Muscles

Form, structure, function and injury

Construction – from inside to out

Every muscle is made up the same way. Muscles can be long, short, fat, flat, bulky, lean etc etc, but they all have exactly the same structure. They are present all over the body, whether they have been trained, or left to degenerate. At any time during a lifetime, a muscle can be trained to recover, to maintain or to increase its strength. When increasing its strength, the muscle can be better informed by the nerves giving it orders, and it can increase the number of the smallest unit in order to grow from the inside out.

The smallest unit is a sarcomere, of which there are between 2,000 and 2,500 in every 10mm of muscle fibre. The way each and every sacomere works is exactly the same – whether the muscle working then lifts weights, causes jumping or simply swallowing. The sacomere has a wall at each end – the Z-disc – and inside a construction of protein filaments, most importantly actin (thin) and myosin (thick). (See diagram 1,2,3.)

Diagram 1

Recovered from - http://www.foodnetworksolution.com/wiki/word/1325/myofibril
The myosin heads engage on the actin filaments, and then “row”, moving all the actin filaments towards the sarcomere’s middle, which pulls the outer walls (the Z-discs) towards each other. This shortening is repeated over many thousands of sarcomeres, and in this manner the muscle as a whole becomes shorter, which contracts. This is called **concentric work** in a muscle. Examples are rising to demi-pointe (concentric work of the plantar flexors), or doing a pull-up (concentric work of the biceps brachii and its synergists).

The opposite happens in order for the muscle to become longer again, the actin slides back over the myosin and therefore the sarcomere is lengthened again. This is called **eccentric work**. Examples are lowering an extended leg (eccentric work of the hip flexors), or bending the body forward when standing up straight (eccentric work of the hamstrings).

When the muscle is working, and not becoming longer or shorter, the heads of the myosin are still engaged, in order to not let the actin filament slip past. This is called **isometric work**.

Every myosin engagement needs energy, but this will be discussed later.
Now let’s look at the build up, how all these sarcomeres make up a whole muscle.

Diagram 4

This diagram (4) shows the structure of a whole muscle, made of fascicles, each made of fibres (cells), each of which is made of myofibrils, which are made of the basic element the sarcomeres (see above).

Every part of the structure is coated in fascie (soft connective tissue), and has blood supply (in and out) as well as nerves. The blood supply ensures the delivery of oxygen, minerals and nutrients, as well as the removal of waste products. Nerves must reach every cell, because a muscle cannot work without an impulse from the brain (a command). The exception to this rule are the heart muscles which generate their own muscle contractions.

Through training there are theoretically two ways to increase the size of a muscle. The first, hypertrophy, is when the cells increase in size as the actin and myosin filaments increase in size. Today it is generally accepted that this is the principle method of gaining strength and volume of a muscle.

The second method is hyperplasia, which is an increase in the actual number of cells (fibres) in a muscle. Obviously this happens during growth periods, but is thought to happen less as a direct result of training. (See diagram 5.)
Striated, non-striated and heart muscles

In diagram 4, above, the sarcomeres are lined up, creating stripes. This is true for the striated muscles – the muscles for holding and moving the framework. They are controlled by the animalistic nerves (conscious control).

When the sarcomeres are not lined up, the muscle is non-striated. Examples are the muscles of the digestive system. They are controlled by the vegetative system (subconscious control.) An example of such subconscious activity is the peristaltic activity of the digestive system.

The third category of muscles is the heart muscles. These are also striated muscles – but are controlled by the vegetative nerves, not the animalistic nerves.

Fast and slow twitch fibres

There are two types of muscle fibre which have important qualities, which make huge differences to the way a muscle works. Remember no muscle is made entirely of either Type 1 or Type 2 fibres, but it can be generally said that some muscles have predominantly slow – or fast – twitch fibres. The exact balance is genetically programmed, and can only be changed to a certain extent by training.

Slow twitch (Type 1) fibres are more red when examined, due to the greater number of mitochondrion and blood vessels. (Think of beef, lamb and pork). This means they are better able to produce aerobic energy, which results in production of energy which can be maintained for longer periods of time. In turn, this means that the muscle with more Type 1 fibre content can produce work over a long time, and will not tire easily. The aerobic process takes longer than the anaerobic
process to produce energy, therefore the muscle is adapted to work slower (=slow twitch). Examples of mainly slow twitch work are adage or marathon running.

Fast twitch muscles (Type 2 fibres) are the opposite. They are more white when observed (think chicken, turkey. They use predominantly anaerobic process for their energy production, resulting in more instant power and a higher amount of energy production. But they tire more quickly than Slow Twitch fibres and produce lactic acid - which (as an acid) turns the muscle tissue from alkaline to acid. In this acidic environment the muscle is eventually prevented from working and therefore the intense activity eventually is forced to end. An example from sport is the 100m sprint, which is maximum effort for 9 seconds, but this velocity cannot be maintained for greater distances. In dance one needs anaerobic activity for very explosive jumps or lifts, and these also cannot be maintained for long periods of time.

The amount of change which can be achieved through training varies from author to author, but the principle of “A sprinter is born, a marathon runner is trained” seems to hold true – meaning genetically one is blessed with a high percentage of Fast Twitch fibres from birth; whereas with training one can always increase ones Slow Twitch fibre percentage.

<table>
<thead>
<tr>
<th></th>
<th>Slow Twitch</th>
<th>Fast Twitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capillary density</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Mitochondrion density</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Aerobic ability</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Anaerobic ability</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Power</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Fatigue resistance</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Contraction time</td>
<td>slow</td>
<td>fast</td>
</tr>
<tr>
<td>Motor unit size</td>
<td>small</td>
<td>large</td>
</tr>
</tbody>
</table>

Internal and external muscles

Muscles are divided into internal (or intrinsic) and external (or extrinsic). The two have differing functions and are specialized to perform these roles. The intrinsic muscles’ role is to support and stabilize joints, while extrinsic muscles move bones. A combination of the two is used to hold posture. While extrinsic muscles may seem more desirable (optically), the role of the intrinsic muscles is far more important for dancers. Without them, there is no stabilization and the outer muscles must try and compensate, thereby losing the ability to do their own job. When stabilizing occurs from the inside, the extrinsic muscles are relieved of working unnecessarily, and are then able to achieve more when needed to perform work (=cause movement). This economy of movement is what typifies a dancers’ ease in carrying out extremely strenuous activity.

Well trained intrinsic muscles often contain more slow twitch fibres, and have a smaller motor unit size which makes fine coordination in these muscles easier than in extrinsic muscles with larger motor units.
Building extrinsic muscles often leads to bulky muscle mass (pectoralis major, trapezius, quadriceps femoris etc.), whereas intrinsic muscles can be strengthened and built up without adding optically to the body’s form.

Causing movement

Every muscle must be attached to bone otherwise it cannot move our framework. This happens logically at both ends, the proximal end (nearer the centre of the body) is (usually) called the origin and the distal end (further away), on the other side of a joint or two, is the insertion. The origin is usually the punctum fixum while the insertion is the punctum mobile. The punctum fixum remains fixed in space, while the muscle then contracts concentrically (see above), and the punctum mobile is then moved. This is similar to a door where the hinges are the joint, a man with a rope is the punctum fixum and the side with the handle is punctum mobile. The man stands still and pulls on the rope, the door moves.

These two points can reverse their roles, so that a new movement is caused. The door (now punctum fixum) in the example would then “pull” the rope, and the man (now punctum mobile) would be pulled towards the door!

Functions of groups of muscles

As Dr. L. Simmel says “A muscle rarely contracts in complete isolation” (Simmel, 2014). There are however a variety of ways of describing the work of muscles.

A) Concentric, isometric or eccentric

(see above)

B) Intrinsic and extrinsic muscle groups

(see above)

C) Synergists, agonists and antagonists

Agonist The primary mover muscle is known as an agonist (e.g. M. iliopsoas, when flexing in the hip joint to lift from passé when performing a développé).

Synergists Muscles which support or help the agonist (e.g. stomach muscles, M. rectus femoris, M. tensor fascie latae, M. Sartorius in the développé example).
Antagonists

Muscles which control or oppose the movement (here the Hamstrings).

Movement is always a combination of intrinsic and extrinsic; of agonists, antagonists and synergists; and a variety of isometrics, concentric and eccentrics. The names of the different groups are to explain different functions and characteristics of the muscles. All groups must all work together, to perform a smooth coordinated movement – this is coordination.

One form of coordination is intramuscular coordination, this is the coordination between various parts of one muscle – a good example is the M. rectus femoris. This central component of the quadriceps muscle is a two joint muscle, and has to cause flexion in the hip, while also straightening at the knee joint. The coordination of these two functions is intramuscular coordination. When it is improved the function of a muscle increases, therefore an increase in intramuscular coordination is another form of strengthening a muscle – highly desirable for a Dancer, as there is no gain in bulk of the muscle. Better intramuscular ability is due to better activation of the motor units.

The other form of coordination is intermuscular coordination, and this is better synergistic activity, in other words a more functional balance between muscles when working together. An example of this is when one learns a new movement which is tiring to begin with. After some weeks, the movement feels easier and freer – this is due to the better intermuscular coordination which the body has learnt.

Motor unit size

The motor unit size of a muscle is a description of how many muscle fibres (cells) are controlled by one nerve. The nerve has endings (similar to a trees branches), and these spread out inside the muscle to make contact with individual muscle cells. Muscles with a smaller motor unit size can be much more finely tuned than muscles with a large motor unit size. Intrinsic muscles tend to have small motor units (making them very controllable and well coordinated), perfect for stabilizing and making tiny adjustments.

Extrinsic muscles tend to have large motor units. This means they are not so precisely controlled – which is appropriate as their main job is moving the bodys’ framework.

With specific coordination training the number of muscle fibres actually fired by the commands from the nerves can be increased. In a normal situation the figure is ca. 60%, with training it can increase to ca. 90-95%. 100% is never reached, as a certain reserve is always kept free for emergency situations (“fight and flight” situations).

Muscle tone

A muscle can be described as hypertone (having too much tension) or hypotone (having too little). These are subjective terms, and vary from individual to individual. When an individual has a tendency to “hang in his joints” the muscle tone can be hypotone (fails to activate sufficiently), whereas when driving in stressful conditions one can often feel hypertone muscles of the neck and shoulder regions. No muscle is ever without tone completely.
Reciprocal inhibition

A hypertone muscle will inhibit its’ antagonist. Therefore it is often advisable to address the hypertone muscle before attempting to build up the hypotone antagonist. This is important because the inhibition is a neurological situation, which no amount of training can change.

Muscle injuries

Muscles can be injured by over straining, over stretching or by over loading. Terms and definitions vary widely in the literature, (see http://bjsm.bmj.com/content/early/2012/10/17/bjsports-2012-091448.full for a VERY detailed study of this). The extent of the depth of the subject can be seen here: https://www.thieme.de/shop/Sportmedizin/Mueller-Wohlfahrt-Ueblacker-Haensel-Garrett-Muscle-Injuries-in-Sports-9783131624710/p/000000000271220101 !!

The following table is a general guide:

<table>
<thead>
<tr>
<th>Injury</th>
<th>Cause</th>
<th>Symptoms</th>
<th>Treatment</th>
<th>Length of recovery (round about)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle ache (Z-Disc damage)</td>
<td>Over use, unexpectedly high intensity or too many repetitions. Often assumed to be linked to eccentric work</td>
<td>General soreness of the whole muscle, especially when using the muscle again</td>
<td>Warmth; light general activity; no intense work and no stretching</td>
<td>1 to 4 days</td>
</tr>
<tr>
<td>Muscle cramp (uncontrolled contraction without conscious command)</td>
<td>Normally dehydration, or overloading a muscle, especially when already contracted</td>
<td>Sudden uncontrollable contraction of the entire muscle, which doesn’t relax in the usual manner</td>
<td>Slow stretch, gentle strokes along the length of the muscle and slow rhythmical shaking of the muscle</td>
<td>Contraction length varies, from seconds to minutes – usually the longer it lasts the longer the after effects are felt</td>
</tr>
<tr>
<td>Pulled muscle (Fibres damaged, called a minor partial muscle tear in the illustration below)</td>
<td>??*</td>
<td>Painful cramp during activity – sometimes not very noticeable. Mostly one can carry on – but shouldn’t! Increasing lack of elasticity in the muscle. Pain when stretching,</td>
<td>RICE Later electro, detonising massage (proximal and distal from pain area) From 4th day return to activity if pain free. Stretching should</td>
<td>3 days to 2 weeks, but depends a lot on location, seriousness and care when returning to activity</td>
</tr>
<tr>
<td>Injury Type</td>
<td>Symptoms</td>
<td>Treatment</td>
<td>Recovery Time</td>
<td></td>
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<td>------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Rupture of muscle fibre (More fibres damaged, called a moderate partial muscle tear in the illustration below)</td>
<td>Immediate visible bleeding in muscle tissue (bruise), and hardening around the injured area. Pain when contracting AND stretching, exact pain location (“like a knife digging in”)</td>
<td>RICE Complete rest from activity for a week (minimum), electro, Lymph Drainage after 24 hours; after 5 days careful massage proximal and distal from injured location. Tape and where necessary avoidance of weight bearing</td>
<td>2 weeks minimum</td>
<td></td>
</tr>
<tr>
<td>Complete muscle rupture (complete tear of all structures)</td>
<td>Bleeding as above, sometimes with accompanying “snap” sound. Injured location can be felt as a “hole” in the muscle body. Complete lack of function</td>
<td>Appointment with emergency Doctor Bandage or tape to completely relieve muscle of any work, minimum 3 days. Then see above, with return to activity very slowly and pain free</td>
<td>Up to 3 months before complete work load restored</td>
<td></td>
</tr>
<tr>
<td>Contusion of muscle (bleeding in muscle tissue)</td>
<td>Traumatic blow to a muscle Bleeding in the tissue (often visible), pain when stretching and in contraction</td>
<td>RICE 2 days rest, then pain free mobilization and slow return to activity, warmth and Lymph Drainage. No massage</td>
<td>Up to 10 days, depending on seriousness</td>
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</tbody>
</table>

*Causes can be overloading a muscle before warming up, too sudden movements, unprepared workload, ignoring earlier signs of damage etc. The unexplainable question is why these injuries can occur to anyone, anytime, even when trained and carrying out regular and normal activities.
The fascia (Endomysium) is a soft connective tissue carpet around every single muscle cell.

Through training, the muscle becomes bigger, because the number and size of MYOFIBRILLE increases, NOT the number of muscle cells. This is called hypertrophy.

A damaged muscle (torn/ripped) is healed with scar tissue – not original muscle tissue. This means that once damaged, a muscle will never regain its full performance.

Muscle ache is damage to the Z-discs, which heals without scar tissue – the cell just repairs itself.

The late onset of muscle ache (often felt on the day following strenuous activity) is due to the build up of fluid in the damaged muscle tissue (a natural response to the damage – just as swelling after more serious injuries), which is then interpreted by the body as painful.

Muscle coordination training leads to an immediate increase in the coordination ability. This is one way to increase strength without building bulk.

Muscle size (hypertrophy), occurs on average after 12-15 training sessions.

Hypertrophy of the heart muscles will occur after aerobe training 3 times a week for 6 weeks.

With the exception of muscle ache (where warmth, gentle exercise and gentle massage is helpful), the rule to apply for all muscle injuries is RICE (Rest, Ice, Compression, Elevation). Things to avoid so that healing is not prevented are outlined in the HARM rule (Heat, Alcohol, Running=activity,Massage). Also avoid continually testing the injured muscle – healing cannot be spontaneous!!