Running Physiology

Dr. Mustafa Agaoglu

The spine is broadly divided into five regions-- the cervical spine, the thoracic spine, the lumbar spine, and the sacrum and the coccyx. Each has its own unique set of chromatic functions, pathologies, and treatment. In fact, the cervical, thoracic, and lumbar regions are further divided based on kinematic and clinical considerations. The cervical spine consists of seven vertebra in all mammals-- the occiput, atlas, and axis make the upper axis to fifth cervical vertebra meet the middle.

In the fifth cervical, the first thoracic vertebra make the lower regions. The thoracic spine consists of 12 vertebrae and is divided into upper, which is T1 to T4, the middle, which is T4 to T8, and the lower, which is T8 to L1 regions. The ribs attach to the thoracic vertebra.

The lumbar spine consists of five vertebrae in humans. The sacrum and the coccyx consists of five fused vertebra each. In some cases, coccyx maybe out of four vertebrae. The junctions between the broad regions, the cervical thoracic, the thorical lumbar. Lumbosacral junctions frequently are sites for degenerative changes over the long term-- most likely due to abrupt changes in stiffness that occurs at these junctions.

The spine, as a complete structure, can undergo axial, lateral, and saggital rotations and axial, lateral, anterior, posterior translations. First, the spine is said to possess six degrees of freedom. A functional spinal unit is comprised of superior vertebra, intervertebral disc, inferior vertebrae osteoligamentus unit.

A functional spinal unit therefore possesses a six-degree of freedom as well and is the basic unit of study of the spine. Motions are reported as one vertebra relative to another. Hence the motion is that of a functional spinal unit.

The spinal ligaments serve to protect neural structures by restricting the motion of functional spinal unit. The ligaments also absorb energy during high speed and potentially injurious motions. The spinal ligaments are primarily collagenous, except for the ligamentum flavum, which is primarily comprised of elastin, anterior longitudinal ligament originates at the base of the occiput and extends the entire length of the spine into the sacral region, along the anterior aspect of the spine. Fibers of the anterior longitudinal ligament firmly attach to each other, as well as to the entire vertebral disks.

The posterior longitudinal ligament also extends the length of the spine along the posterior aspect of each vertebral body and anterior to the spinal cord. The ligamentum flavum originates bilaterally on the anterior inferior aspect of the laminar of the superior vertebral body and inserts on the posterior superior aspect of the lamina of the inferior vertebrae, the intertransverse ligaments and interspinous ligaments joint transverse and spineless processes of adjacent vertebrae. The super spinous ligament originates as the ligamentum nuchae of the neck and extends the length of the spine posterior to the interspinous ligament while attaching firmly to the tip of each spinous process. The capsule ligaments surround each facet joint.

Mechanically, spinal ligaments behave as other soft tissues of the body. They are viscoelastic with non-linear elastic responses. They are mechanical response has been characterized predominantly ex vivo, and little is known about their in vivo mechanical environment. In general, it is believed that spinal ligaments do not enjoy the same margin of safety as bones do, as they can operate under conditions relatively close to their failure strengths. This belief is based on combining the ex vivo mechanical behaviors of individual ligaments and functional spinal unit with motion, radiographs, and mathematical models of the spine.

Here you can see the positionings of the osteo ligaments of the functional spinal unit as described above in the previous slide. Here you can get an idea of the failure loads in newtons of each osteo ligament or the functional spinal unit. Kinematics is the study of the motion of bodies and the motion patterns of the spine.

Normal patterns are characterized by parameters common across regions of the spine. If a load is applied to a functional spinal unit or a multi-level spine unit, the unit first displaces from a neutral position to a position where an appreciable resistance is first encountered. The initial lax region of the motion is termed the neutral zone. The presence of a neutral zone allows the spine to undergo relatively large motions with very little muscular effort.

Enlargement-- of a neutral zone can indicate an abnormal structural change and be a cause of concern. A region of stiffening next is encountered, termed the elastic zone. The displacement at the largest applied load or at the limit of motion for an activity is termed the range of motion.

Spine, as a structure, displays viscoelastic characteristics due to the viscoelastic nature of its constituents. The relative kinematic terms of the study of spinal cord kinematics are flexion, extension, lateral bending, and axial rotation. Flexion refers to bending forward above an axis perpendicular to the saggital plane.

Extension refers to bending backward about that axis. Together, flexion extension is referred to as saggital bending. Lateral bending refers to bending either side and can be either left or right lateral bending. Axial torsion refers to turning to either left or right. The determination of in vivo mechanical loading and motion is perhaps the most challenging aspect of biomechanics, especially for the spine, a structure with complex motion patterns.

What is known has been determined in a variety of methods, and analysis of a free-body diagram can provide costatic forces acting on into vertebral joints. These kinds of analysis indicate compressive forces approaching 10 times the weight of the body above the joint of interest. For everyday activities, such as bending over to pick up something off the floor, a method has been the invasive measurement of pressures within the vertebral disk via a microneedle pressure transducer.

In the slide, you can see the intradiscal pressures in different movement patterns of L3, L4 disk. The vertebral bodies are connected and kept separated by the intervertebral disks. The disk is comprised of the anulus fibrosis and the nucleus pulposus and is firmly joined with the end plates of vertebral bodies around the outer periphery of the annulus.

The end plates are composed of hyaline cartilage. Vascular channels within the vertebral bodies have been observed to run directly at the end plates, representing the predominant nutrient source for the adult disk cells. Some blood vessels approach to annulus and at the periphery but do not penetrate. The end plates undergo progressive calcification with age, which impedes the nutrient source and contributes to the progressive degeneration of the disk throughout adulthood.

The nucleus pulposus is located poster central in the disk where in the lumbar region, it fills 30% to 50% of the cross-sectional area of the disk. The normal nucleus contains almost exclusively type 2 collagen fibers in an aqueous gel rich with proteoglycans. The collagen molecules in the nucleus also have been found to have proteoglycan molecules bound to their ends.

The water content in the normal nucleus of human lumbar disks decreases from about 90% of its total volume during the first year of the life to 70% in the 80th year and beyond. The annulus fibrosis is composed of concentric layers of collagen fiber bundles wound in helecoid manner. Observations using scanning electron microscopy have shown the fibers in the inner third of the annulus to interconnect with the cartilaginous end plate.

The fibers in the outer portion are firmly bounded to the epiphyseal ring of the vertebral body. The disk fibers have been found to be almost exclusively of type 1 collagen in the outer portion and gradually change to a 40% type 1 and 60% type 2 mixture in the inner portions. The annulus has a laminate structure. The fiber orientations alternate from layer to layer with the fibers generally oriented at an angle of approximately plus or minus 30 degrees with respect to the horizontal plane. Specifically, the fiber orientations change from about plus or minus 31 degrees in the outer annulus to plus or minus 22 degrees in the inner annulus.

The disk is more morphologically structured so as to be predisposed to injury at the sight of high stress. Disk cells are poorly serviced with nutrients-- a service which only gets worse with age. Injury or degeneration decreases the functional ability of the disk to transmit body forces through hydrostatic pressure, which, in turn, decreases the ability of the cells to maintain the extracellular matrix.

Running is a matter of bipedal gait that represents a natural progression from walking. The progression from walk to run occurs at a strategy to conserve energy. Increasing velocity comes at an energetic cost. Running typically commences at a speed of 2.1 to 2.2 meters per second, which is about 4.92 miles per hour or 7.91 kilometers per hour.

As a hallmark, running gait replaces the double support phase of walking with a double float phase where there is no contact with the ground. There is a series of single leg sport and double float periods. Running stands phase is limited to 40% or less of the gait cycle.

Vertebral column height decreases throughout the course of the day. This decrease is the result of a loss of fluid from the integral table disks due to compressive loading. When the load changes during the day, as a result of varying physical activities, the rate of disk shrinkage changes in relation to those activities.

One study shows a correlation between long distance running and an increase in the loss of vertebral column height. 30 elite male runners, ages 17 to 29, participated in the study. Subjects' vertebral column heights were measured in the morning upon waking, in the afternoon prior to running 9 miles, which is about 14.48 kilometers, and then immediately following the run. Paired t-tests revealed, one, that the virtual column height was significantly less following the run, two, that a significantly greater amount of height was lost during one hour of running then during 7.5 hours of relatively static activities.

The vertebral column is a strong yet flexible shaft which provides support of the body weight at bases for locomotion and protection of the spinal cord and its nerve roots. Intervertebral disks are interposed between adjacent services of the vertebral bodies and provide the strongest attachment between the vertebra. The principal functions of the vertebral disks are to allow movement between vertebral bodies, transmit forces evenly from one vertebral body to the next, and absorb and store energy.

Throughout the day, the vertebral column is subjected to compressive, as well as other types of loading by gravity, changes in position, muscle activity, external forces, and external work. The fluid pressure within the nucleus pulposis is related to the axial compression applied to the disk. When the compressive load exceeds the interstitial osmotic pressure of the tissues of the disk, water is extruded through the disk wall.

The result is a loss in disk height and thus a loss in total body height. The gelatinous nature of the nucleus allows it to imbibe fluid and regain its original size when the axial compression is minimized. During the day when a person is usually under the constant force of gravity and muscular activity, the intervertebral disks lose as much as an inch in height, which is about 2.5 to 3 centimeters. However, at night, while a person is recumbent, that height is restored.

This shrinkage has been used as a measure of the effect of the load on the spine. Consequently, the observed changes in height can be considered to reflect the magnitude of the vertebral column loading. It has been asserted that greater losses in height occur when dynamic, rather than static, loading is involved and that dynamic loads on the spine result in faster rate of shrinkage. Running studies using force plate gait analysis have shown a marked increase in the ground reaction force, as compared to walking.

During running, the force generated at the point of heel strike has been shown to be three times that of walking. This means that significant compressive forces are being transmitted to the spine. Intervertebral disk is of great mechanical and functional importance. Fundamental understanding of this structure and biomechanics is necessary in order to hypothesize a relationship between physical activity and intervertebral disk height. The intervertebral disks comprise over one fourth the length of the vertebral column.

Intervertebral disks are fibrocartilaginous, articulations designed for strength, and together, with their adjoining vertebral bodies, function as synthesis joints. They serve as a cushion between vertebral bodies to store energy and distribute loads. Each disk is comprised of three distinct parts-- nucleus pulposis, the annulus fibrosis, and cartilaginous end plates. At the center of the disk is the nucleus pulposis, which is encased above and below by the cartilaginous end plates and encircled by the annulus fibrosis.

The nucleus pulposis is composed of a loose network of fibers in a mucopolysaccharide gel, containing from 70% to 90% of water. It is essentially avascular and aneural. Nutrients reach the nucleus proposes by diffusion from the blood vessels that lie around the periphery of the annulus fibrosis and from the vascular cavities in the central portion of the cartilaginous end plates.

The nucleus pulposis allows for movement in the spine by deforming under compression, tilting and twisting to alter the shape of the disk, and circling the nucleus pulposis are the highly organized layers of collagen fibers, which comprise the annulus fibrosis. The annulus contains essentially the same material as the nucleus, although its water content is greatly reduced. And its fiber content is greatly increased.

The fibers are oriented obliquely with each layer, about 60% to 70% for vertical with adjacent layers running in alternating directions. This highly organized arrangement and substantial fiber content is what gives the annulus fibrosis its great strength thus allowing it to function as a load bearing structure. The annulus and the nucleus work together to distribute forces evenly over the vertebral end plates.

Running is similar to walking in terms of locomotive activity. However, there are key differences. Having the ability to walk does not mean that the individual has the ability to run. Running requires greater balance, greater muscle strength, and greater joint range of movement.

There is a need for greater balance because of double sport period present in walking is not present when running. There is also the additional of a double float period during which both feet are off the ground, not making contact with the sport surface. The amount of time that the runner spends in float increase as the runner increases in speed.

The muscles must produce greater energy to elevate the head, arms, and the trunk higher, in comparison to normal walking. The muscles and joints must also be able to absorb increased amount of energy to control the weight of the head, the arms, and the trunk. During running gait cycle, the ground reaction force at the center of pressure have been shown to increase to 250% of the body weight.

The joint motion of the running gait cycle-- The running gait cycle, beginning of stance phase, hip is in about 50 degrees flexion at heel strike, continuing to extend during the rest of the stance phase. It reaches 10 degrees of hyperextension after toe off. The hip flexes to 55 degrees flexion in the late swing phase. Before the end of the swing phase, the hip extends to 50 degrees to prepare for the heel strike. The knee flexes to about 40 degrees, as the heel strikes, then flexes to 60 degrees during the loading phase.

The knee begins to extend after this and reaches 40 degrees flexion just before tore off during swing phase and the initial part of the float period, the knee flexes to reach maximal flexion of 125 degrees during the mid swing. The knee then prepares for heel strike by extending to 40 degrees. The ankle is in about 10 degrees of dorsiflexion when the heel strikes and then dorsiflexes rapidly to 25 degrees.

Plantar flexion happens almost immediately continuing throughout the rest of the stands phase of running and as it enters swing phase also. Plantar flexion reaches a maximum of 25 degrees in the first few seconds of the swing phase. The ankle then dorsiflexes throughout the swing phase to 10 degrees in the late stage swing phase, preparing for the heel to strike. The lower limb immediately rotates during the swing phase, continuing to medially rotate at heel strike. The foot pronates at heel strike. Lateral rotation of the lower limbs stance leg begins as the swing leg passes by the stance leg in mid stance position.

Lower extremity muscle activity during running-- gluteus maximus and gluteus medias are both active at the beginning of stance phase and also at the end of swing phase. Tensor fasciae latae is active from the beginning of stance and also the end of swing phase it is also active between early and mid swing.

Adductor magnus is active for about 25% of cycle from late stance to early part of the swing phase. Iliopsoas activity occurs during swing phase for 35 to 60% of the cycle. Quadriceps, they work in an eccentric manner for the initial 10% of the stance phase.

Its role is to control knee flexion as the knee goes through rapid flexion. It stops being active after the first part of the stance phase. There is then no activity until the last 20% of the swing phase.

At this point, it becomes concentric in behavior, so it can extend the knee to prepare for heel strike. Medial hamstrings become active at the beginning of the stance phase, which is 18 to 28%. They are also active throughout much of the swing phase, which is 40% to 60% of initial swing. Then the last 20% of swing, they act to extend the hip and control the knee through concentric contraction. In late swing, the hamstrings act eccentrically to control knee extension and take the hip into extension again.

Gastricnumerous muscle activity starts just after loading at heel strike, remaining active up until 15% of the gait cycle. It then restarts its activity in the last 15% of the swing phase to balance interior muscle is active through both stance and swing phases in running. It is active for about 73% of the cycle. The swing phase, when running, is 623% of the total gait cycle. Its activity is mainly cocenteric or isometric, enabling the foot to clear the sport phase during the swing phase of the running gait.

Elastic sport strategy is described as a mechanism for transferring force from the lower control zone to the upper control zone and back again. In runners, the diagonal elastic mechanism is utilized. This is produced by a constant diagonal stretch and release that is enabled by the body's counterrotation.

The force continually flows up and down these force pathways, ultimately. The pattern of force distribution prevents force being concentrated in one area but allows wide distribution of force throughout the body. At this point, it is only logical to say that it is crucial to have a well functioning central core area to allow this pattern of force distribution to take place efficiently.

The kinetic chain can be described as a series of joint movements that make up a larger movement. Running mainly uses saget or movements as the arms and legs move forward. However, there is also a rotational component as the joints of the leg lock to support the body weight on each side. There is also an element of counter pelvic rotation as the chest moves forward on the opposite side.

This rotation is produced at the spine and is often referred to as the spinal engine. This is also linked to running economy. Discount rotation enables the spinal forces to be dissipated as the foot hits the ground. Runners may complain of feeling of restriction in hamstrings or even shoulders. However, when examined, it may be found that there is actually limitation in rotation of the pelvis causing the problem.

The motion will be altered and a compensational pattern will develop should there be a dysfunctional unit within the kinetic chain. The alteration and the compensation may result in loss of energy, reduction in performance, and it'd be a cause of injury. Spinal engine theory or prospective of human locomotion developed by Dr. Serge Gracovetsky, a professor which prioritizes the observation and analysis of tiragolumab pelvic biomechanics.

This theory holds that woven into the human body design is a fundamental biomechanical couple motion mechanism which serves as the drive for human ambulation. The spinal engine theory also assigns a supportive functional role to the lower extremities, in keeping with the theory of human evolution. Dr. Serge considered the legs as instruments of expression and extensions of the spinal engine.

Coupled motion is a second plane of motion that occurs within a joint system part and parcel to the primary motion. Two or more motions are considered coupled when it is not possible to produce one motion without inducing the second motion. Spinal coupling is due to the morphological shape of the facet joint surfaces and connect the ligaments and spinal curvatures. For example, in the cervical and thoracic spines, left the vertebral rotation in transverse plane is coupled with left vertebral lateral flexion in frontal plate.

Lumbar lateral flexion in frontal plane is coupled with contradirectional vertebral rotation. Right lumbar lateral flexion is coupled with left lumbar rotation. The contradirectional coupled motion patterns of the various regions of the spine evolved for a reason forms its function. The opposing directions of the coupled motion is synergistic. It is the lumber lateral flexion rotation coupling that serves as the spinal engine.

The drive train-- right lateral lumbar flexion will drive, lift the rotation of the lumbar spine and the pelvis, and vice versa. This specific mechanism during right-legged weight bearing, the lumbar spine is pulled into right side bending by the multifidus, longissimus, iliocostalis, and thoracolumbar fascia. This action counter rotates the pelvis as the sacrum is forced into left-side bending and right rotation and vice versa, respectively to the other side. The induced lumbar rotation effectively stores elastic energy in spinal ligaments and annulus fibrosis or intervertebral disks.

It is the return of that energy that drives the gate. In order to return the energy, the spine must be stabilized from above this is accomplished via contralateral arm swing and torso rotation obtained from the contralateral gluteus maximus and tatissimus involvement. The coupling patterns of the spine has evolved to facilitate the return of this force.

The counter rotation is obtained from the spine and not from the legs. The legs do not apply a countertorque to the ground. The countertorque must be provided by the structures above the pelvis. Now consider the biomechanical effect of inadequate arm swing, poor spinal mobility, poor hip mobility, degenerative disk disease, or disco ligamentus injury on a person's walking or running gait.

Most common running injuries-- there are seven injury hotspots that most frequently plague runners. The first one on the list is the runner's knee or patellafemoral pain syndrome. It's the irritation of the cartilage on the underside of the patella. About 40% of running injuries are knee injuries. According to a poll responded by 4,500 runners done by the Runner's World, 13% of the runners suffered with runner's knee.

The second one in the list is the Achilles tendinitis. The Achilles tendon connects the two major calf muscles to the back of the heel. Under too much stress, the tendon tightens and becomes irritated. It makes up 11% of all running injuries. The third one in the list is the hamstring issues-- the muscles that run down the back of our thighs and bend our knees, extend our legs.

It drives us up on the hills and power finishes line kicks. So when our hamstrings are too tight or too weak or they don't perform well, we definitely notice it in our performance. The fourth one down the line is plantar fasciitis. It is not shocking that about 15% of all running injuries strike the foot. With each step, our feet absorb a force several times our body weight.

Plantar fasciitis-- small tears or inflammation of the tendons and ligaments that run from your heel to your toes is usually the top foot complaint among runners. 10% of runners struggle with it in the past year in 2017. The pain which typically feels like a dull ache or bruise along your arch or on the bottom of your heel is usually worse first thing in the morning.

Shin splints-- they refer to the medial tibial stressostrome, an achy pain that results when small terrors occur in the muscles around your tibia. This makes up about 15% of all running injuries. Iliotibial band syndrome-- the Iliotibial band lies along the outside of your thigh from the hip to the knee.

When you run, your knee flexes and extends, which causes the Iliotibial to rub on the side of the femur. This can cause irritation if you take up your mileage too quickly, especially if you're doing a lot of track work or downhill running. It takes up about 12% of all running injuries.

And the seventh one in our list is the stress fracture. Unlike an acute fracture that happens as a result of a slip or a fall, stress fractures develop as a result of cumulative strain on the bone. Runners most often have stress fractures in their tibias, metatarsals, or calcaneus Now one of the most serious of all running injuries-- almost 6% of all respondents to polls being done had one within the past year of their running careers. A new study shows that running can benefit the spine.

A study conducted at Deakin University in Australia implicated 79 participants, and its conclusions challenge existent perceptions of the value of running to the spine-- formerly believed that into vertebral disks were too slow to response and to change in shape and contours. Because disks regenerate at a much slower rate than other tissues, the prestudy perception was that they didn't respond quickly enough. It was even believed that regeneration could not occur within the human lifespan due to the nature of the tissue.

It was believed that the intervertebral disks did not respond to exercise in the same way our muscles do. On the contrary to formal beliefs, the study found that disks were materially strengthened by running. The preventative link between running and back pain was also touched upon in the Deakin University study. It was determined that regular exercise as a lifestyle component was desirable for people of all ages but that starting in the teens through the early 30s had a substantial impact on spine health.