Musculo-Skeletal Mechanics

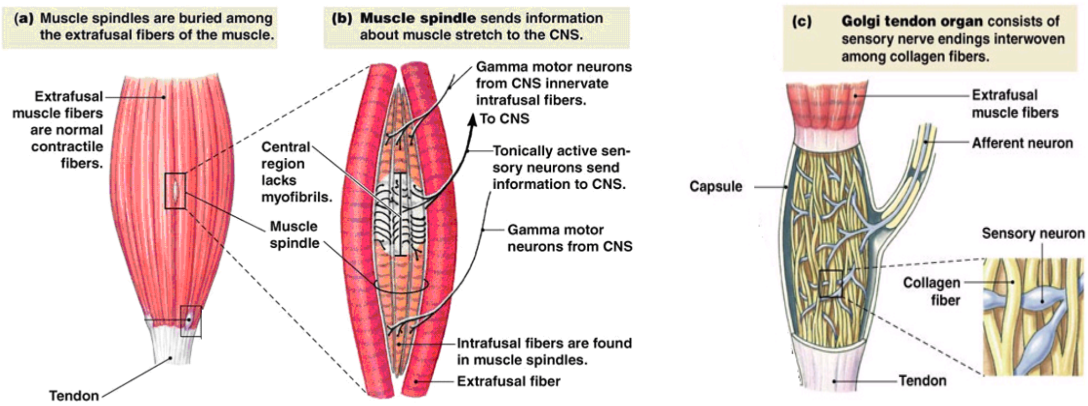
Learning Objectives

1. **To understand that skeletal muscle can function in a number of ways to provide both movement and stability.**
2. **To appreciate the variety of muscle shapes which contribute to function.**
3. **To understand why there are limitations to the function of skeletal muscle**
4. **To understand basic lever principles**
5. **To appreciate the role of skeletal muscle in maintaining core stability.**

NB. Before beginning this course, it would be helpful if you have read, and are familiar with, the information in the Skeletal Muscle Structure & Function course, also available on this site.

Muscle Reflexes

Within skeletal muscles there are two specialized types of nerve receptors that can sense stretch - muscle spindles and Golgi tendon organs. Muscle spindles are long and thin, and consist of tiny modified muscle fibres (intra-fusal fibres) and nerve endings, encased together within a connective tissue sheath. They lie between, and parallel to, the main muscle fibres. The Golgi organs are located mostly at the junction of muscles and their tendons (or aponeurosis).



Stretch Reflex

The stretch reflex helps control posture by maintaining muscle tone. It also helps prevent injury, enabling a muscle to respond to a sudden or unexpected increase in length. When a muscle is lengthened (or stretched), the muscle spindles are also stretched, causing each spindle to send a nerve impulse to the spinal cord. The spinal cord immediately sends an impulse back to the stretched muscle fibres, causing them to contract in order to resist further stretching of the muscle. This is the classical reflex arc. At the same time as this, a further impulse is simultaneously sent from the spinal cord to the antagonistic muscle group of the contracting muscle (i.e. the muscle opposing the contraction), causing the antagonist to relax, so that it cannot resist the contraction of the stretched muscle. This process is known as reciprocal inhibition.

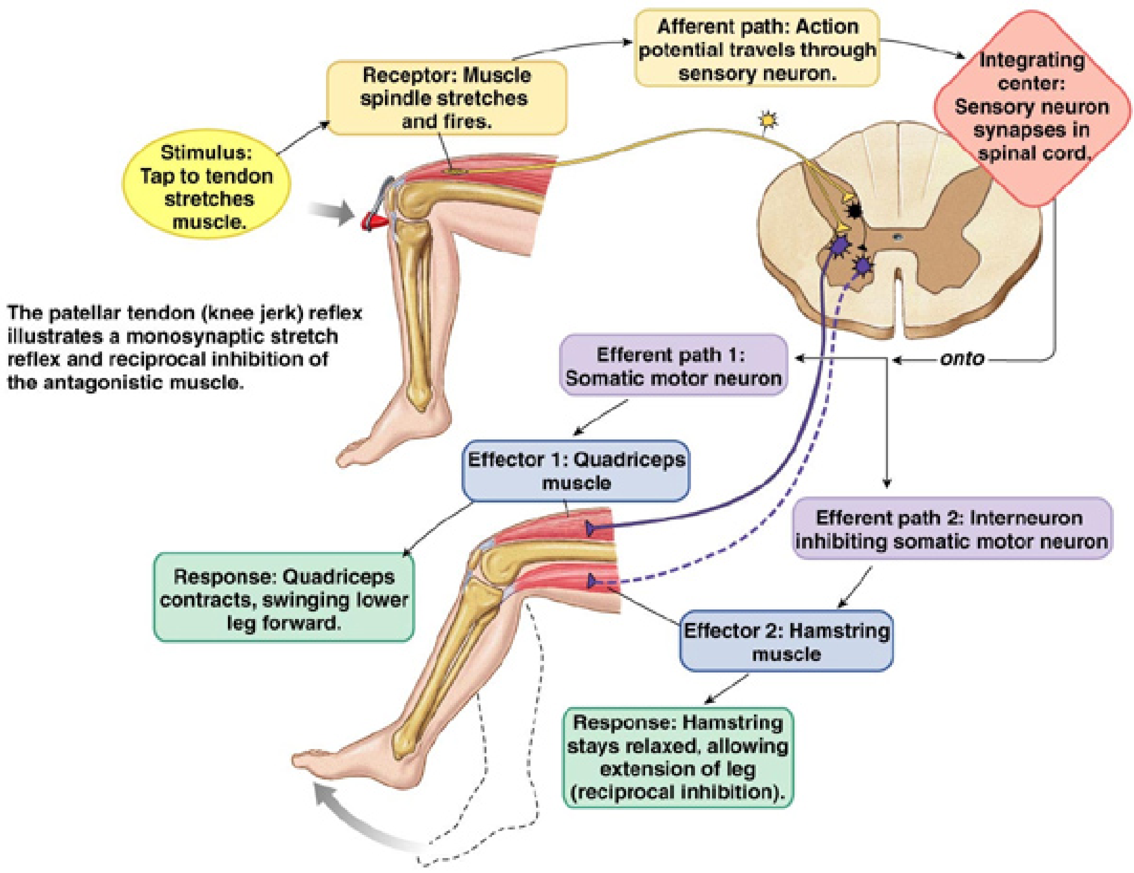
In addition, nerve impulses are also sent up the spinal cord to the brain to relay information on muscle length and the speed of muscle contraction. A reflex in the brain send more impulses back to the muscle to ensure the appropriate muscle tone is maintained to meet the requirements of posture and movement.

Also, the stretch sensitivity of the intra-fusal muscle fibres within the muscle spindle are regulated by gamma efferent nerve fibres arising from motor neurons within the spinal cord. In this way a gamma motor neuron reflex are ensures the smoothness of muscle contraction – without it the stretch reflex alone would result in jerky muscle movement.

The classical example of the stretch reflex in action is the patellar reflex;

The patella tendon is struck, causing a sudden stretch of the tendon, and a stretching of the quadriceps. This rapid stretch is registered by the muscle spindles within the quadriceps, causing the quadriceps to contract. This causes a small kick as the knee straightens suddenly, and takes the tension off the muscle spindles. Simultaneously, nerve impulses to the hamstrings, which are the antagonists of the quadriceps, are blocked, causing the hamstrings to relax.

Diagram of patella stretch reflex.

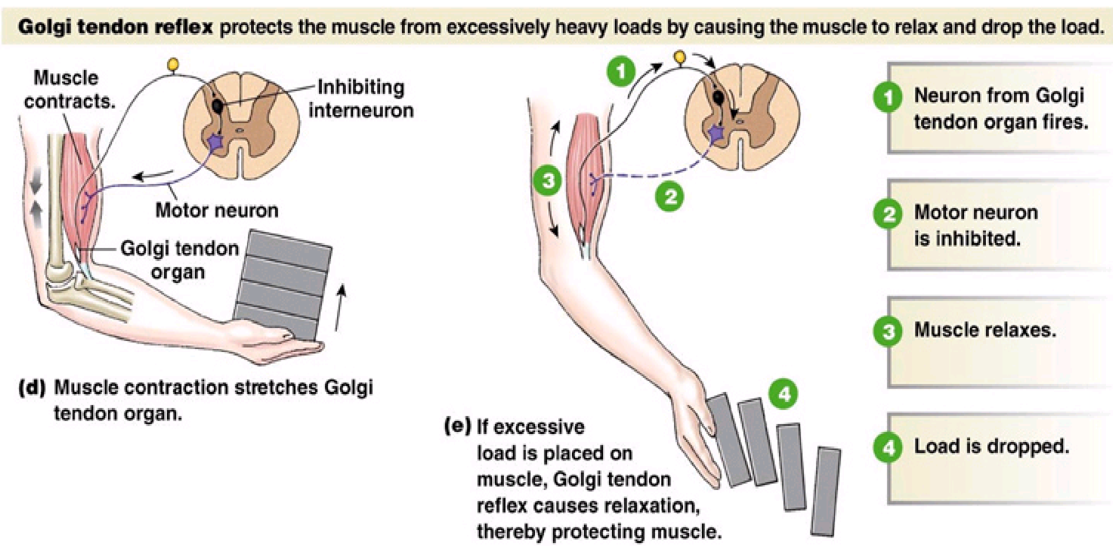


Generally, the stretch reflex works constantly to maintain the tonus of our postural muscles, enabling the body to maintain posture without conscious effort.

Deep Tendon Reflex (Autogenic Inhibition)

In contrast to the stretch reflex, this involves the reaction of Golgi tendon organs to muscle contraction, creating the opposite effect to the stretch reflex. When a muscle contracts it pulls on the tendons which are situated at either end of the muscle. The tension in the tendon causes the Golgi organ to send impulses to the spinal cord, inhibiting the motor nerves supplying the contracting muscle, causing it to relax. At the same time the motor nerves supplying the antagonist muscle are activated, causing it to contract. This process is called reciprocal activation. In addition to this, impulses are also sent to the cerebellum, and subsequent impulses are sent back to help re-adjust muscle tension.

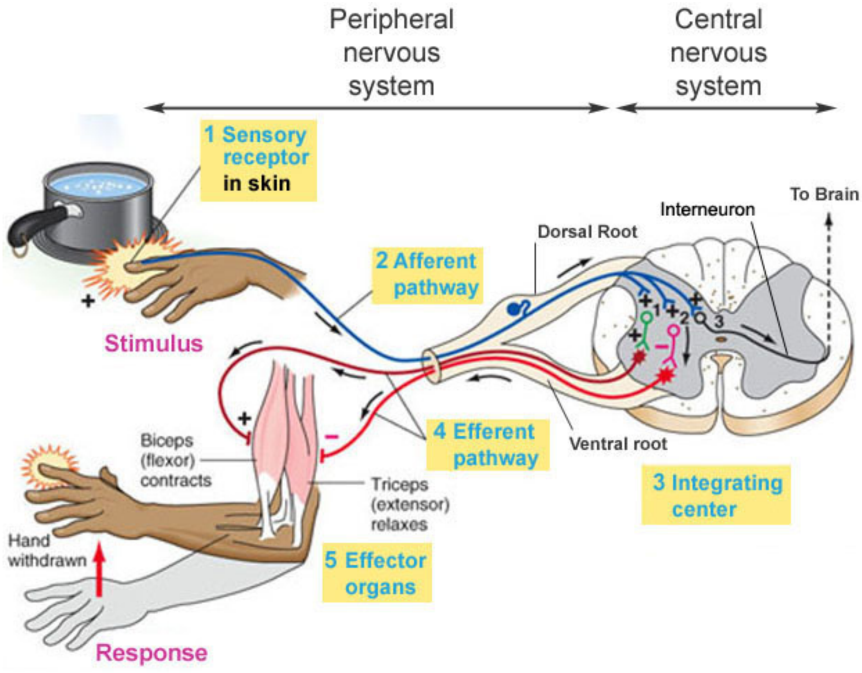
The deep tendon reflex has a protective function, preventing the muscle from contracting so hard that it rips its attachment off the bone. It is particularly important during activities such as running, which involve rapid switching between flexion and extension, but is also valuable in preventing damage when excessive strain is placed on the muscle.



Usually in normal movement there is insufficient tension in the muscles to activate the deep tendon reflex, whereas the threshold of the muscle spindle stretch reflex is set much lower, because it must constantly maintain sufficient tonus in the postural muscles.

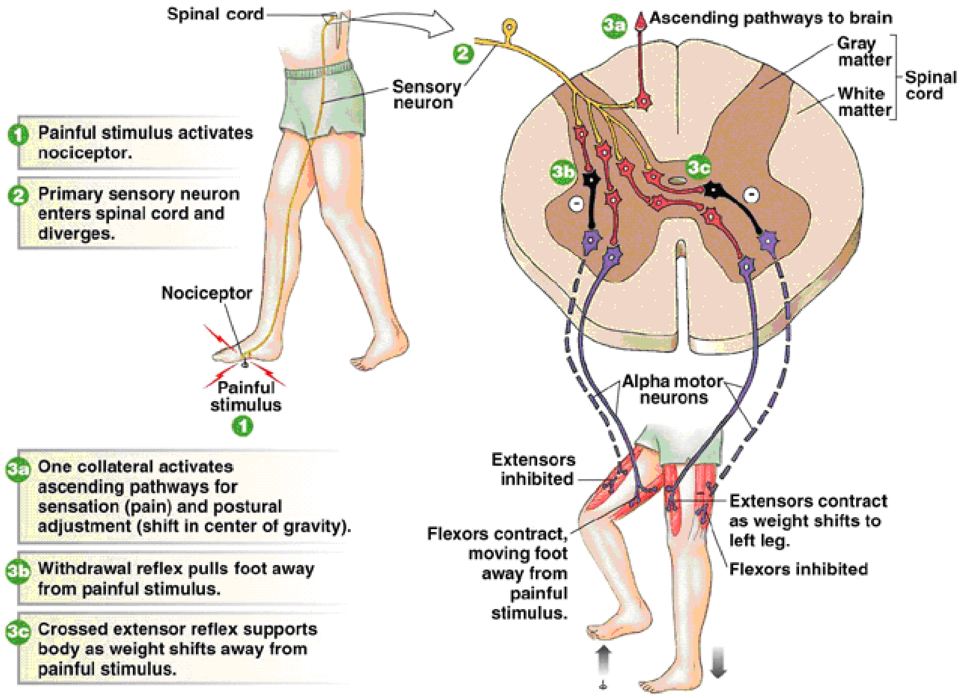
Nociceptive withdrawal reflex

The nociceptive withdrawal reflex (NWR) is a spinal reflex intended to protect the body from damaging stimuli. The classic example is when a person touches something hot and withdraws their hand from the hot object. The heat stimulates temperature and pain receptors in the skin, triggering a sensory impulse that travels to the central nervous system. The sensory neuron then synapses with interneurons that connect to motor neurons. Some of these send motor impulses to the flexors to allow withdrawal, some motor neurons send inhibitory impulses to the extensors so flexion is not inhibited – another example of reciprocal innervation. While all of this occurs, other interneurons relay the sensory information up to the brain so that the person becomes aware of the pain and what happened. The NWR is also known as the flexion reflex.



Crossed extensor reflex

The crossed extensor reflex is a withdrawal reflex on one side with the addition of inhibitory pathways needed to maintain balance and coordination. For example, stepping on something painful initiates a withdrawal of that leg. Since the quadriceps muscles (the extensors) were contracting to place the foot forward, they will now be inhibited and the flexors (the hamstrings) will now be stimulated on that same leg. So that balance can be maintained, the other leg, which would have been flexing, will now be extended to place the other foot in ground contact (e.g. crossed extensor), and that leg's flexor muscles, which were contracting, will be inhibited, and the extensor muscles will be excited.



Isometric and Isotonic Contractions

A muscle will contract upon stimulation in an attempt to bring its attachments closer together, but this does not necessarily result in a shortening of the muscle. If no movement results from contraction, such a contraction is called isometric. If the contraction of muscle results in the muscle creating movement of some sort, the contraction is called isotonic.

Isometric contractions

An isometric contraction occurs when a muscle increases its tension, but the length is not altered - the muscle is activated, but the joint over which the muscle works does not move. One example of this is holding a heavy object in the hand with the elbow held stationary and bent at 90 degrees. Trying to lift something that proves to be too heavy to move is another example. Note also that some of the postural muscles are largely working isometrically by automatic reflex. For example, in the upright position, the body has a natural tendency to fall forward at the ankle. This is prevented by isometric contraction of the calf muscles. Likewise, the centre of gravity of the skull would make the head tilt forwards if the muscles at the back of the neck did not contract isometrically to keep the head centralized.

Isotonic contractions

Isotonic contractions of muscle enable movement. There are two types:

Concentric - In concentric contractions, the muscle attachments move closer together, causing movement at the joint. Using the example of holding an object in the hand, if the biceps muscle contracts concentrically, the elbow joint will flex and the hand will move towards the shoulder.

Eccentric - Eccentric contraction means that the muscle fibres work in a controlled manner to slow down movements which gravity, if unchecked, would otherwise cause to be too rapid. For example, lowering an object held in the hand, or sitting down into a chair.

Therefore, the difference between concentric and eccentric contraction is that in the former, the muscle shortens, and in the latter, it lengthens.

KEY LEARNING POINTS.

1. **Muscle spindles and Golgi bodies are specialised receptors related to stretching of skeletal muscle fibres.**
2. **The stretch reflex maintains the tonus of postural muscles.**
3. **Autogenic inhibition has a protective function, preventing muscle damage.**
4. **In isometric contraction, muscle length does not alter when muscle tension increases.**
5. **In isotonic contraction, there is a change in length when muscle tone increases.**

Muscle Shape

Muscle fascicles can be arranged so as to produce muscle bodies of different shapes. This provides optimum mechanical efficiency for a muscle in relation to its position and action. The most common arrangement of fascicles give muscle shapes described as parallel, pennate, convergent and circular. Each of these shapes may nave further sub-categories.

Parallel - This arrangement has the fascicles running parallel to the long axis of the muscle. If the fascicles extend throughout the length of the muscle, it is known as a strap muscle, eg sartorius. If the muscle also has an expanded belly and tendons at both ends, it is called fusiform muscle, eg the biceps brachii of the arm. A modification of this type of muscle has a fleshy belly at either end, with a tendon in the middle. Such muscles are referred to as digastric.

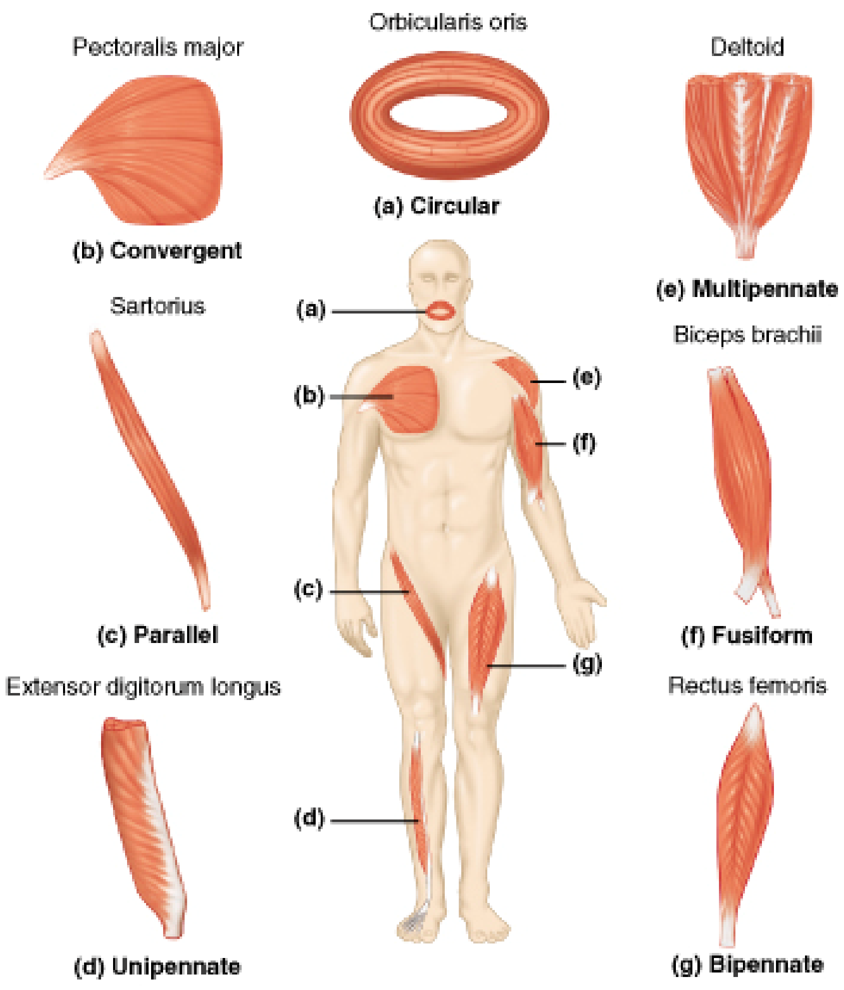
Pennate - these are so named because their short fasciculi are attached obliquely to the tendon, like the structure of a feather (penna = feather). If the tendon develops on one side of the muscle, it is referred to as unipennate, eg the flexor digitorum longus in the leg. If the tendon is in the middle and fibres are attached obliquely from both sides, it is known as bipennate, eg rectus femoris. If there are numerous tendinous intrusions into the muscle with fibres attaching obliquely from several directions, thus resembling many feathers side by side, the muscle is referred to as multipennate, eg, middle part of the deltoid muscle.

Convergent - Muscles that have a broad origin with fascicles converging toward a single tendon, giving the muscle a triangular shape, are called convergent muscles, eg pectoralis major.

Circular - When the fascicles of a muscle are arranged in concentric rings, the muscle is referred to as circular. All the sphincter skeletal muscles in the body are of this type; i.e. they surround openings, which they close by contracting. A further example is orbicularis oculi around the eye.

When muscles contract, they can shorten by up to two thirds of their original length, so the longer the fibres, the greater the range of movement. On the other hand, the strength of a muscle depends on the total number of muscle fibres it contains, rather than their length. Therefore muscles with long parallel fibres produce the greatest range of movement, but are not usually very powerful.

Muscles with a pennate pattern, especially if multipennate, contain the highest number of fibres. Such muscles shorten less than long parallel muscles, but tend to be much more powerful.



Functional Characteristics

Excitability - the ability to receive and to respond to a stimulus. In the case of a muscle, when a nervous impulse from the brain reaches the muscle at the neuromuscular junction, a neurotransmitter is released which then alters the electrical potential of the muscle fibre, eventually resulting in contraction of the muscle fibre.

Contractility - the ability of a muscle to shorten forcibly when stimulated. In other words, the muscles themselves can only contract. They cannot lengthen, except via some external means (i.e. manually) beyond their normal resting length so they can only pull together rather than push them.

Extensibility - the ability of a muscle to be extended, or returned to its resting length.

Elasticity - the ability of a muscle fibre to recoil after being lengthened, and therefore resume its resting length when relaxed. In a whole muscle, the elastic effect is supplemented by the important elastic properties of the connective tissue sheaths (endomysium and epimysium). Tendons also contribute some elastic properties.

Tonus - the term used to describe the slightly contracted state which muscles resume during the resting state. Muscle tonus does not produce active movements, but it keeps the muscles firm and ready to respond to stimulation. An alternative term used is 'muscle tone'. It is the tonus of skeletal muscles that also helps stabilize and maintain posture.

Generally, the other functions of skeletal muscle are to facilitate movement, maintain stability and posture, and to generate heat (utilised for normal body temperature).

KEY LEARNING POINTS.

1. Differences in muscle shape can alter mechanical efficiency.
2. Long muscles tend to produce the greatest range of movement, but are not usually powerful.
3. Pennate muscles tend to produce less movement, but are usually more powerful.
4. ‘Tonus’ refers to the state in which muscle reside during the resting state, and is sometimes referred to as muscle tone.

Mechanics.

Origins and Insertions

In the majority of movements, one attachment of a muscle remains relatively stationary while the attachment at the other end moves. The more stationary attachment is the origin whilst the other attachment is the insertion. In some types of movement this situation differs in that the insertion is fixed and the origin moves, eg, when climbing the arms are fixed whilst the body is pulled towards the limb. This is known as reversed action.

In practice, muscle attachments that are more proximal, i.e. more towards the trunk or on the trunk, are usually referred to as the origin. Attachments that lie more distally, i.e. away from the attached end of a limb, or away from the trunk, are referred to as the insertion.

Group Action of Muscles

Muscles work together, or in opposition, to achieve a wide variety of movements. Therefore, whatever one muscle can do, there is usually another muscle that has the opposite action it. Muscles may also be required to provide additional support or stability to enable certain movements to occur elsewhere.

There are four classifications for muscle function:

- Agonist
- Antagonist
- Synergist
- Fixator

Agonist - An agonist is a muscle that contracts to produce a specified movement. An example is the biceps brachii, which is the prime mover of elbow flexion. Other muscles may assist the prime mover in providing the same movement, and these muscles are called assistant or secondary movers. For example, the brachialis assists the biceps brachii in flexing the elbow, and is therefore a secondary mover.

Antagonist - The muscle on the opposite side of a joint to the agonist and which must relax to allow the prime mover to contract, is called an antagonist. For example, when the biceps brachii on the front of the arm contract to flex the elbow, the triceps brachii on the back of the arm must relax to allow this movement to occur. When the movement is reversed, i.e. when the elbow is extended, the triceps brachii becomes the prime mover and the biceps brachii assumes the role of antagonist.

Synergist - Synergists prevent any unwanted movements that might occur as the prime mover contracts. This is especially important where a prime mover crosses two joints, because when it contracts it will cause movement at both joints, unless other muscles act to stabilize one of the joints. For example, the muscles that flex the toes not only cross the interphalangeal joints, but also cross the ankle joint, potentially causing movement at both joints. Other muscles act synergistically to stabilize the ankle joint so that digital flexion occurs independent of ankle movement.

An agonist may have more than one action, so synergists also act to eliminate the unwanted movements. For example, the biceps brachii will flex the elbow, but its line of pull will also supinate the forearm (twist the forearm, as in tightening a screw). If flexion is needed without supination, other muscles must contract to prevent this supination. In this context, such synergists are sometimes called neutralizers.

Fixator - A synergist is more specifically referred to as a fixator or stabilizer when it immobilizes the bone of the prime mover's origin, thus providing a stable base for the action of the prime mover. The muscles that stabilize the scapula during movements of the upper limb are good examples. The sit-up exercise gives another good example: The abdominal muscles attach to both the ribcage and the pelvis. They contract to perform a sit-up, but the hip flexors will contract synergistically as fixators to prevent the abdominals tilting the pelvis; enabling the upper body to curl forward as the pelvis remains stationary.

Leverage

The bones, joints, and muscles together form a system of levers in the body, in order to optimize the relative strength, range and speed required of any given movement. The joints act as the fulcra (sing. fulcrum*),* while the muscles apply the effort and the bones bear the weight of the body part to be moved.

A muscle attached close to the fulcrum will be relatively weaker than it would be if it were attached further away. However, it is able to produce a greater range and speed of movement; because the length of the lever amplifies the distance travelled by its moveable attachment.

Classes of levers.

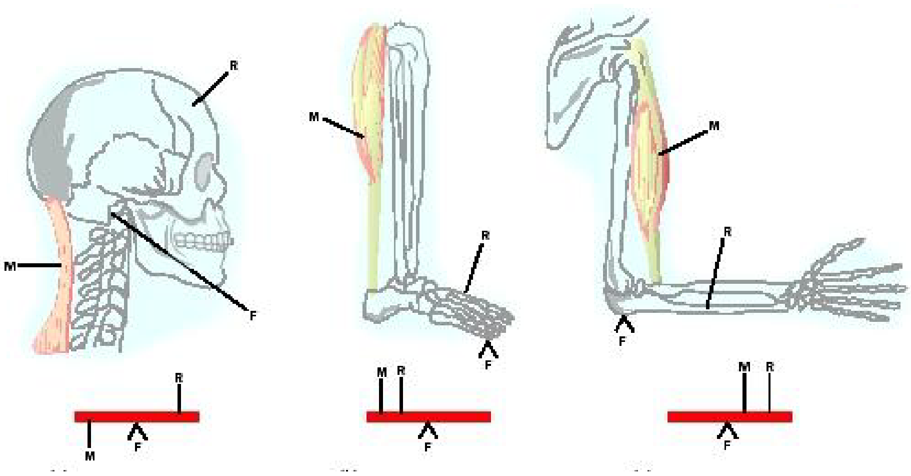
Biomechanics applies the principles of physics to human movement. Some joints work like levers, others like pulleys, and still others like a wheel-axle mechanism. Most motion uses the principle of levers. A lever consists of a rigid "bar" that pivots around a stationary fulcrum. In the human body, the fulcrum is the joint axis, bones are the levers, skeletal muscles usually create the motion, and resistance can be the weight of a body part, the weight of an object one is acting upon, or the tension of an antagonistic muscle.

Levers are classified by first, second, and third class, depending upon the relations among the fulcrum, the effort, and the resistance.

First-class levers have the fulcrum in the middle, like a seesaw. Nodding the head employs a first-class lever, with the top of the spinal column as the fulcrum.

Second-class levers have a resistance in the middle, like a load in a wheel-barrow. The body acts as second-class lever when one engages in a full-body push-up. The foot is the fulcrum, the body weight is the resistance, and the effort is applied by the hands against the ground.

Third-class levers have the effort (the muscle) in the middle. Most of the human body's musculoskeletal levers are third class. These levers are built for speed and range of motion.



First class Second class Third class

A few muscle-bone connections work on the principle of a pulley, which changes the direction of an applied force. A classic example is the patella (kneecap), which alters the direction in which the quadriceps (patellar) tendon pulls on the tibia.

Muscle attachments are usually close to the joint. As the length of the lever increases, the possible speed increases, but so does the force required to produce it. For instance, the forearm is a third-class lever, controlled by the biceps muscle. A longer forearm can produce faster motion of the hand, but requires more effort to move than a shorter forearm.

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Limitations of movement.

The inability of a muscle to contract or lengthen beyond a certain point can prevent some bodily movement.

Passive Insufficiency - Muscles that span over two joints are called bi-articular muscles. These muscles may be unable to function sufficiently to allow full movement of both joints simultaneously. For example, most people need to bend the knees in order to touch the toes. This is because the hamstrings (which span the hip and knee joints) cannot lengthen enough to allow full flexion at the hip joint without also pulling the knee joint into flexion. For the same reason, it is easier to pull the thigh to the chest if the knee is bent than if it is straight. This limitation is called passive insufficiency.

Active Insufficiency - this is the opposite of passive insufficiency, resulting from the inability of a muscle to contract by more than a fixed amount. For example, the knee can be flexed to bring the heel close to the buttock, if the hip is flexed, because the upper part of the hamstrings are lengthened and the lower part is shortened. However, one is normally unable to fully flex the knee when the hip is extended. This is because with the hip extended, the hamstrings are already shortened, meaning that there is insufficient 'shortening' potential remaining in the hamstrings to then fully flex the knee.

Concurrent Movement - If extension of the hip is required at the same time as extension of the knee, as in the push off from the ground in running, the phenomenon known as concurrent movement applies. To understand the concept of concurrent movement, using the example of running, it should first be remembered that when the hamstrings contract, they are able to both extend the hip joint and flex the knee joint, either singly or simultaneously. In the process of running, the following happens :

- As the foot pushes against the ground, the hamstrings contract to extend the hip.
- Meanwhile, fixators prevent the hamstrings from flexing the knee.
- Therefore, the hamstrings are shortened only at their upper end (origin), but remain lengthened at their lower end (insertion).
- The antagonist to the hamstring's action of flexing the hip is the rectus femoris, which relaxes because of reciprocal inhibition to allow the hamstrings to contract.
- When the hip is fully extended, the already stretched rectus femoris is unable to lengthen further, causing it to pull the knee into extension.
- Therefore, the rectus femoris is lengthened at its upper end and shortened at its lower end.

Concurrent movement therefore avoids passive and active insufficiency of the hamstrings and rectus femoris by neither shortening nor stretching both ends of either muscle, but by having one end lengthen as the other shortens, and vice versa in the other muscle.

Countercurrent Movement - If flexion of the hip is required to occur at the same time as extending the knee, as in kicking a ball, a countercurrent movement occurs. In this situation, the following will occur :

- To kick a ball, the rectus femoris acts as a prime mover to flex the hip and extend the knee, shortening the upper and lower sections of rectus femoris are shortened.
- The hamstrings relax due to reciprocal inhibition, so that they can

extend at both ends and allow kicking.

- The rectus femoris relaxes once the movement has been made, but the momentum of the movement is still propelling the leg forward.
- At this stage, the hamstrings contract to act as a 'brake' for the leg, as it moves forward.

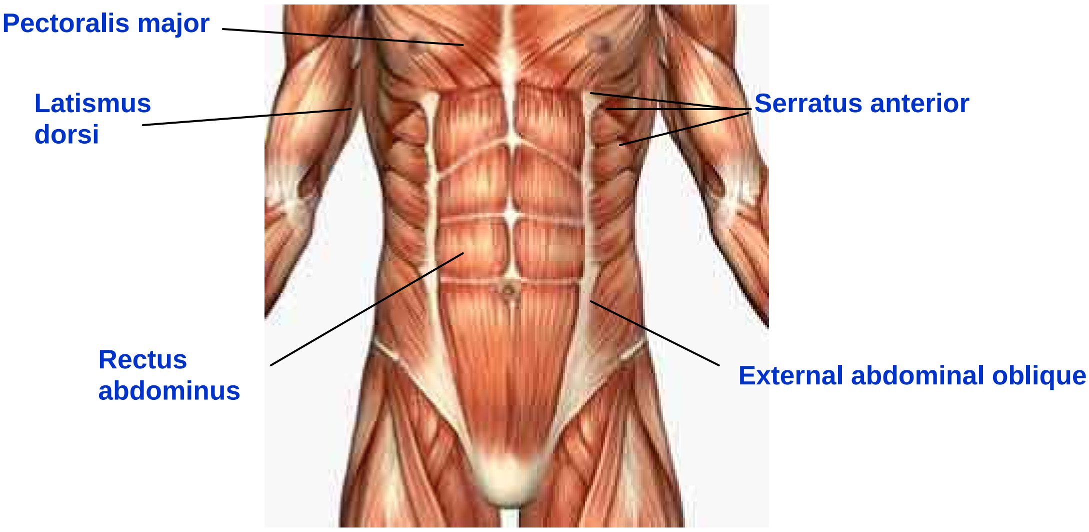
Countercurrent movements therefore prevent injury by ensuring the antagonist relaxes first, then contracts at the right time to prevent the forces of momentum from overstretching muscles and ligaments. So called 'ballistic' movements are relying on this principle, but are often done so forcefully that the power of momentum is greater than the ability of the antagonist to 'brake' that momentum. In such instances, muscle and ligament damage often occurs.

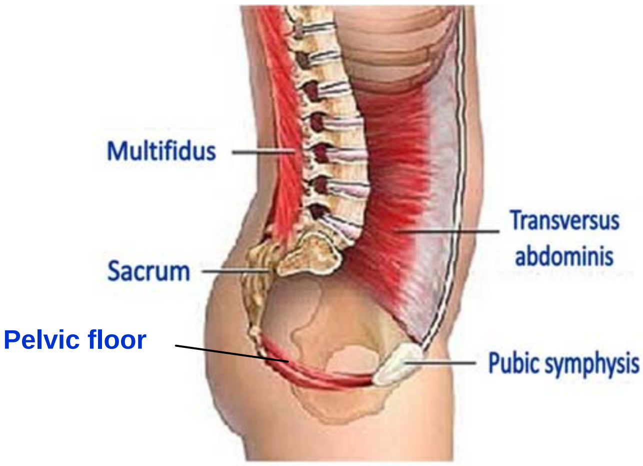
Core Stability

As part of normal everyday activity skeletal muscle acts to stabilise the body in order to maintain posture, and control movement. The muscles responsible for this stabilising action are usually located deep within the body, and usually consist of slow-twitch fibres so that they can carry out minimal work over a long period of time. When these stabilizing muscles are under-used, the fibres become less sensitive to action potentials, leading to what is referred to as poor recruitment – if the muscle is not used for an extended period of time, it becomes more difficult to re-enervate that muscle back into use, hence the development of poor posture. It is particularly important to maintain stability in the body, and the torso acts as a stable platform in relation to the movements carried out by the limbs. As the torso or mid-section is the 'core' of the body, its success as a stable platform is referred to as core stability. Good core stability therefore allows the maintenance of a rigid mid-section without gravity or other forces interfering with movement. Core stability muscles can be retrained, especially through bracing and stabilizing exercises. This is frequently employed during physiotherapy treatment, as well as activities such as Pilates and Yoga. In essence, core stability can be summarized as the successful recruitment of deep muscles that maintain the natural curvatures (neutral alignment) of the spine during all other movements of the body.

Core muscles lie deep within the torso and are generally attached to the spine, pelvis and shoulder blades. The contraction of these core muscles stabilises the spine, pelvis and shoulders to form a solid base for movements of the arms and legs. The main concept of core strengthening programs involves using many muscles in a coordinated movement. Rather than isolating a specific joint core stability exercises focus on working the deep muscles of the entire torso at once. For example, in the lower torso, the abdominal muscle group is made up of the rectus abdominus, the internal and external obliques, and the transversus abdominus (acting like a corset), found at the deepest layer. Research suggests that the transverse abdominus is one of the most important providers of support to the lower back. It has been suggested that in almost 90% of all body movements, core muscles are active supporting the entire trunk region.

The dynamic relationship between the control of the lower back area by the transversus abdominus and multifidus muscles (between the vertebrae) working synchronously together with other the muscles that move the limbs is a fundamental part of the Core Stability concept.





The deep stabilizing or 'core stability' muscles collectively create what is known as an 'inner unit' of muscle. These muscles include the tranversus abdominis, multifidis, pelvic floor, diaphragm and posterior fibres of the internal oblique. The main muscles that initiate movement of the limbs whilst working in unison with the inner unit are collectively referred to as the 'outer unit' or global muscles; i.e. the spinal erectors, external and internal obliques, latissimus dorsi, gluteals, hamstrings and adductors.

In addition, other mechanical systems contribute to, and increase, core stability.

Thoraco-Lumbar fascia gain - As the abdominal wall is pulled in by the contraction of the transversus abdominis, the internal oblique acts synergistically to pull upon the thoraco-lumbar fascia (which wraps around the spine, connecting the deep trunk muscles to it). This in turn exerts a force on the lumbar spine that helps support and stabilize it (this force is called thoraco-lumbar gain). More specifically, the increased tension of the thoraco-lumbar fascia compresses the erector spinae and multifidis muscles, encouraging these to contract and resist the forces that are trying to flex the spine. The classic analogy is that of the guide ropes of a tent acting together to support the main structure of the tent.
Research demonstrates that in addition to the above, the paraspinal muscles - interspinalis and intertransversarii - assist core stability insofar as they provide an individual stabilizing effect on their adjacent vertebrae, acting in a similar way to ligaments.

Intra-abdominal pressure - Pressure in the abdominal cavity is increased as a result of the abdominal wall being pulled inwards by the transversus abdominis, along with a co-contraction of the pelvic floor, internal oblique and low back muscles. This in turn exerts a tensile force on the rectus sheath, which encloses the rectus abdominis muscle. Because the rectus sheath attaches to the internal oblique and transversus abdominis muscles, it effectively surrounds the abdomen. The tension of the rectus sheath therefore increases the pressure within the abdomen like a pressurized balloon. This further facilitates the stability of the core.

KEY LEARNING POINTS.

1. **The four types of muscle function are agonistic, antagonistic, synergistic, and fixator.**
2. **The bones, joints, and muscle form a system of levers, which optimise the strength and range of movement.**
3. **There are a range of first, second and third class levers throughout the musculo-skeletal system.**
4. **Movement is limited by passive and active insufficiency, as well as concurrent and counter-current movement.**
5. **A number of deep stabilising muscle groups are employed to maintain core stability.**
6. **Thoraco-lumbar fascial gain and intra-abdominal pressure both contribute to core stability.**