Physiology of Stretching

Musculoskeletal biomechanics are under our conscious control. For example, when we want to straighten the knee, the brain signals the quadriceps to contract and the knee straightens, stretching the hamstrings. This action triggers a chain of physiological responses that take place without our conscious awareness.

Receptors within the joints and muscles detect movement and changes in muscle tension and length. These receptors signal the central nervous system, which responds by regulating the contractile state of the muscles. This, in turn, affects the range of motion of a given joint.

In this way, conscious biomechanical actions influence unconscious physiological responses. Moving the body into a Yoga posture initiates a cascade of these biomechanical and physiological events.

The Spinal Cord Reflexes

Spinal cord reflex arcs regulate the tension and length of skeletal muscle contractile elements. This regulation occurs automatically in response to biomechanical actions. When a muscle contracts or stretches, receptors within it alert the central nervous system to this event. The central nervous system then signals the muscle to respond appropriately, either by relaxing or by contracting. All of this takes place without our being aware of it by way of an arc of nerves between the muscles and the spinal cord. The result is a Yin/Yang feedback mechanism that balances and fine-tunes movement.

A complex array of receptors and their corresponding reflex arcs connect the musculoskeletal system to the central nervous system. For practical purposes, I have limited the discussion in this chapter to the three major spinal cord reflexes: the muscle spindle, reciprocal inhibition, and the Golgi tendon organ.

Methods of Stretching Muscles

There are basically three methods of stretching.

1. Ballistic stretching: This type of stretching uses jumping type actions to stretch target muscle groups. Vinyasa Flow series are an example of ballistic stretching. This method is useful for “resetting” muscle length to that attained in a previous practice. Practicing the Sun Salutations in the morning is an example of this.

2. Passive stretching: This type of stretching involves the use of body weight, gravity, and synergist/agonist muscle groups to create a stretch. The body is placed into the position of stretch and held there for longer periods to allow the stretch receptors to “acclimate.” This type of stretch affects the muscle spindle receptor in particular. Holding passive stretches for longer periods lengthens the noncontractile elements of the muscle, such as the fascial sheath.

3. Facilitated stretching: Also known as “PNF,” or proprioceptive neuromuscular facilitation, involves briefly contracting the muscle targeted for stretch. This action stimulates the Golgi tendon organ stretch receptor, resulting in the spinal cord signaling the muscle to relax. The “slack” created by this response is then taken up by deepening the stretch.
**Stretching and Endorphins**

Endorphins are responsible for a variety of physiological responses, including the sense of relaxation and well-being that follows a Yoga practice. Stretching triggers the release of these neuroendocrine factors. Endorphins act in a lock-and-key fashion, with receptors on the surface of cells within the central nervous system. Gates on the cell membrane open to allow endorphins to pass into the nerve cell where they have their effect.

This image is an artistic interpretation of endorphin release and internalization across the synaptic cleft between neurons.
The Muscle Spindle Stretch Receptor

The muscle spindle stretch receptor is a modified muscle cell located in the “belly” of all skeletal muscles. It detects changes in length and tension within the muscle. Basically, when a muscle stretches, the muscle spindle sends a signal to the spinal cord, which then signals the muscle to contract and resist the stretch. This protects the muscle from over-stretching or tearing and is known as a “spinal cord reflex arc.”

Never force the body into a stretch in Yoga, because this intensifies the firing of the muscle spindle, causing the muscle to contract. This mechanism can block deepening of the stretch. Rather, “dissolve” the blockages slowly by working with the spinal cord reflex arcs to decrease the reflex contraction of the muscle, and then go deeper into the pose.

The figure on the facing page illustrates the spinal cord reflex arc of the muscle spindle. A signal is sent from the muscle spindle receptor to the spinal cord. This signal is then relayed to the motor nerve via the spinal cord, signaling the muscle to contract and resist the stretch. This is a “primitive” reflex that occurs unconsciously in response to a biomechanical event, the stretching of a muscle. Holding a stretch for 30-60 seconds causes the muscle spindle to decrease its firing, and the muscle begins to relax. Backing part-way out of a stretch also decreases firing of the muscle spindle, relaxing the muscle and allowing a deeper stretch.

The following page uses the forward bend Uttanasana to describe a technique for “reassuring” the muscle spindle and decreasing its firing. This technique involves backing out part-way from the stretch for a few moments and then going into a deeper stretch. It may seem counterintuitive, but we can actually deepen a stretch by first backing off. This helps to decrease the reflex contraction of the muscles we are targeting for stretch.
muscle spindle located in the muscle belly sensing changes in muscle length and tension

muscle contracting in response to inhibitory signal
Figure 1: Coming part way out of a deeper stretch such as Uttanasana "acclimates" the muscle spindle so that the intensity of its firing decreases. The target muscle then relaxes, allowing length to be created by deepening the stretch. This image illustrates coming halfway out of Uttanasana using a chair. This acts to decrease firing of the muscle spindle and reflex contraction of the calf muscles, hamstrings, gluteals, and back muscles.
The muscle spindle in Uttanasana

Carefully bend forward in Uttanasana until you feel a moderate stretch. The muscle spindles of the hamstring, gluteus maximus, and erector spinae muscles will fire in response to this stretch and send a signal to the spinal cord. This is the first part of the reflex arc, with the muscle spindle connecting to the spine via the efferent nerve. The second part is the outgoing signal from the spinal cord via the afferent nerve to the muscle, signaling it to contract. The reflex contraction of the muscles of the back of the body—those being stretched—is part of what may prevent deepening in the posture Uttanasana.

The next step is to back off or "dissolve" reflex contraction of the stretched muscles by slightly relaxing the stretch. Chair Uttanasana is one way to acclimate the muscle spindle for forward bends, since lifting the torso decreases the intensity of the stretch of the muscles of the back body. Decreasing the stretch decreases the intensity of the firing of the muscle spindle, thus minimizing reflex contraction of the stretching muscles.

Hold this milder stretch for a few breaths. This quiets the muscle spindle stretch receptors and interrupts their ‘alarm.’ Once the muscle spindle adjusts to the milder stretch, contract the muscles at the front of the thigh to straighten the knees and deepen the pose.

Figure 2: The firing of the muscle spindle has decreased, and the calf muscles, hamstrings, gluteals, and back muscles are more relaxed, allowing the target muscles to relax. This image illustrates deepening of the stretch in Uttanasana.
Reciprocal Inhibition

The concept of the balanced Yin/Yang appears throughout the body. It is present in anatomy where the form of a joint fits its function. Consider again the shape of the hip and shoulder joints to see this concept in action.

The Biomechanical Yin/Yang

Muscles fall into two basic groups, depending on what we are doing at any given moment. For example, the quadriceps are the agonists for extending or straightening the knee. The hamstrings along the back of the thigh stretch when the knee extends and thus are the antagonists for this action. Conversely, the hamstrings become the agonist muscle when the knee bends, and the quadriceps become the antagonist. This is a biomechanical Yin/Yang.

Reciprocal Inhibition—A Physiological Yin/Yang

It makes sense that there would be a corresponding physiological Yin/Yang to make biomechanical processes such as bending and straightening the knee energy-efficient, i.e., when the agonist muscle contracts, its antagonist relaxes. This exists as the primitive spinal cord reflex known as reciprocal inhibition, meaning that muscles on one side of a joint relax to accommodate contraction on the other side of that joint. We can consciously access this reflex arc to deepen and improve our poses.

In Paschimottanasana, the quadriceps muscle along the front of the thigh is the agonist and the hamstring muscles along the back of the thigh are the antagonists. Contracting the quadriceps signals the hamstrings to relax. This takes place via the spinal cord. The nerve impulse that results in contraction of the quadriceps is called excitatory and the impulse to the hamstrings is called inhibitory.

Try this technique to get a bit deeper into this pose: firmly contract the quadriceps to straighten the knee, and note how the hamstring muscles relax. Apply it to different agonist/antagonist muscle groups in other poses. Note the added biomechanical benefit of improved bone alignment when you apply this technique.
Figure 1: The brain signals the quadriceps to contract and straighten the knee. At the same time, the brain also signals the hamstrings to relax. In this image, the plus sign signifies excitatory impulses from the brain to the quadriceps, stimulating contraction. The minus sign signifies inhibitory impulses to the hamstrings, blocking contraction with resultant relaxation. This combination of impulses allows the knee to straighten.
Golgi Tendon Organ

The Golgi tendon organ is a sensory receptor that is located where the muscle and tendon are joined. It detects changes in tension, and when tension increases, it signals the muscle to relax. This acts like a "circuit breaker" to prevent injury to the tendon when tension generated by the contracting muscle becomes too high. This contrasts with the muscle spindle receptor, which detects change in length and tension in the body of the muscle and signals the muscle to contract.

The Golgi tendon organ forms the basis for a phenomenon used by physical therapists and sports trainers known as proprioceptive neuromuscular facilitation, or "PNF." In PNF we temporarily contract a target muscle that we are stretching in order to stimulate the Golgi tendon organ. The Golgi tendon organ then signals the muscle to relax. This creates "slack" in the muscle that we can take up by going deeper into the stretch. This is known in physiology as the "relaxation response."

This may seem counterintuitive at first—contracting a muscle that we are trying to stretch; however, when applied carefully, this technique can be used to "dissolve" blocks and deepen poses. To understand the technique, we will look at lengthening the hamstrings in Janu Sirsasana. The technique is generally applied as follows:

1. First, take the muscle out to length. This establishes where the "set length" of the muscle is, the point that the brain recognizes as the end of the stretch.
2. Next, gently contract the target muscle. In this case, we are focusing on the hamstrings of the straight leg, so we attempt to bend the knee to create a contraction in the hamstrings (the action of the hamstrings is to bend the knee). I generally access this by slightly bending the knee and pressing the heel into the floor. This causes the hamstrings to contract.
3. Contract the muscle to no more than 20% of its maximum force and hold this for 8 to 10 seconds. Then relax for 1 breath.
4. Now, contract the antagonist muscles at the front of the thigh to take the target muscle out to a new "set" length. In this case, we contract the quadriceps to straighten the knee and bend deeper into the stretch of the hamstrings.

Hints and Cautions:

1. If you are new to Yoga, spend a few months conditioning your body first before using these powerful techniques to deepen stretches.
2. Remember that the Golgi tendon organ is there to protect the tendon from injury, but its ability to protect the tendon has limits. Never overdo it when using this technique. Never contract the target muscle more than about 20% of its maximum force.
3. The force generated by contracting muscles is transmitted to the joints. This is called the "joint reaction force," so you must always protect your joints by maintaining them in their natural alignment while stretching. If you experience joint pain, then back off from the stretch and stop.
4. Focus on one muscle group at a time, and limit your PNF stretching to one pose in a practice session. Do no more than 2 to 3 cycles of the stretch described above.
5. Allow ample time (48 hours) for recovery before repeating this technique.
6. Always practice under the guidance of an experienced and qualified teacher.
sensory nerve

spinal cord

motor nerve

Golgi tendon organ
sensing tension at the muscle-tendon junction

muscle relaxing in response to inhibitory impulse
The Golgi Tendon Organ and Facilitated Stretching

Attempting to pull the hands apart in Gomukhasana increases the tension at the muscle-tendon junctions of the upper extremities. This affects the muscle-tendon junctions of the infraspinatus and teres minor muscles of the rotator cuff, as well as the front portion of the deltoid and the upper pectoralis (in the lower arm of the pose). In the upper arm of the pose, the increased tension is felt in the subscapularis muscle of the rotator cuff as well as the latissimus dorsi and teres major.

The firing of the Golgi tendon organ in response to this tension results in the spinal cord signaling these muscles to relax. This relaxation response persists for a brief period, even after release of the tension created by pulling the hands apart. The pose can then be deepened by moving the hands closer together and taking up the slack created by the relaxation response.
The back leg in modified Lunge Pose illustrates facilitated stretching of the hip flexors. The knee of the back leg and the foot of the front leg are both fixed on the mat. This means that the force generated by contracting the back leg flexors will manifest as tension at the muscle-tendon junctions of these muscles. The Golgi tendon organs of the hip flexors will send their signal to the spinal cord which, in turn, will signal the flexors to relax. The slack created by the relaxation response is then taken up by going deeper into the lunge.

**Figure 1:** The psoas is a flexor of the hip that has been isolated for this illustration. The hip is taken into extension, stretching the psoas. Attempting to drag the back knee toward the front foot causes the stretched psoas to contract eccentrically, stimulating the Golgi tendon organs at its muscle-tendon junction. This tension can be increased by contracting the front leg hamstrings and attempting to drag the front foot toward the back knee. The front foot is fixed, so the force of this contraction is transmitted to the back leg psoas, increasing the firing of the Golgi tendon organs of that muscle.

**Figure 2:** The slack in the flexor group is then taken up by deepening the pose. Activating the front leg psoas flexes the hip, while the hamstrings bend the knee. Pressing down on the front knee with the hand lifts the trunk. All of these actions deepen the pose and lengthen the hip flexors of the back leg.
Combining Biomechanics and Physiology in Stretching

Here we use Janu Sirsasana to illustrate stretching the hamstrings by moving their origins and insertions in combination with techniques we have gained from knowledge of the muscle spindle, reciprocal inhibition, and the Golgi tendon organ.

1. Take the general form of the pose to apply a moderate stretch to the hamstring muscles of the straight leg. This stimulates the muscle spindle to fire, resulting in reflex contraction of the hamstrings.

2. Bend the knee to lighten the stretch of the hamstrings, releasing their insertion on the lower leg. Hold this relaxed position for 2 or 3 breaths as the muscle spindle accommodates to the lighter stretch.

3. Now that the firing of the muscle spindle has decreased, contract the quadriceps to straighten the knee and draw the hamstrings out to length, moving the insertion at the knee away from the origin. This action signals the hamstrings to further relax via reciprocal inhibition.
4. Attempt to press the heel into the ground by contracting the hamstrings. This increases tension at the muscle-tendon junction and stimulates the Golgi tendon organ to fire. The spinal cord then signals the hamstrings to relax.

5. Contract the quadriceps to straighten the knee and move the insertion of the hamstrings away from the origin. Straightening the knee takes up the "slack" created by the relaxation response. Contracting the quadriceps creates reciprocal inhibition, further relaxing the hamstrings. The psoas tilts the pelvis forward, moving the hamstring origin away from the insertion. Bending the elbows by contracting the biceps bends the trunk forward, deepening the pose.