Running Physiology

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Anatomy and Biomechanics of the Spine and the Pelvis

The spine, or vertebral column, is broadly divided into five regions: the cervical spine, the thoracic spine, the lumbar spine, the sacrum, and the coccyx. Though these regions have similar morphology, they have variable biomechanical characteristics, giving rise to the spine's S-shaped curvature. The spinal column forms the central axis of weight-bearing and supports the head as well as transfers the weight of the trunk and abdomen to the legs. The spine provides structure and flexibility to the body. Its unique jointed structure of the spine allows rotation and bending. The spine, plus the rib cage in the thoracic region provides attachment site for multiple muscles.

The cervical spine comprises of 7 vertebrae. It is divided into 2 major segments. Cephalad, occiput and the top 2 vertebrae, the atlas (C1) and the axis (C2), form the craniocervical junction (CCJ). Caudally, C3 to C7, comprise the sub-axial spine, together supports the weight of the cranium and motion. The cervical vertebrae, as a group, produce a lordotic curve.

The thoracic spine comprises of 12 vertebrae. Upper Thoracic Region (T1-T4) is closer to the cervical spine and has similarities in movement and function of the cervical spine. It provides support to the upper body and allows for the attachment of the rib cage. Mid Thoracic Region (T5-T8) makes up the central part of the thoracic spine. It is more rigid and less mobile compared to the upper and lower regions. It provides structural support and stability, protecting vital organs such as the heart and lungs. Lower Thoracic Region (T9-T12) makes up the lower thoracic spine as it transitions into the lumbar spine. It is more flexible compared to the mid thoracic region, allowing for a greater range of motion, and plays a crucial role in weight-bearing and movement.

The lumbar spine consists of five vertebrae, labelled L1 to L5. These vertebrae are larger than those in the cervical and thoracic regions to support the weight of the upper body and allow for movement and flexibility. The vertebral bodies are thick, cylindrical front portion that bears weight. The vertebral arches are rostral, forming the vertebral foramen (spinal canal) where the spinal cord passes through. The spinous processes project off the back of each vertebra, providing attachment points for muscles and ligaments. The transverse processes are laterally situated horizontal projections, serving as additional muscle and ligament attachment points.

Except at the craniocervical junction there are intervertebral discs between each vertebra throughout the spine, providing cushioning and support. Intervertebral discs are cartilaginous structures between adjacent vertebrae composed of annulus fibrosus and nucleus pulposus. The discs comprise about 25% of the length of the vertebral column.

The sacrum and the coccyx consist of five fused vertebrae each. In some cases, the coccyx may be one of four vertebrae. There are junctions between the broad regions of the spine; the cervicothoracic, the

thoracolumbar and the lumbosacral junctions. Spinal junctions are frequent sites for degenerative changes over the long term resulting in stiffness and loss of motion.

The spine, as a complete structure, can undergo axial, lateral, and sagittal rotations and axial, lateral, anterior, and posterior translations.

Pelvis is responsible for supporting upper body weight being defined as the middle part of the human body between the lumbar region of the abdomen superiorly and thighs inferiorly. The human pelvis is composed of the bony pelvis, the pelvic cavity, the pelvic floor, and the perineum. In addition to carrying upper body weight, this multi-surfaced girdle can transfer upper body weight to the lower limbs and act as attachment points for lower limb and trunk muscles.

Spinal and Pelvic Ligaments

The spinal ligaments serve to protect neural structures by restricting the motion of functional spinal units. 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. The 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. The fibres of the anterior longitudinal ligament firmly attach to each other as well as to the entire vertebral disc.

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 portion of the superior vertebral body and inserts into the posterior superior aspect of the lamina of the inferior vertebrae. The intertransverse ligaments and interspinous ligaments join the transverse and spinous processes of adjacent vertebrae. The supraspinous 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.

The key ligaments of the pelvis are the sacrotuberous, sacrospinous, and iliolumbar ligaments that are present in both sexes. Further ligaments include the anterior sacroiliac, anterior sacrococcygeal, posterior sacroiliac, posterior sacrococcygeal, and pectineal ligaments.

Mechanically, ligaments behave like other soft tissues in the body. They are viscoelastic in nature with non-linear functional elastic responses to loading. Their mechanical response has been characterised 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 behaviours of individual ligaments and functional spinal units with motion, radiographs, and mathematical models of the spine.

Failure load is the amount of force at which a ligament or the functional spinal unit fails. The failure loads of spinal ligaments vary depending on the spinal region, and the specific ligament. Anterior Longitudinal

Ligament (ALL) failure load is approximately 2500 N, posterior longitudinal ligament (PLL) failure load is approximately 400-600 N, ligamentum flavum failure load is approximately 300-500 N, interspinous ligament failure load is approximately 300 N, supraspinous ligament failure load is approximately 400 N and the capsular ligament (facet joint capsules) failure load is approximately 700 N.

Failure loads of FSUs are influenced by various factors, including the specific spinal segment (e.g., cervical, thoracic, lumbar), age, and condition of the spine. General failure loads for the cervical FSUs are approximately 1000-1500 N, 2000-3000 N for thoracic FSUs and 5000-6000 N for lumbar FSUs.

The mechanical load on the spinal functional units (FSUs) and ligaments during running varies based on intrinsic and extrinsic factors such as running speed, technique, individual biomechanics, sneakers and surface. When running, the spine experiences a combination of compressive, tensile, and shear forces. These forces are transmitted through the vertebrae, intervertebral discs, and associated ligaments. The lumbar spine, in particular, is subjected to significant compressive forces during running. These forces can be 3 to 5 times of the body weight, depending on running speed and form. For an individual weighing 70 kg (approximately 686 N), this translates to compressive forces of 2058 to 3430 N.

Shear forces, which act parallel to the plane of the vertebral bodies, are also present but are generally lower in magnitude compared to compressive forces. These forces can be influenced by running mechanics and the incline of the running surface.

Ligaments provide stability and limit excessive movement between vertebrae. During running, these ligaments experience dynamic loading as the spine flexes, extends, and rotates. ALL and PLL experience tensile forces as they resist the anterior-posterior motion of the vertebrae. The forces can be substantial but typically remain well below their failure thresholds of 100-300 N. Ligamentum flavum stretches and recoils with spinal motion. Forces in the ligamentum flavum are generally lower compared to the ALL and PLL, estimated to be in the range of 50-150 N. Interspinous and supraspinous ligaments connect the spinous processes of adjacent vertebrae, experience tensile forces during flexion and extension. The forces are variable but generally range between 100-200 N.

The mechanical load on the pelvis and its associated ligaments during running is substantial due to the forces transmitted through the lower extremities and the need to stabilize the body. During running, the pelvis experiences both compressive and shear forces due to the impact of foot strikes and the dynamic movement of the lower limbs. The compressive forces can reach up to 3-5 times body weight while the shear forces are generally lower than compressive forces but significant due to lateral and rotational movements.

During weight bearing posture as well as in running the pelvic ligaments help stabilize the pelvis and transfer loads between the spine and lower limbs. Sacroiliac ligaments are crucial for maintaining pelvic stability and can endure substantial tensile loads during dynamic activities like running. Vleeming et al. (1995) highlight the importance of these ligaments in load transfer, though specific numerical values for failure loads are less commonly detailed in literature focused on dynamic activities like running. Iliolumbar ligament similar to the sacroiliac ligaments, stabilizes the connection between the lumbar spine and the pelvis. Tensile forces in the iliolumbar ligament during running are significant, though

precise values during running are not often specified. Pubic symphysis absorbs and distributes forces from the legs through the pelvis. It can endure significant compressive and shear forces during activities like running.

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 for 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 sagittal plane.

Extension refers to bending backward about that axis. Together, flexion and extension are referred to as sagittal 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.

Lumbar Intervertebral Discs

The vertebral bodies are connected and kept separated by the intervertebral disks. The disc is composed of the annulus fibrosus 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 disc cells. Some blood vessels approach the annulus and 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 disc throughout adulthood.

The nucleus pulposus is located poster-centrally in the disc, 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 fibres in an aqueous gel rich with proteoglycans. The collagen molecules in the nucleus have also been found to have proteoglycan molecules bound to their ends.

The water content in the normal nucleus of human lumbar discs decreases from about 90% of its total volume during the first year of life to 70% in the 80th year and beyond. The annulus fibrosus is composed of concentric layers of collagen fibre bundles in a helicoid manner. Observations using scanning electron

microscopy have shown the fibres in the inner third of the annulus to interconnect with the cartilaginous end plate.

The fibres in the outer portion are firmly bound to the epiphyseal ring of the vertebral body. The disc fibres have been found to be almost exclusively composed 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 fibre orientations alternate from layer to layer, with the fibres generally orientated at an angle of approximately plus or minus 30 degrees with respect to the horizontal plane. Specifically, the fibre orientations change from about plus or minus 31 degrees in the outer annulus to plus or minus 22 degrees in the inner annulus.

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

Intradiscal pressure (IDP) is a measure of the pressure within the intervertebral discs of the spine, which can vary significantly with different postures and activities. Understanding these pressures, particularly in the L3-L4 disc, is crucial for assessing the biomechanical impact of various movements and for developing guidelines to prevent disc injury. The intradiscal pressures for L3-L4 disc during various movement patterns are as follows; Standing posture is approximately 0.5 MPa, sitting (relaxed posture) is approximately 0.83 MPa, sitting (with forward lean) is approximately 1.1 MPa, lifting (straight back, bent knees) is approximately 1.7 MPa, lifting (bent back, straight legs) is approximately 2.3 MPa, lying down is approximately 0.1 MPa, flexion (forward bending) is approximately 1.2 MPa and extension (backward bending) is approximately 0.6 MPa

Though direct intradiscal pressure measurements during running are difficult to attain and are rare Wilke et al, Rohlmann et al, and Brinckmann et al have documented the following measurements of the lumbar IVDs during daily activities of dynamic loading; 1.5-3.0 MPa, 2.5 MPa, and 2.3 MPa.

Throughout the day, the vertebral column is subjected to compressive stress 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 pulposus is related to the axial compression applied to the disk. When the compressive load exceeds the interstitial osmotic pressure of the tissues of the disc, water is extruded through the disc wall.

The result is a loss in disc 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 axial compression is minimized. During the day, when a person is usually under the constant force of gravity and muscular activity, the intervertebral discs lose as much as an inch in height, which is about 2.5 to 3 centimetres. 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 a 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.

Biomechanics of Running

Running is a matter of bipedal gait, which represents a natural progression from walking. The progression from walk to run occurs as 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 kilometres per hour.

As a hallmark, the running gait replaces the double support phase of walking with a double float phase where there is no contact with the ground. There are a series of single-leg and double-float periods. The running stand 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 discs due to compressive loading. When the load changes during the day as a result of varying physical activities, the rate of disc 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 kilometres, and then immediately following the run. The findings revealed that the spinal column height was significantly less following the run. More interestingly there was a significant greater amount of height loss during one hour of running than during 7.5 hours of relatively static activities.

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. The intervertebral disc is of great mechanical and functional importance. A fundamental understanding of this structure and biomechanics is necessary in order to hypothesise a relationship between physical activity and intervertebral disc height. The intervertebral discs comprise over one-fourth the length of the vertebral column.

Intervertebral discs are fibrocartilaginous articulations designed for strength, and together with their adjoining vertebral bodies, they function as synthesis joints. They serve as a cushion between vertebral bodies to store energy and distribute loads. Each disc is composed of three distinct parts: the nucleus pulposus, the annulus fibrosus, and cartilaginous end plates. At the centre of the disc is the nucleus pulposus, which is encased above and below by the cartilaginous end plates and encircled by the annulus fibrosus.

The nucleus pulposus is composed of a loose network of fibres in a mucopolysaccharide gel, which contains from 70% to 90% water. It is essentially avascular and not innervated. Nutrients reach the

nucleus by diffusion from the blood vessels that lie around the periphery of the annulus fibrosus and from the vascular cavities in the central portion of the cartilaginous end plates.

The nucleus pulposus allows for movement in the spine by deforming under compression, tilting and twisting to alter the shape of the disc, and circling the highly organised layers of collagen fibres that comprise the annulus fibrosus. The annulus contains essentially the same material as the nucleus, although its water content is greatly reduced. And its fibre content has greatly increased.

The fibres are orientated obliquely with each layer, about 60% to 70% vertical, with adjacent layers running in alternating directions. This highly organised arrangement and substantial fibre content are what give the annulus fibrosus 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.

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

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 the double-sport period present in walking is not present when running. There is also the addition of a double float period during running which both feet are off the ground. The amount of time that the runner spends in a float increases as the runner increases in speed.

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

The joint motion of the running gait cycle, at the beginning of the stance phase, the hip is in about 50 degrees of 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 of 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 of flexion just before the swing phase, and during 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 the 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 standing

phase of running and as it enters the swing phase. 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, preparing for the heel to strike. The lower limb medially rotates during the swing phase, continuing to medially rotate at heel strike. The foot pronates at heel strike. Lateral rotation of the lower limb, 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 Medius are both active at the beginning of the stance phase and also at the end of the swing phase. Tensor fasciae latae is active from the beginning of stance and also at the end of the swing phase; it is also active between early and mid-swing.

Adductor magnus is active for about 25% of the cycle, from late stance to the early part of the swing phase. Iliopsoas activity occurs during the swing phase for 35–60% of the cycle. Quadriceps work in an eccentric manner for the initial 10% of the stance phase. The role of the quadriceps muscle 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 behaviour, so it can extend the knee to prepare for a 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 the initial swing. Then, in the last 20% of the 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.

Gastrocnemius 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 activity through both stance and swing phases in running. It is active for about 73% of the cycle. Its activity is mainly concentric 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. The pattern of force distribution prevents force from being concentrated in one area but allows a 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 movements that make up a larger movement. Running involves a complex sequence of coordinated movements primarily utilizing the lower body, core, and to some extent, the upper body for balance and propulsion. Here are the main types of movements and muscle actions involved in running:

Lower Body Movements

1. Hip Flexion and Extension:

- Flexion: Bringing the thigh forward, primarily using the hip flexors such as the iliopsoas and rectus femoris.
- Extension: Driving the thigh backward, primarily using the gluteus maximus and hamstrings.

2. Knee Flexion and Extension:
   - Flexion: Bending the knee during the swing phase, involving the hamstrings.
   - Extension: Straightening the knee during the stance phase, involving the quadriceps.
3. Ankle Dorsiflexion and Plantarflexion:
   - Dorsiflexion: Lifting the toes up towards the shin, involving the tibialis anterior.
   - Plantarflexion: Pushing the foot down (toe-off), involving the gastrocnemius and soleus.
4. Foot Pronation and Supination:
   - Pronation: Rolling the foot inward to absorb shock.
   - Supination: Rolling the foot outward to stabilize and push off.

Core Movements

1. Trunk Rotation:
   - Rotation of the torso, aiding in balance and transferring momentum. This involves the oblique muscles and the transverse abdominis.
2. Lateral Flexion:
   - Side-to-side movement to maintain balance, involving the oblique muscles and quadratus lumborum.
3. Stabilization:
   - Core muscles, including the rectus abdominis, obliques, and erector spinae, work to stabilize the spine and pelvis.

Upper Body Movements

1. Arm Swing:
   - Forward and backward motion of the arms, which helps with balance and propulsion. This involves the deltoids, biceps, and triceps.

Phases of Running Gait Cycle

1. Stance Phase:
   - Initial Contact: Heel (or midfoot/forefoot) strikes the ground.
   - Midstance: The body weight moves over the support leg.
   - Toe-Off: The foot pushes off the ground.
2. Swing Phase:
   - Initial Swing: The leg lifts off the ground, moving forward.
   - Mid swing: The leg moves directly under the body.
   - Terminal Swing: The leg prepares for initial contact again.

Key Muscles Involved

- Gluteus Maximus: Hip extension
- Hamstrings: Knee flexion and hip extension
- Quadriceps: Knee extension
- Calf Muscles (Gastrocnemius and Soleus): Plantarflexion
- Hip Flexors (Iliopsoas and Rectus Femoris): Hip flexion
- Tibialis Anterior: Dorsiflexion
- Core Muscles (Rectus Abdominis, Obliques, Transverse Abdominis, Erector Spinae): Stabilization and rotation
- Upper Body Muscles (Deltoids, Biceps, Triceps): Arm swing

Coordination and Efficiency

Efficient running involves the coordinated action of these muscle groups and unrestricted movements of the related skeletal articulations to minimize energy expenditure and reduce the risk of injury. Proper form and technique are crucial for optimizing performance and maintaining the health of joints and muscles involved in running. Understanding these movements can help in designing effective training and rehabilitation programs, as well as improving running form to enhance performance and prevent injuries. The rotation is produced at the spine and is often referred to as the spinal engine. This is also linked to the running economy. The rotation enables the spinal forces to be dissipated as the foot hits the ground. Runners may complain of a feeling of restriction in their hamstrings or even their shoulders. However, when examined, it may be found that there is actually a limitation in the 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 a loss of energy and a reduction in performance, and that would potentially be a cause of developing an injury. Spinal engine theory, or the perspective of human locomotion, was developed by Dr. Serge Gracovetsky, a professor who prioritises the observation and analysis of thoracolumbar pelvic biomechanics.

This theory holds that the human body design is a fundamental biomechanical couple motion mechanism that 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 of 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, which connect the ligaments and spinal curvatures. For example, in the cervical and thoracic spines, left vertebral rotation in the transverse plane is coupled with left vertebral lateral flexion in the frontal plate. Lumbar lateral flexion in the frontal plane is coupled with contra-directional vertebral rotation. Right-lumbar lateral flexion is coupled with left-lumbar rotation. Though the cervical spine coupled motion studies show consistency and agreed upon the thoracic and the lumbar spine coupled motions do not.

The contra-directional coupled motion patterns of the various regions of the spine evolved for a reason to form their function. The opposing directions of the coupled motion are synergistic. It is the lumbar lateral flexion-rotation coupling that serves as the spinal engine.

The drive train—right lateral lumbar flexion—will drive the rotation of the lumbar spine and the pelvis, and vice versa. In this specific mechanism, during right-legged weight bearing, the lumbar spine is pulled into the 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 the spinal ligaments and annulus fibrosus of the intervertebral discs.

It is the return of that energy that drives the gate. In order to return the energy, the spine must be stabilised from above; this is accomplished via contralateral arm swing and torso rotation obtained from the contralateral gluteus maximus and latissimus involvement. The coupling patterns of the spine have 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 counter torque to the ground. The counter torque 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 disc disease, or ligamentous injury on a person's walking or running performance.

The most common running injuries: There are seven injury hotspots that most frequently plague runners. The first one on the list is runner's knee, or patellofemoral pain syndrome. It's an irritation of the cartilage on the underside of the patella. About 40% of running injuries are knee injuries. According to a poll of 4,500 runners done by the Runner's World, 13% of the runners suffered from a runner's knee. The second one on the list is Achilles tendinitis. Under increased amounts of physical stress, the tendon tightens and becomes irritated. It makes up 11% of all running injuries. The third one on the list is hamstring issues. Hamstrings drive 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. 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 refer to the medial tibial stress syndrome, an achy pain that results when small tears occur in the muscles around the tibia. This makes up about 15% of all running injuries. Iliotibial band syndrome is when the knee flexion and extension cause the iliotibial band 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 on 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.

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