Histology of Training

A thesis submitted by Don Tanchin as consideration for the rank of ShoDan in the Matsubayashi Ryu style of Shorin Ryu karate.

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Introduction

The martial arts were born out of a time when each day brought real opportunities for self preservation. Back then, karate prepared a man to defend himself. Today most of us train not as warriors for literal battle, but to fight the disease and decay brought on by the information age and a sedentary lifestyle. Interestingly, karate remains timeless and perfectly suited for both.

We already know that constant training promotes healthy living and happy lives. We also know that healthy eating and rest play a large part as well. But what exactly is going on in our bodies when we train? How do muscles grow? Why is that other guy faster than me? At the same time, karate training can push us over the limits of our physical abilities. Why doesn't that thumb go back to its normal position? Why have I lost feeling in my toes? In order to find that balance, it may help to better understand our *histology* or, the body's tissues and how they work. Here I examine different tissue types that make up the human form. I researched medical journals, books and current strength training manuals to unlock their unique cellular characteristics. I present this information as a series of facts mixed with conclusions from related clinical research. With this knowledge of how our tissues work and how they respond to conditioning, I hope you will train smarter, avoid injury and enjoy your karate-do.

The spirit of Karate is meant to not only benefit all those who practice but also those who encounter the practiced. Karate is a holistic, mind, body, spirit approach to life with the goal of benefiting all members of society and just as there are many people with different strengths and weaknesses working together for the common good, so too our bodies contain many members with different forms and functions all working in accord to maintain our wellbeing.

Skin

When we hear the term 'tissue' most of us think of skin. Right out of the box, skin is soft and easily bruised but according to Shoshin Nagamine, the hands and feet of a karate student "are traditionally hardened or toughened by striking and kicking makiwara to such an extent that they become powerful weapons." So what exactly is skin and how does it react to this repetitive impact conditioning?

Your skin is constructed of two main layers: the sub-layer or *dermis* and the exposed layer or *epidermis*. The dermis is a multi-functional layer of *adipose* or fatty tissue that contains hair follicles, nerves, capillaries, sweat glands and ducts. The epidermis is our simpler, outer protective layer and, as you can see in the figure below, is further sub-divided into sub-layers. The *stratum basale* is the cell layer where the dermis ends and the epidermis begins. It is this layer of basal cells that rapidly divide and push outward to provide new cells to the epidermis. The new cells begin to bind together and flatten as they are pushed away from the basal layer by newer cells. As the cells flatten, their contents are slowly replaced by the protein *keratin*. The middle layers are defined by this level of *keratinization*. Once a cell has reached the surface layer or *stratum corneum*, it consists almost entirely of waterproofing keratin and no longer even resembles a cell. The figure below illustrates the difference in the stratum corneum layer between typical thin skin and the thick skin found in the heel of the foot or palm of the hand. In contrast, fingernails and toenails are nearly solid keratin.

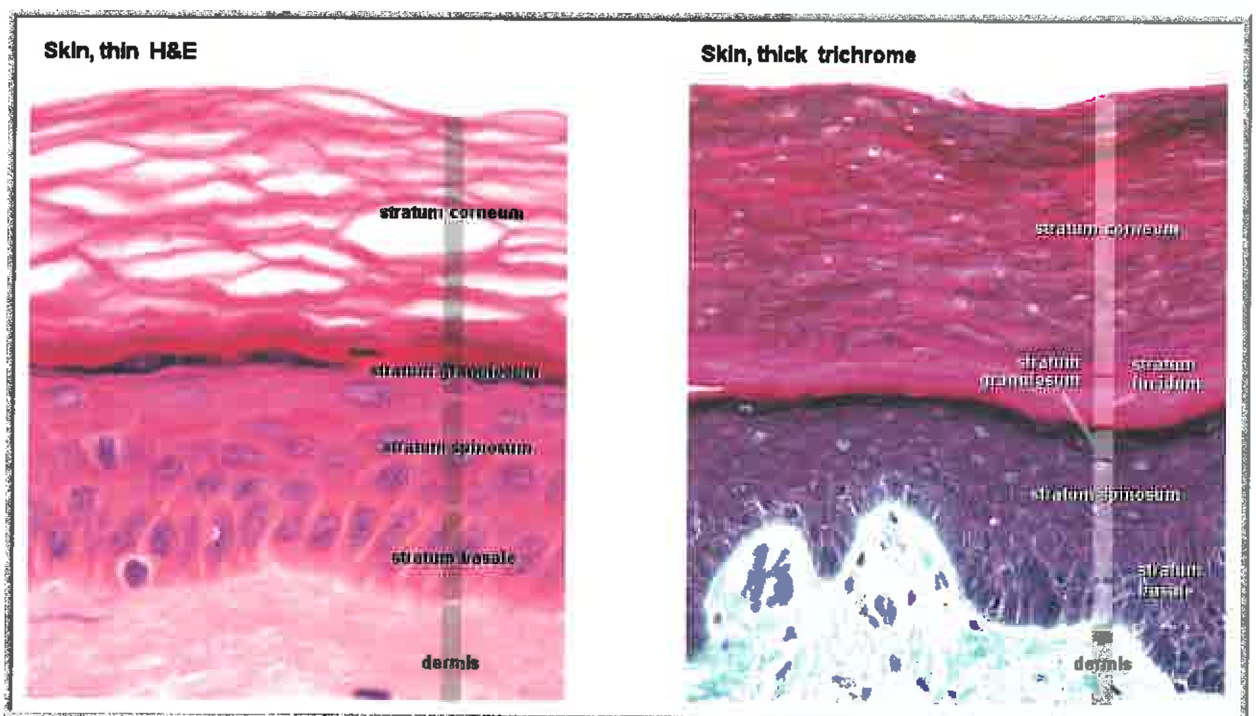

Figure 1 - Thin vs. thick skin views

So how do we cause the skin of our hands and feet to become like weapons? Skin reacts to repetitive impact (makiwara) through a process called *hyperkeratinization*. When the skin is repeatedly abraised or subjected to repetitive forces, it senses a need to improve the epidermal layer and increases the keratinocyte activity in that area. As more keratin is delivered and the area continues to be subjected to pressures, the stratum corneum retains more layers of dead keratinized cells. On average, your thick skin consists of 15-20 layers with fewer layers as you approach the less impacted parts of the body. One obvious benefit is that thicker skin improves the protective barrier over the underlying nerves and bones. The exact reason why this process takes place is still unknown despite the fact that calluses are mentioned as far back as the reign of Cleopatra.

Facts Box

- Your skin is considered an organ and consists of around 800,000 cells.
- It weighs 6-9lbs and covers almost $21ft^2$.
- It takes skin cells about 4 weeks to travel from the basal layer to the surface.
- We shed roughly 30,000 skin cells per minute or about 1lb of skin a year.

Muscle

Muscle is the largest tissue in the body and its function is to generate force. Interestingly, muscles can only contract. To go back to their original shape they relax and passively respond to *antagonist* muscles that contract in the other direction. There are three types of muscle tissue: smooth, cardiac and skeletal. Smooth and cardiac muscle tissue are classified as *involuntary*, meaning they function automatically, usually in a rhythmic pattern, to provide some function such as breathing, digestion or the circulation of blood. Our focus is on the *voluntary system* of skeletal muscle.

So what exactly is a muscle and how does it work? A motor unit consists of the muscle cell, and its corresponding motor neurons. As you can see in Figure 2 below, muscle is made up of bundled strands (*fascicles*) like bungee cord. A fascicle is in turn a bundle of *myofibers* or muscle fibers. These fibers are actually cells but unlike a typical cell with a single nucleus, muscle cells can contain 100 or more nuclei. That's because while some muscle cells may be .0004 inches thick they can reach 12 to 16 inches long. These nuclei work together with the motor neurons (discussed later in Nerves) to trigger the instantaneous release of chemicals throughout the entire muscle fiber. Subsequently, the myofibers are bundled *myofibrils* and finally, myofibrils are bundled *myofilaments*. It is in these tiny individual myofilaments where the heavy work actually takes place.

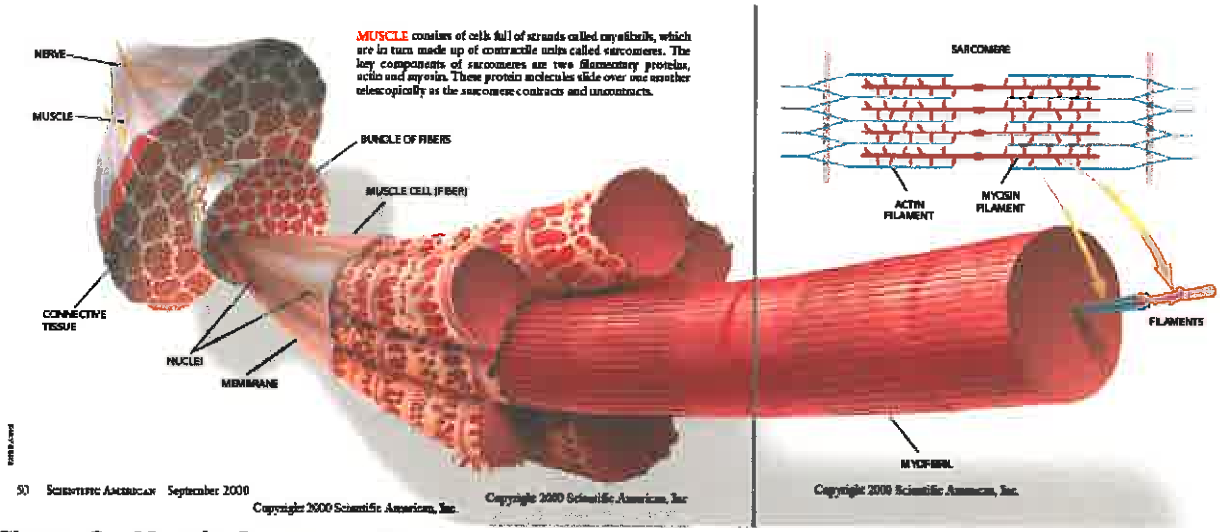

Figure 2 - Muscle Components

Microscopic views of the myofibrils reveal the proteins *myosin* and *actin* arranged in an interlocking filament pattern resulting in light and dark bands. The space between each dark band is called a *sarcomere.* The figure below illustrates how the center of the myosin filament is anchored in the middle of the sarcomere surrounded on each side by six actin filaments. According to the "sliding filament" theory, contraction occurs when nerve impulse are sent to the motor neurons. Calcium, and subsequently *adenosine triphosphate* or ATP, are released into the sarcomere causing the myosin thick filament to pull the actin thin filaments in from both sides.

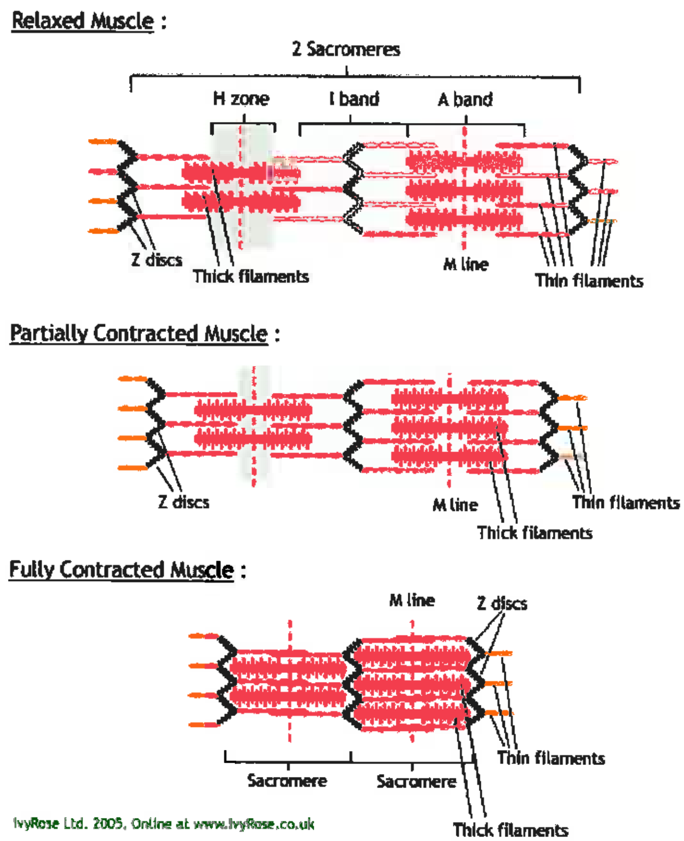

Figure 3 - Sliding Filament Theory

So how do our muscles react to conditioning? One theory is that under significant mechanical loading, muscle fiber begins to tear. The body reacts by producing more actin and myosin proteins that not only repair the damage but also add additional proteins anticipating this new environmental condition. The addition of myofibrils and subsequently thicker muscle fibers is known as *hypertrophy.*

How can I become as fast as the other karate students? While form and practice will improve your speed, genetics could play a larger role than you think. The myosin protein chain comes in 3 variations or *isoforms*. Type I is categorized as the slow twitch or "red" muscle fibers and types IIa and IIx are fast twitch or "white" muscle fibers. Type IIx fibers contract approximately ten times faster than type I fibers with type IIa somewhere in between. Type I slow twitch muscles function aerobically and require a steady supply of oxygen to handle light to moderate loads over a sustained period of time. For short bursts of faster, heavier loading, Type II fast twitch muscles are recruited. These muscles can react anaerobically but only for very short durations since oxygen is necessary to continue muscle contraction. The typical adult packs equal number of slow and fast isoforms; however we are not all created equal. The quadriceps muscle in sprinters can have an abundance of type II isoforms (70% to 95%) while marathon and endurance athletes will pack a majority of the type I isoform. Since type IIx fast twitch fibers are larger than type I slow twitch fibers, it is then speculated that as muscles begin protein remodeling, the type II fibers will grow at a faster rate. Recent reports suggest that type IIa fibers may be converted to type IIx. Research is still being done to determine if world class athletes achieve high concentrations of their particular isoforms predominantly through training or if they are genetically predisposed.

Some recommendations to target type II muscle and improve response times include:

- Stretching before and after you work out.
- Lift weights using over 60% of your one rep maximum.
- Train at over 75% of your maximum speed.
- Plyometric training (see Connective Tissues)
- Over-speed training such as running down hill.
- Sufficient rest especially 24-48 hours prior to the actual competition.

Facts Box

- There are approximately 750 different muscles in the human body.
- While we never add new muscle fibers "myofibers", we do lose some with age.
- Without exercise, a muscle can lose about 20% of its mass in two weeks.
- Muscle accounts for 23% of a woman's body weight and 40% for men.
- During vigorous exercise, two-thirds of the heart's output of blood goes to the muscles, compared to only one-fifth at rest.

Connective Tissue

Tendons and ligaments are types of *connective tissues.* Primarily composed of collagen and elastin, tendons and ligaments may be laterally flexible, but are not considered linearly elastic. While *fibroblasts* cells maintain the collagen/elastin matrix, your tissues become less active and less dense as we age. The collagen and elastin protein composition also varies along the tissue as you approach the point of connection to the bone. It is the "Sharpey's fibers" that penetrate and blend into the bone's periosteum. It is at this point of *bone insertion* that severe injury typically occurs.

Research shows that under mechanical stress, a ligament can stretch approximately 6% of its original size before reaching *ultimate elongation* beyond which it cannot return to its original size. A complete rupture occurs at just under 8% on average. This demonstrates the importance of proper technique in that with almost every kick or strike we deliver, we have a 6% margin of error between healthy exercise and a debilitating injury. Tendons are less elastic than ligaments.

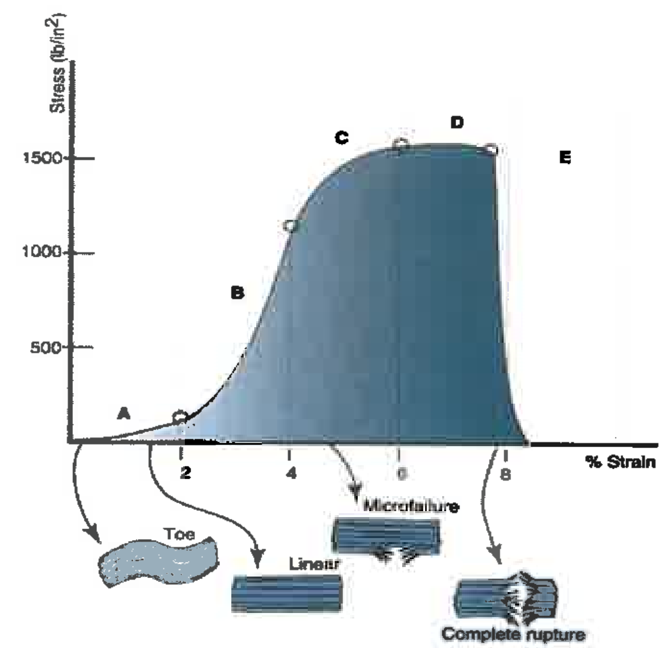

Figure 4 - Stress Analysis of Connective Tissue

Injuries to tendons and ligaments are classified based on their severity:

- **First degree** ~ Minor stretching or tearing can cause mild pain, tenderness, and swelling. Full functionality is retained but full recovery from pain and discomfort can take up to 4 to 6 weeks.
- **Second degree** ~ You may feel something tear, pop or snap followed by swelling and tenderness. Bruising may occur after several days and some functionality may be lost. Full recovery can take up to 1 or 2 months.
- **Third degree** ~ When a joint slips out of it's socket, there is significant swelling, tenderness, and loss of functionality. Full recovery can take up to 3 months. Surgery may be required.

It is important to have a doctor examine any significant injury. If you suffer a ruptured tendon and allow it to heal on its own, the gap could fill in with scar tissue. This could result in restoring a muscle/tendon length different from the original, compromising your ability to return to full strength. Injured ligaments could also present complications if not properly treated. Some research shows that while sutured ligaments are more likely to heal properly, ligaments left to heal on their own may not restore the original shape or length. The difference could result in weakness or improper joint motion leading to secondary damage to cartilage, other ligaments or given time, improper alignment of the back.

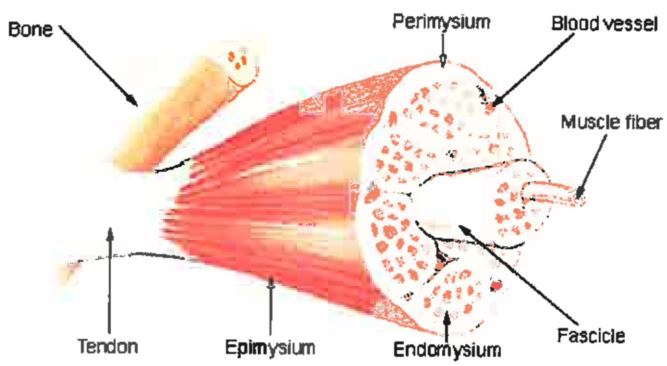

Figure 5 – Tendon

Tendons connect muscle to bone. Muscle tissue is made up of bundles of bundles of muscle fiber. These bundles are contained or separated by several types of connective tissue. These connective tissues (*epimysium*, *perimysium*, and *endomysium*) all come together at the ends of the muscle to form the tendons. The ends or *entheses* of the tendons are then connected to the bone.

It is important to note when strength training that muscles develop and adapt much faster than connective tissues. Before pursuing any significant strength training, such as body building, make sure you include a phase of training aimed at preparing your bones, tendons and ligaments to handle the anticipated increased muscle forces. How to achieve this is still under research. The best approach is to load your musculoskeletal infrastructure using moderate weight for 6-12 months. While inconclusive, it is widely accepted that loading your connective tissues should result in the cellular remodeling needed to handle the increased activity and forces. Isotonic training with weights is said to provide the most benefit during this phase of your training. For speed training, sensor receptors in the muscles and tendons report the amount of tension to the brain during the full range of motion. At the end of the range, the brain triggers a *stretch-shortening cycle* (SSC) to prevent rupture. *Plyometrics* is a technique of using the SSC response to increase muscle reaction and efficiency.

Ligaments help dictate the direction and range of motion of the joints. They connect bones to other bones and attach through bone insertion just like tendons. Ligaments are constructed of reticulated bundles of collagen fibrils not unlike the bundled assembly of muscle fibers. One difference however, is that collagen fibers do not enjoy the abundance of nuclei that muscle fibers do. Fewer nuclei mean fewer capillaries and

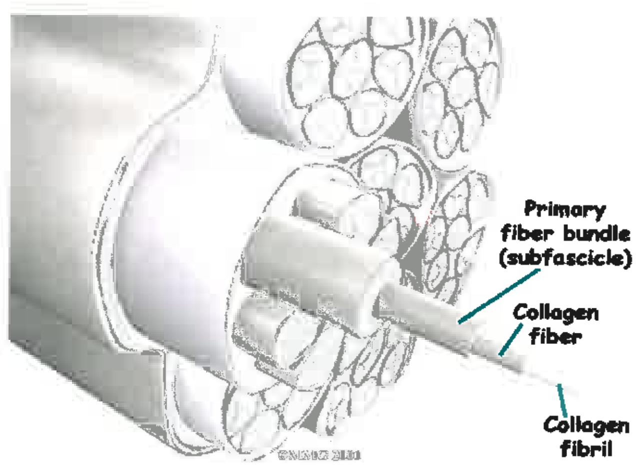

Figure 6 – Tendons & Ligaments

without a rich supply of nutrients from the blood, ligaments will develop at a slower rate than muscle.

Facts Box

- Tendons have the highest tensile strength of any other soft tissue in the body.
- Collagen is the most abundant protein in the human body.
- Collagen fibers have a tensile strength close to that of steel.
- Ligaments can lose up to two thirds of their strength and elasticity as we grow older.

Bone

Bone is also a connective tissue. It provides the physical infrastructure to support the body and its parts. It's easy to think of bone as a solid member and while bone is very rigid compared to the other tissues, it is a remarkably dynamic system, capable of responding to stresses and adapting to mechanical loads.

The bones found in the arms and legs are referred to as the long bones. The ends (*epiphysis*) are covered in *articular cartilage* providing protection against bone on bone wear. The middle section (*diaphysis*) is a straight hollow shaft filled with bone marrow. This tubular structure is composed of unique cells called *osteons*. These cells derive their strength from being long and close together. This cortical or compact bone is covered with *periosteum*; a thin fibrous membrane. The transitional section of bone between the diaphysis and the epiphysis is the *metaphysis*.

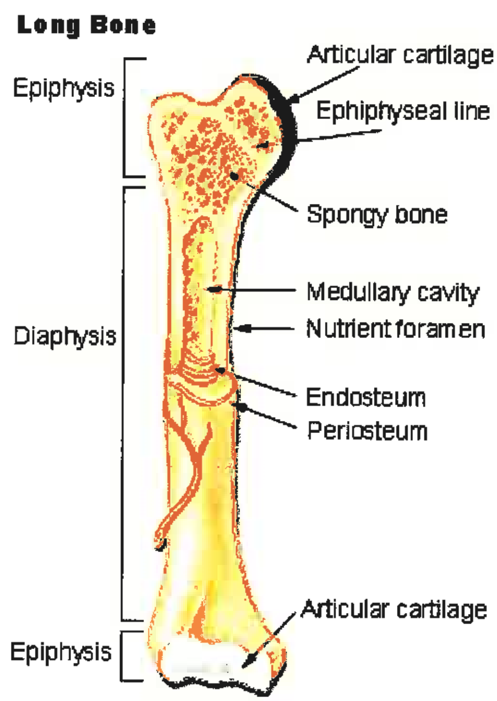

Figure 7 - Long Bone

Three kinds of cells are responsible for the direct care and feeding of our bones. *Osteoblasts* deliver the calcium/collagen combination that replenishes the hard but flexible bone matrix. These osteoblasts mature to become *osteocytes*. Osteocytes work to manage the calcium levels as *osteoclasts* break down unhealthy bone and release calcium and phosphate into the blood. The percentage of each of these cell types varies as we grow older or when a calcium deficiency occurs as with osteoporosis.

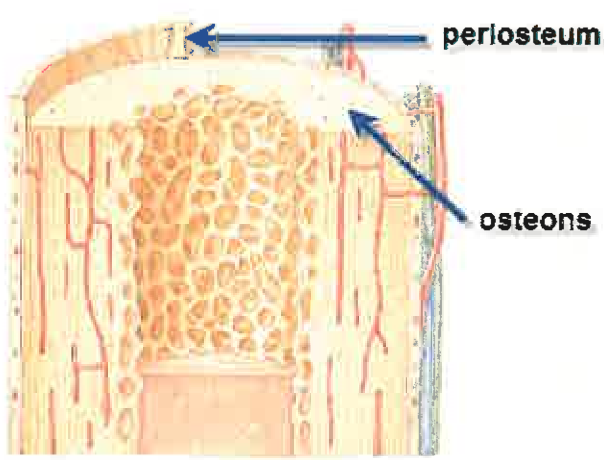

Figure 5 - Bone cross section 8

Bone strengthens itself by concentrating osteoblasts wherever mechanical loads are applied. The osteoblasts deliver additional collagen fibers that develop thicker bone tissue with a greater density. But be patient. It requires months of consistent loading and conditioning to realize any significant bone remodeling. Further research has shown that static loading does little to promote increased density while dynamic exercise, under moderate to high loads, can produce more significant results.

Facts Box

- There are approximately 206 bones in the human body.
- Over half of our bones are located in the arms and legs.
- The strength to weight ratio of bone is six times that of steel.
- Bone is the only tissue that repairs itself with new tissue, not scar tissue.
- The hyoid bone in the throat is the only bone not touching another bone.

Nerves

The brain uses nerves to gather information from and send appropriate responses to the body. The spinal cord and brain together define the *Central Nervous System*. The approximately 100 billion nerve cells remaining make up the *Peripheral Nervous System* branching out to all parts of the body. These two distinct systems cooperate in a feedback/response relationship where *afferent fibers* carry information from tissues and cells to the CNS (feedback) and *efferent fibers* carry information from the CNS to the muscles and glands (response).

Nerves can range from over 1 cm in diameter to much less than 1 mm. The further they get from the CNS, the smaller they become. All nerves are protected by a *myelin* *sheath*. This thick fatty covering is made up of *glial cells* and performs the following functions:

- improves the speed of communication
- transfers nutrients from capillaries to neurons
- protects against infection
- removes degenerated neurons

There are two methods that the CNS/PNS uses to regulate muscle for force production: the rate of firing neurons, *twitch and tetanus* and the number of active motor units it employs, *recruitment*. Nerve impulses, or *action potentials*, are less than one-tenth of a volt and last less than a millisecond. One impulse, or twitch, triggers a muscle response but just for that brief moment so more impulses are needed to continue the force production. The CNS sends impulses at greater frequency to handle larger loads to the point of tetanus or fully sustained contraction (see figure below).

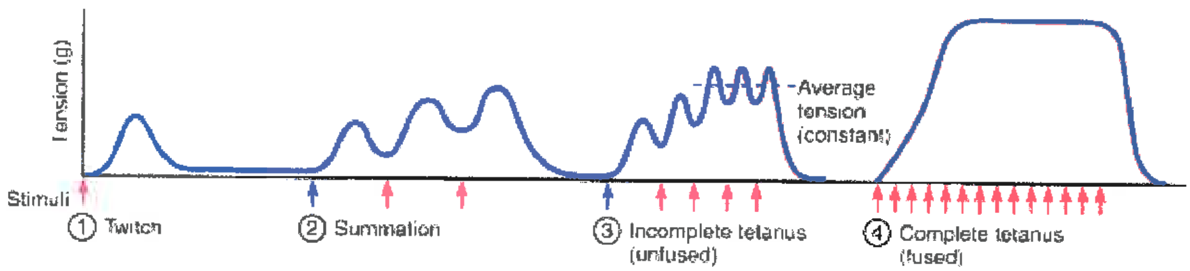

Figure 9 - Twitch and Tetanus

At the same time, the CNS will 'recruit' only the amount of muscle it needs by empowering an appropriate number of motor units. Light loads require fewer motor units while heavy loads could involve all of the participating muscle.

When most people begin a training program, it is the neural responses that adapt first. These early improvements last a few weeks while our bodies determine the full tetanus and recruitment capabilities of our motor units. After that, neural adaptation levels off and additional strength is gained through muscle growth. Keeping our nervous system fully adapted requires persistent full body training like that of Karate and other martial arts. Any additional improvements might be found from herbal supplements claiming to improve myelin growth but I make no recommendations.

Conclusion

Anyone wishing to improve their health must exercise. There are no shortcuts. There is no magic pill. Exercise in itself is the process of pushing our body beyond its comfortable range of function in order to exact an adaptive response. In other words, we must deliberately damage ourselves in order to become faster and stronger. But since the body is such a complex and dynamic system, we have to be careful. The tissues of our bodies are not only susceptible to acute damages, such as strain and rupture; they can also be subject to overuse injury as well.

The key to safe conditioning is a balanced strategy of calculated physical destruction. First, know your limits. Then begin any new regimen with a phased approach to prepare your slower developing infrastructure. Always practice sufficient stretching and proper technique while you train and good nutrition with the appropriate amount of rest when you don't. I now realize how paramount nutrition is when meeting the needs of the millions of ravenous proteins and unrelenting chemical reactions that repair and improve those tissues that are pushed to new levels.

When Chotoku Kyan said "A mastery of karate does not depend on the learner's physical constitution, but mainly on constant practice" , he understood what man had learned from generations of physical conditioning. There was no way to know how or why but thanks to advances in research and the advent of the electron microscope, we are just now beginning to figuring it out.

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Figure 2
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