by slow-cooking the tendons, ligaments, sometimes bones of animals, namely cows and pigs, in vats of boiling water. Another beneficial molecule is lysyl oxidase, which is activated by copper. So what's packed with gelatin and copper? Jell-O and oysters, respectively. "This is something you'd take 30-60 minutes before activity," says Baar. Knowing it's going to be tough to convince athletes to gorge on these foods just prior to exercising, he's developing supplements instead. "These nutritional interventions we've identified should improve your performance." Baar sums it up: "The result of all this research is that we're going to have really new ways to increase muscle mass and muscle strength."

Or, put another way, an athlete with robust connective tissue will be at an advantage because his muscles will be able to do more with less. After all, he's no longer working out just half his body–he's targeting the whole machinery.

Your "matrix": reloaded

SCULPTING HEALTHY, well-rounded muscles doesn't only require that you bomb them with heavy weight. (Though that certainly helps, of course.) New science shows that light sets of low-impact exercises specifically target your connective tissue—tendons, ligaments, and the "extracellular matrix"—and allow for "improved energy transfer to the overall muscles" when you work them out, says Luke O'Brien, a physical therapist at Howard Head Sports Medicine in Vail, CO.

In other words: The stronger and more robust your connective tissue, the stronger your overall muscles. But remember: This collagen-building workout should be considered supplemental training. Do it independently of your normal routine.

BY SEAN HYSON, C.S.C.S.

DIRECTIONS

Perform this workout at least six hours before or after your normal training. For example, if you lift weights at night, complete this routine in the morning. Perform four sets of 15 reps for each exercise, moving slowly so that it takes five seconds to complete each repetition.

1

SINGLE-LEG DEADLIFT

Raise your right leg slightly behind you so you're standing on your left leg, and bend your hips back. Try to bend until your torso is parallel with the floor, or you're about to lose your balance. Your lower back should be flat and your right leg in line with your torso. Squeeze your glutes to return to the starting position. Complete your reps, then repeat on the opposite leg. That's one set.

2

CALF RAISE

Stand on a block or step (hold on to something for support if you need to). Bend your knees slightly and sink your heels toward the floor until you feel a stretch in your calves. Rise back up until you're standing on the balls of your feet. Complete your next set with your knees locked the entire time; alternate sets of bent-knee calf raises and straight-leg calf raises until you've completed four total sets. If the reps feel too easy, hold a dumbbell in each hand.

4

REVERSE LUNGE

Hold a dumbbell in each hand and step backward. Lower your body until your rear knee nearly touches the floor and your front thigh is parallel with the floor. Complete your reps, then repeat on the opposite leg. That's one set.

3

LATERAL BAND WALK

Loop a band around your shins and assume an athletic stance (hips and knees bent) so there's tension on the band. Take a wide step to your left, then bring your right foot in to return to the athletic stance, keeping the band taut. Each step is one rep. Repeat in the opposite direction (that's one set).

Hoodie: H&M
Watch: G-SHOCK
Shorts: ASICS
Sneakers: BROOKS
Want it? See page 158.

Styling by Delvin Lugo; Grooming by Megan Lanoux/Exclusive Artists using Baxter of CA

5

T PUSHUP

Grasp light dumbbells and get into pushup position with your body straight. Perform a pushup, then row the dumbbell on your right side. From there, rotate your torso to the right, raising your right hand overhead so your body faces 90 degrees to the right and forms a "T" shape. Repeat on your left side.

6

WRIST EXTENSION

Hold a light bar in both hands and sit on the edge of a chair. Rest your forearms on your thighs with palms facing down. Extend your wrists, raising them so your knuckles face the ceiling.