~ EQUINE ANATOMY ~

UNLOCKING THE SECRETS OF THE EQUINE STIFLE JOINT

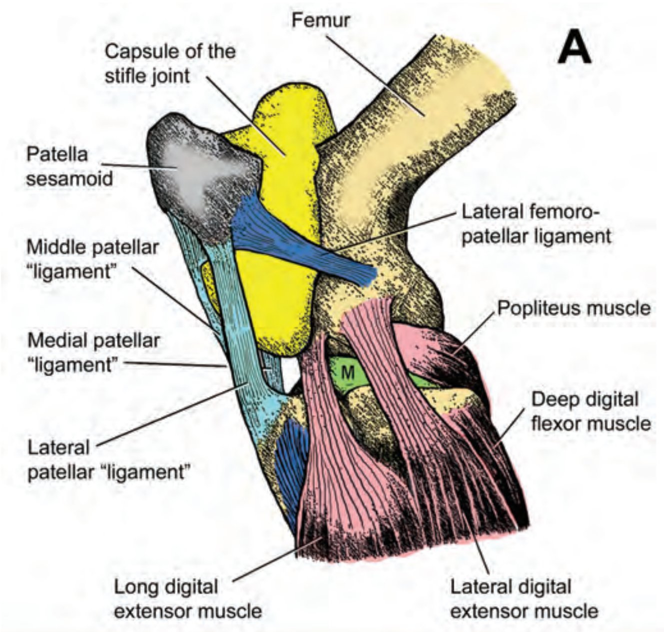
Locking stifle joints are among the most frequently diagnosed locomotion issues in performance Morgans. Dr. Deb explains the mechanics at play.

By Deb Bennett, Ph.D.

A JOINT WITH A TWIST

At first glance, the stifle joint appears to be a huge mistake, the worst-designed part of the musculoskeletal system. Unlike the shoulder joint, hip socket, hock, elbow, vertebral joints, or the coffin joint, the articular surfaces of the femur and tibia, which face each other to form the stifle joint, do not closely correspond in shape. There is no neat ball-and-socket fit, no tight tongue and groove geometry, and because of that the joint appears to have been "post-engineered" with a whole slew of auxiliary rims, pads, and straps that work to stabilize it and hold it together (Figs. 1 and 2).

ABOVE: The ability of the stifle joint to lock permits horses to snooze while standing on only three legs, as illustrated by these resting mares at the Jackson Ranch (photo © Heidi Osgood Metcalf).



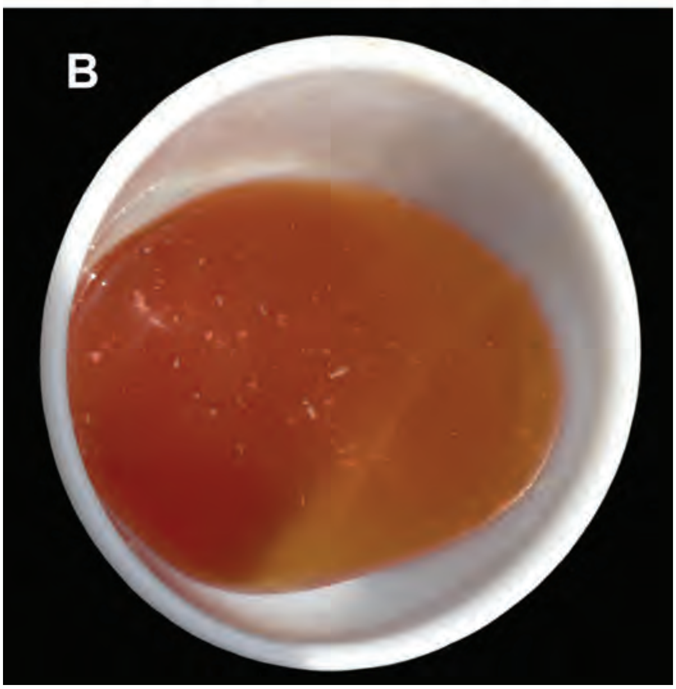


FIG. 1. A. Anatomy of the equine stifle joint; left stifle in lateral view. The stifle capsule (yellow) contains viscous synovial fluid. In this cadaver specimen, it has been injected with saline solution, over-inflating it to show its shape and volume. **B.** This sample of synovium taken from a yearling draft horse cadaver measured 12 ounces (one cup holds 16 ounces). **COLOR CODE: tan:** bone; **gray:** sesamoid; **yellow:** joint capsule filled with synovial fluid; **light blue:** tendon; **dark blue:** ligament; **green:** cartilage ("M" stands for "meniscus"); **red:** muscle.

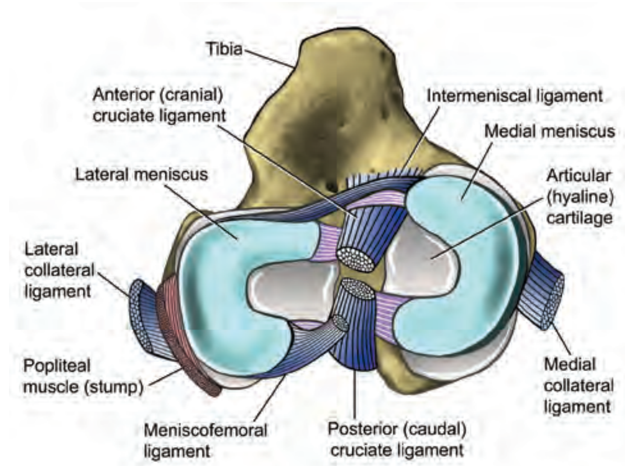


FIG. 2. End-on view of the top of a left tibia showing the menisci and cruciate ligaments that are unique to the stifle joint. The front of the bone faces to the top. The cruciate ligaments connect upward to deep fossae in the distal femur; they're called "cruciate" because they cross. They serve to stabilize the joint when the tibia rotates about its spine. Ligaments that anchor the menisci to the tibia (the menisco-tibial ligaments) are shown in purple.

In terms of fetal development and evolutionary history, the stifle joint's design is indeed something of an "afterthought." In the earliest vertebrates (lungfish), the humerus (upper arm) element of the forelimb has a straight shaft. Ancient amphibians were the first to develop a twisted humeral shaft that reorients the limb so that when it swings forward the palm can be set down flat against the substrate (Fig. 3). Reptiles, birds, and mammals, including horses, have inherited this design (Fig. 4). Because the necessary twist is incorporated into the shaft of the humerus, the elbow joint and all the bones and joints located farther down the limb need none. For example, the design of the elbow joint in horses is very straightforward. It functions as a simple hinge that can make but one motion, flexion-extension. As a result, in horses and other mammals, the elbow joint is rarely injured as a result of normal locomotion.

The anatomical and functional changes that occurred through time in the hind limb are another story. In ancient amphibians, the better the twisted humerus worked, the less the need for the hind limb to assist in crawling. The hind feet could just be dragged along with the body, and thus the shaft of the femur remained untwisted (Fig. 3). Many other changes occurred over a long time before the fossil record presents species in which the palmar surface of the hindfoot can be set down flat against the ground, but this group includes the reptile family from which mammals arose. The genes that govern the developmental sequence in these "higher" vertebrates do not allow for a twist (analogous to that in the humerus) to develop in the femur (Fig. 4). Instead, the necessary twist develops primarily within the stifle joint, and it is this that necessitates all the ancillary reinforcement in the form of menisci and cruciate ligaments that we find in this joint.

In a large animal such as a horse, fast running generates significant forces (torque, angular momentum, concussion, bending) that make it necessary for the hoofs to meet the ground "flat." As part of the twist built into the stifle joint, horses have a prominent tibial spine that fits into a deep notch (the intercodyloid fossa) in the distal aspect of the femur (Figs. 5, 6, 7). The spine allows rotation around the long axis of the tibia in addition to flexion and extension of the stifle joint.

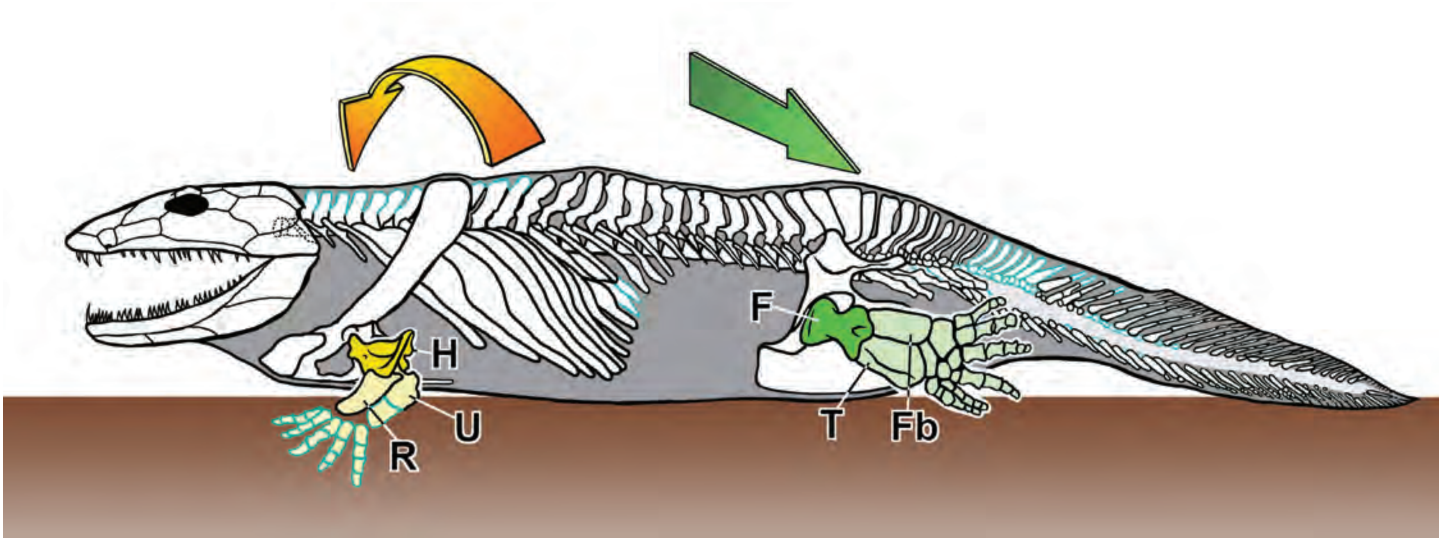


FIG. 3. The amphibian *Ichthyostega* lived at the end of the Devonian Period, about 360 million years ago. It was a fairly large animal, measuring 2 to 3 feet in length from nose to tip of tail. Capable of crawling through muddy swamps, it possessed a twisted humerus (yellow) that permitted it to place its forepaws palm-down against the ground. By contrast, the shaft of its femur (green) is not twisted; neither had it developed a twist within the femoro-tibial joint (the equivalent of the equine stifle) so that when it moved across land, the hind limbs were merely dragged along parallel to the body. Light blue color indicates restored missing elements. The carpal bones and tail vertebrae in this species remained cartilaginous throughout life, did not fossilize and are therefore not preserved in the fossil record. Abbreviations: **H** = humerus; **R** = radius; **U** = ulna; **F** = femur; **T** = tibia, **Fb** = fibula. (*Image: Reconstruction of skeleton after Ahlberg, Clack & Blom, 2005 [Nature 437: 137-140])*

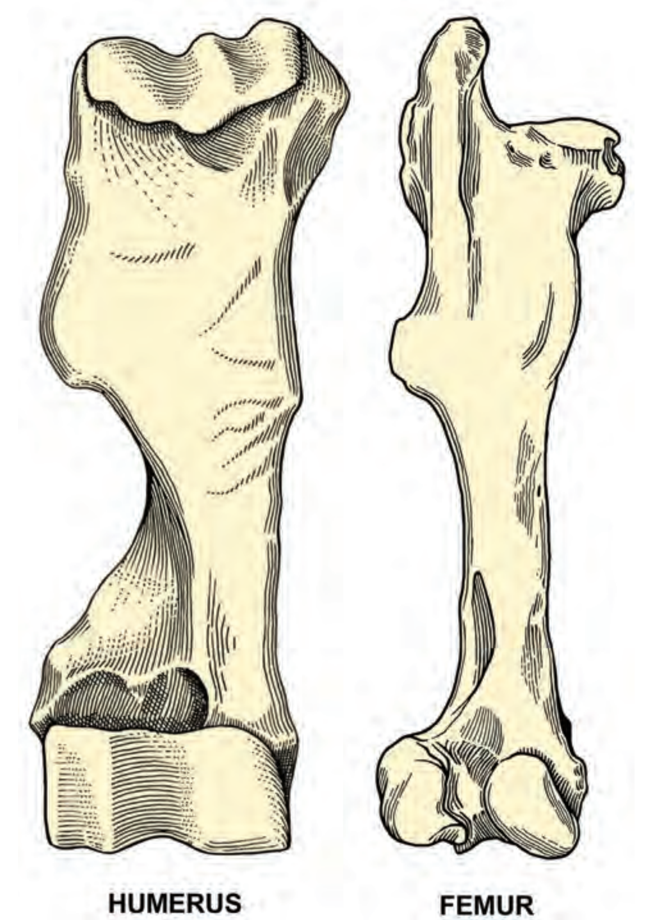


FIG. 4. Humerus and femur bones of the horse in posterior (caudal) view, reduced to approximately the same length. The femur has a straight shaft, whereas the strong twist in the humeral shaft is easy to see.

In normal equine locomotion, the tibia (and all structures below it) rotates outward at the extreme of retraction, then rotates inward again as the limb reaches forward. Looking forward from a point behind the horse, the plane that bisects the horse's hind limb orients outward when the horse stands still. As the limb is brought forward and the tibia rotates inward, the hind limb plane is brought parallel or nearly parallel to the midline plane of the body. This allows the hind hoof to strike on both heels at the same instant and allows the toe to orient forward rather than outward at breakover.

PATELLAR "LIGAMENTS"

Before the stifle locking mechanism can be properly understood, it is necessary to clear up a couple of conceptual confusions in equine anatomy study that arise out of traditional terminology. Sesamoids are usually called "bones." Although they are indeed mineralized, they are not true bones because they do not have the same embryological development and they lack a periosteum or "bone skin." The true nature of sesamoids is that they are fibro-cartilaginous bursae that become mineralized. They are always found within, or closely associated with, muscle tendons, and they exist in order to increase leverage and simultaneously reduce pressure and friction at sharply angled joints. The horse has three sets of sesamoids: the sesamoids properly so-called, a pair located on the rear aspect of each fetlock joint; the navicular sesamoids, located on the rear aspect of the coffin joints; and the patellas, which "cap" the stifle joint. The patella is the largest sesamoid in the mammalian body.

A second terminological confusion relates to the nature of tendons. There is no such thing as "a tendon" that exists by itself; every tendon is an extension of a muscle. Neither are tendons

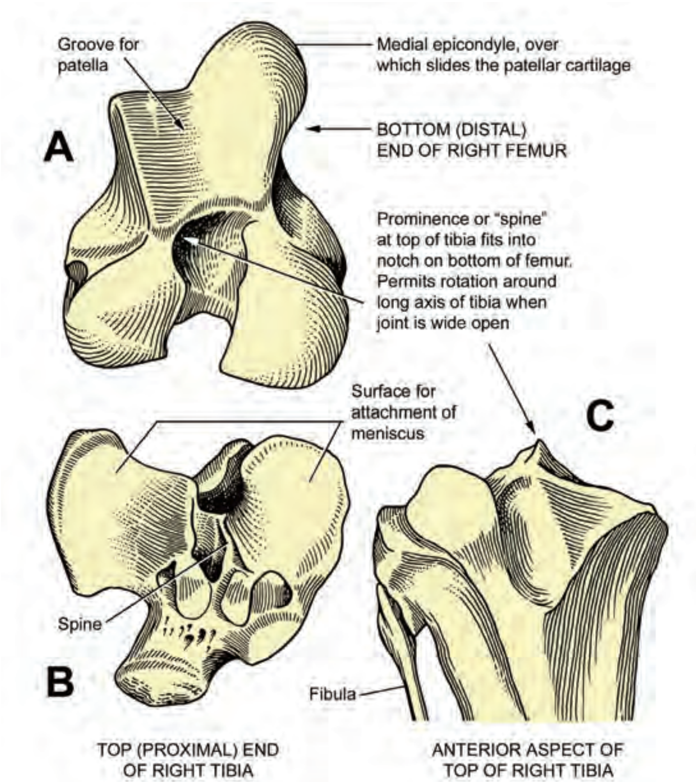


FIG. 5. Bones that articulate to form the stifle joint. **A.** End-on view of distal end of the femur. **B.** End-on view of the proximal end of the tibia. **C.** Tibia viewed from the front.

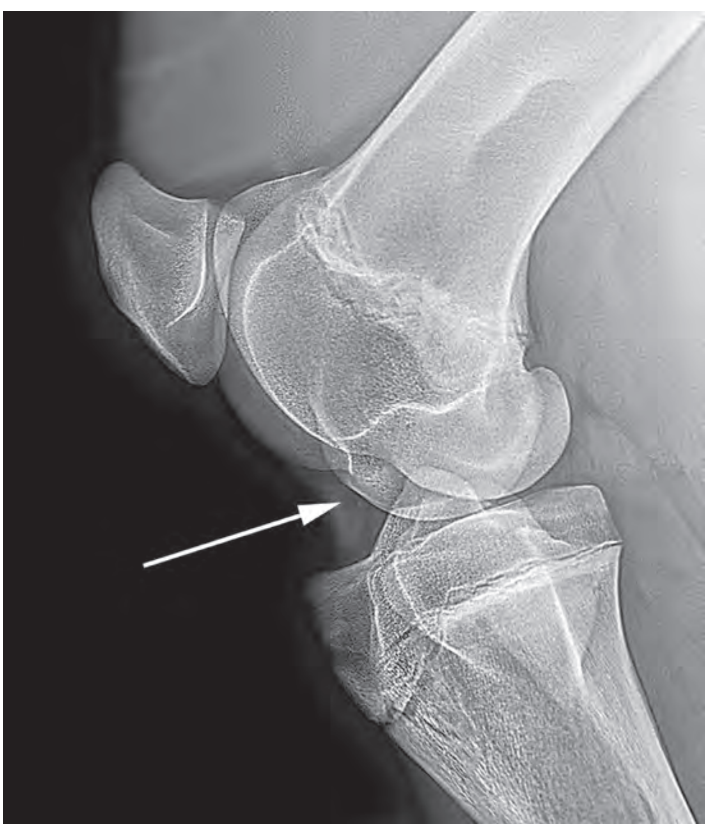


FIG. 6. Digital X-ray of left stifle joint in lateral view; horse's head to left. The tibial spine (arrow) fits up into the space between the distal condyles of the femur *(image courtesy Dan Sweet, DVM).*

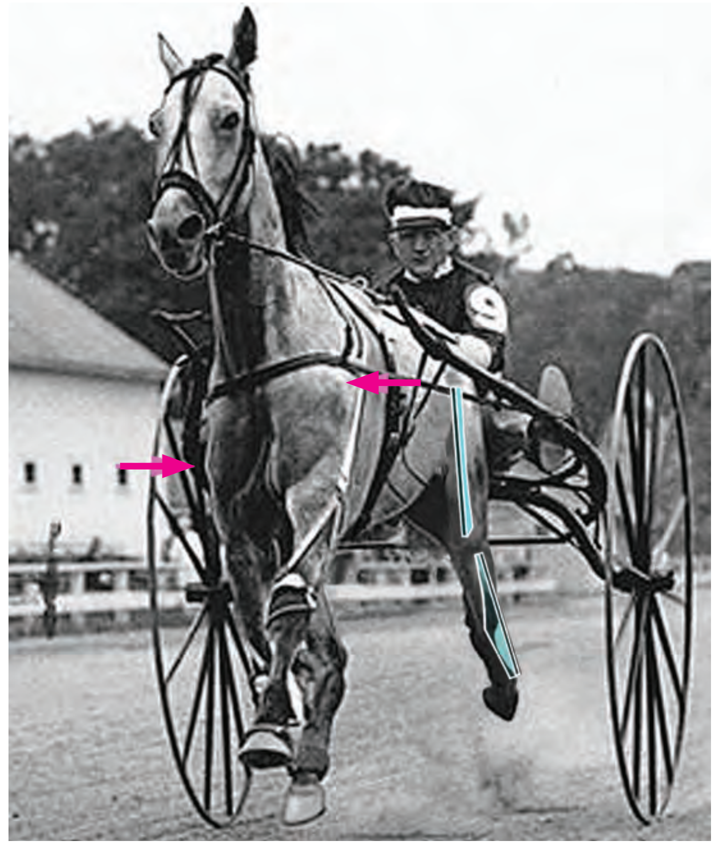


FIG. 7. Greyhound (f.1932–d.1965), an American Standardbred by Guy Abbey out of Elizabeth by Peter the Great. Called "the king of kings," Greyhound is considered by many to be the greatest racing trotter that ever lived. He had flawless technique, and this photo demonstrates everything I am teaching in this article about hindlimb orientation, articulation, and function. Note that the plane that bisects the haunch from hip socket to stifle is not oriented parallel to the long axis of the body, but angles outward to the front. The hock orients inward to the rear and the hind cannon and toe orient more outward than the stifle, because at the extreme of retraction the tibia rotates outward on the femur. It does the opposite at the extreme of protraction, so as to permit the hoof to contact the ground with its toe pointing nearly straight forward. Pink arrows show the huge range of up-down movement of the shoulders.

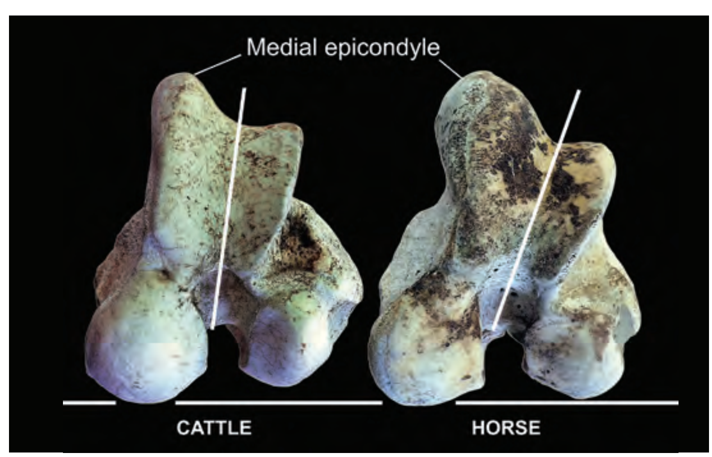
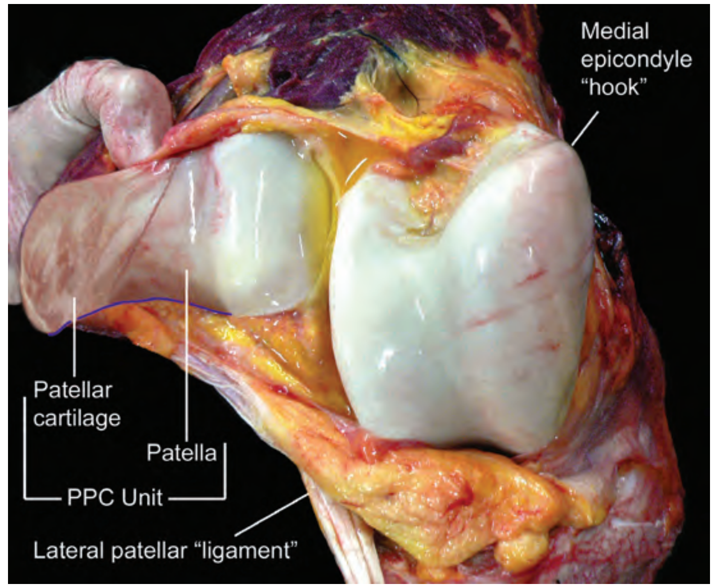


FIG. 8. The distal end of the femur in cattle vs. horses. Differences in shape between the two species are subtle but significant. Both have an enlarged medial epicondyle, but the epicondyles are more asymmetrical in horses than cattle (white lines). Cattle also lack the notch at the top of the medial epicondyle and are thus unable to securely lock the stifle.



LEFT: FIG. 9. A pair of Burchell zebras having a companionable afternoon snooze at Taronga Zoo in Sydney, Australia. The zebra on the left has locked its right stifle joint and is resting its left hind leg; the one on the right has locked its left stifle joint and is resting its right hind leg. When an equine locks one stifle, the pelvis tilts over toward the opposite side; the striped pattern of zebra hide makes this very easy to see.

ABOVE: FIG. 10. This view looks directly at the front aspect of the stifle joint in a carcass donated to my Equine Studies Institute lab. The anterior compartment has been opened by cutting the medial patellar ligament and then swinging the PPC unit to the side like a garden gate. When the membrane that seals the joint (the joint capsule) was cut open, most of the yellow synovial fluid drained out, but some is still visible. The smooth, shiny bluish-white hyaline cartilage that lines the opposing joint surfaces is visible; tiny red lines are blood vessels. The diagonal line of junction between the patella and patellar cartilage (dark red) is easy to see and palpate. The inferior rim of the PPC unit has been highlighted by a thin purple line; it is this rim that slides over the medial epicondyle "hook."

"attached" to muscles, but rather they are intimately part of the muscle; there is no line of junction where you could say "the tendon is 'attached' or 'stitched on' here." Tendons differ from ligaments in terms of cellular composition and histological appearance, but also developmentally and functionally.

Now we can talk about the stifle joint. Every standard anatomy book refers to the three strong bands that connect the patella downward to the tibia as "patellar ligaments" (Figs. 1, 11, 12). If a ligament is defined as a connective tissue band that connects bone to bone, then the use of the term "ligament" in this context is completely inaccurate since the patella is not a bone. The patella is an ossified (mineralized) bursa associated with the tendon of insertion of the powerful quadriceps muscle group, located on the front of the thigh. The patella is embedded within this tendon, and the patellar "ligaments" that extend downward from the patella to the top of the tibia are actually the tendons of insertion of the quadriceps muscle (and this is what embryological studies prove them to be). For this reason, throughout this article the three patellar "ligaments" are referred to in quotation marks.

SNOOZING VS. DEEP SLEEP

The equine stifle locking mechanism is a specialized hook-and-loop system, in which the hook is formed on the end of the femur and the loop is formed by the middle and medial patellar "ligaments." This anatomy is not present in the earliest equids such as *Eohippus* or *Miohippus*. An enlarged medial epicondyle capped by a notch—the lockable stifle design at the bottom end of the femur (Fig. 8)—does not appear until the late Miocene (about 12 million years ago) in the genus *Protohippus*. This equine species lived in open savanna and is a direct ancestor of the modern horse genus *Equus*.

The function of stifle-locking is to allow the horse to rest the muscles of its hindquarters and allow it to snooze in a standing position. To "rest a hind leg" the horse engages the locking mechanism on one side (Fig. 9). The need for this is related to herd behavior as well as physiology. In deep sleep, mammals lose consciousness and along with that, control of most muscles; a horse that loses consciousness while standing will fall down, regardless of whether its stifles are locked. To sleep deeply, a horse must therefore lie down.

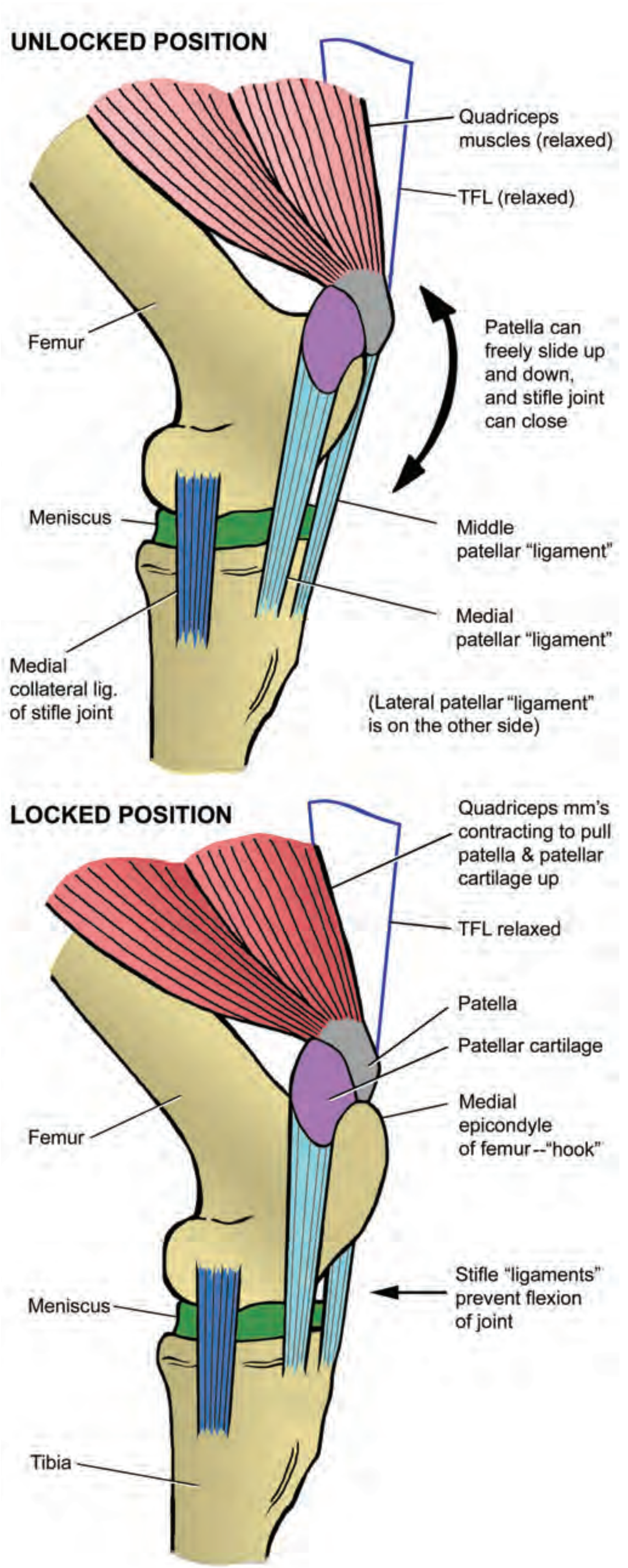


FIG. 11. The stifle locking mechanism; a right stifle in lateral view. **TOP:** unlocked position; **BOTTOM:** locked position. **COLOR CODE: tan:** bone; **gray:** sesamoid; **light blue:** tendon; **dark blue:** ligament; **green:** cartilage; **red:** muscle.

Horses do not sleep straight through the night. Behavioral studies show that the longest deep (rapid eye movement or "REM") sleeps they take are in the range of about a half-hour. During the night, they periodically awaken, arise, and graze. Nonetheless, horses require a total of five to seven hours of sleep per day. Since they generally do not sleep straight through the night, they are fond of taking an afternoon nap. Typically, during naptime, one or a few herd members stand guard while the others lie down. The standing horses merely doze; they remain conscious. The stifle locking mechanism, which holds the locked hind limb in extension, allows them to doze, getting what is called slow-wave sleep. From one day to the next, "guard duty" is passed around the herd, so that every animal gets an adequate amount of rest.

STIFLE LOCKING MECHANISM

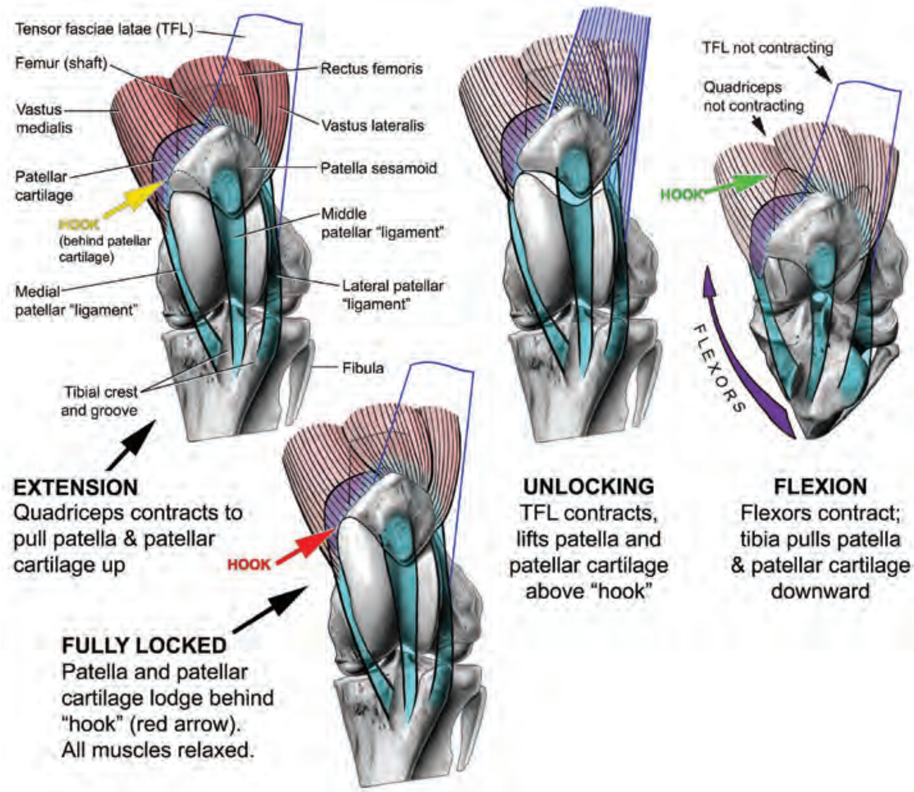
In many of their adaptations, cattle and horses parallel each other. Cattle have an enlarged medial epicondyle—part of the "hook" formation required to lock the stifle joint—(Fig. 8), but they lack the notch that catches the "ligament" loop and that ensures that the equine stifle, once in the locked position, will not slip loose (Figs. 1, 11, 12). As a result, cattle do not characteristically "rest a hind leg" as horses do. Shape differences between the femurs of cattle and horses are subtle but significant. There is more asymmetry and outward orientation in the distal articular surface of horses than in cattle (white line in Fig. 8).

A closer look at the "loop" portion of the locking mechanism reveals that it is created not only by the patellar "ligaments" but also by the patella and patellar cartilage (this forms the patella-patellar cartilage or PPC unit) (Fig. 10). The inferior rim of the PPC unit plus the medial patellar "ligament" form a smooth, broad "U" shape (similar to that formed by the web of your thumb when you close your fingers but spread the thumb wide to form the letter "C"). It is this edge that lodges in the notch atop the medial epicondyle to lock the stifle joint.

One can easily observe the horse deliberately lock one stifle to rest a hind leg; contraction of the bulky quadriceps muscle that lifts the PPC unit is easy to see. The quadriceps then relax, dropping it into the notch above the medial epicondyle. The animal stands higher on the locked hind leg with the hips rolled over toward the opposite hind limb, which often will be flexed and rested upon the toe (Fig. 9). Because the patellar "ligaments" are strong but not very stretchy, when the PPC unit lodges in the medial epicondyle notch, the stifle joint cannot be flexed.

UNLOCKING IS MORE IMPORTANT THAN LOCKING

During normal flexion and extension of the stifle, the patella slides up and down in the patellar groove (black arrow in Fig. 11). The quadriceps pull the PPC unit upward when the joint is opened, while the patellar "ligaments" pull it downward when flexor muscles such as the semitendinosus and semimembranosus pull the tibia back to close the joint (purple arrow in Fig. 12). The tensor fasciae latae muscle (TFL) is the most external of the muscles that extend the stifle joint. Its power to extend the stifle is actually minimal, but its function is crucial because it can lift the patella. It originates on the point of hip high above and lateral to the stifle joint and inserts on the patella be-



ABOVE: FIG. 12. The stifle joint locking-unlocking mechanism as seen from the front. From extension (yellow arrow), the patella can be pulled upward and then released behind the medial epicondyle; this is the fully locked position (red arrow). In movement, the TFL muscle must fire at exactly the right instant; the normal sequence is from extension (yellow) to unlocking to flexion (green arrow). When the flexor muscles contract (curved purple arrow), they pull the distal end of the tibia caudally and the patellar "ligaments" pull the patella downward in the patellar groove. This is a very important image and concept for every horse owner and trainer to grasp.

RIGHT: FIG. 13. The LaBrea Tar Pit horse, *Equus occidentalis* (skeletal mount on display at the George C. Page Museum in Los Angeles, California). The view is of the skeleton directly from the rear. The TFL muscle (in red) is the only hip flexor/stifle extensor whose origin is so far away from the midline plane of the body. Its lateral position gives it leverage so that when it contracts it pulls the patella up and laterally and then holds it up long enough for flexion of the joint to begin *(see Figure 12)*.

low (Fig. 13). Thus, it has the perfect geometry not for stifle locking but for the even more necessary stifle *Un*-locking (Fig. 13).

The stifle joint is opened wide twice in every trot stride (camera frames marked by red stars in Fig. 14) and may be opened so wide that the PPC unit is pulled high enough to clear the medial epicondyle and thus potentially catch on the femoral hook. This is the case even in horses with excellent conformation and even in riding styles that call for sharp flexion of the hind joints. It's a serious potential downside, because having the locking mechanism unexpectedly engage during locomotion totally prevents stifle flexion and jerks the horse to an abrupt and painful halt. Medically this is termed "upward fixation of the patella" or UFP (Fig. 15). If the horse is moving at any speed, it can tear or catastrophically rupture the patellar "ligaments."

It is also possible for the locking mechanism to partially engage without fully locking ("delayed patellar release" or DPR). When this happens, the PPC unit drags over the top of the medial epicondyle ("sticking" or "rubbing" stifles). This irritates or can even abrade the inner lining of the PPC unit, provoking fluid buildup and swelling (a common cause of gonitis, or inflammation of the knee) (Fig. 16b). DPR and UFP are more frequent in horses built with wide-open hindlimb joints ("post-legged" conformation) (Fig. 16a) but discoordination, commonly caused by bad riding practices which prevent the horse from rounding its lumbar back, can cause it to happen in a horse of any build, even one with highly angulated hind limb conformation.

The tensor fascia latae muscle (TFL) is responsible for unlocking the stifle and for preventing it from becoming locked during locomotion. The TFL is structured with a narrow belly that transitions into a strap-like tendon. Its contractions are not very powerful and do not have a lot of up-down range; it can contract only just enough to raise the PPC unit above the medial epicondyle. It is crucial, therefore, that the TFL contract within a small window of time—a matter of milliseconds—at the two points in the trot stride (full protraction and full retraction) during which the PPC unit has been lifted by the quadriceps high enough to potentially

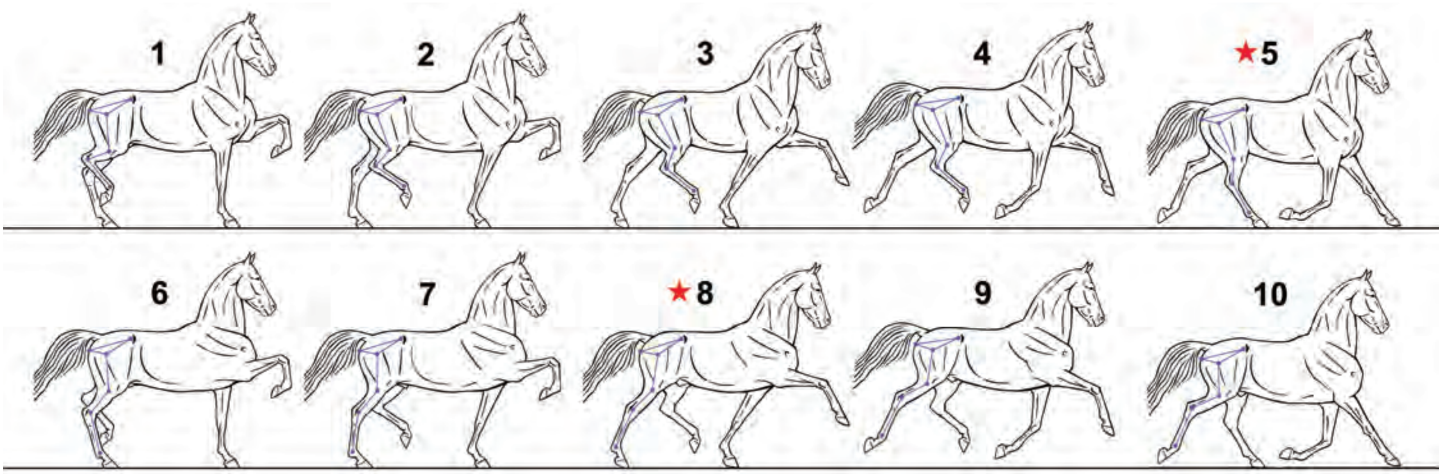
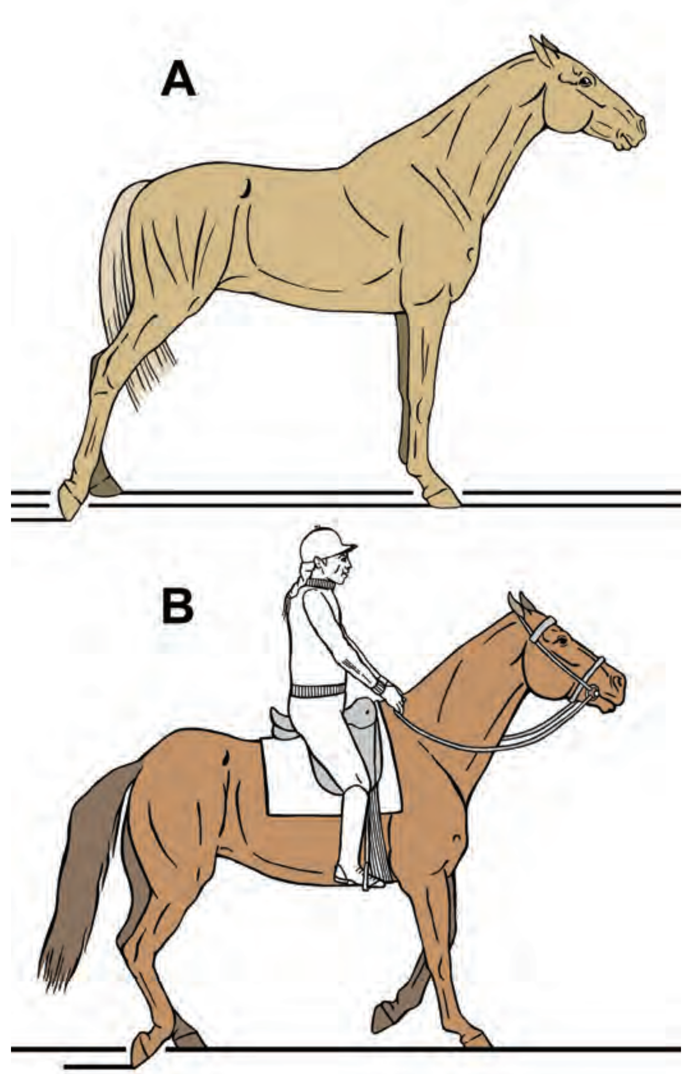


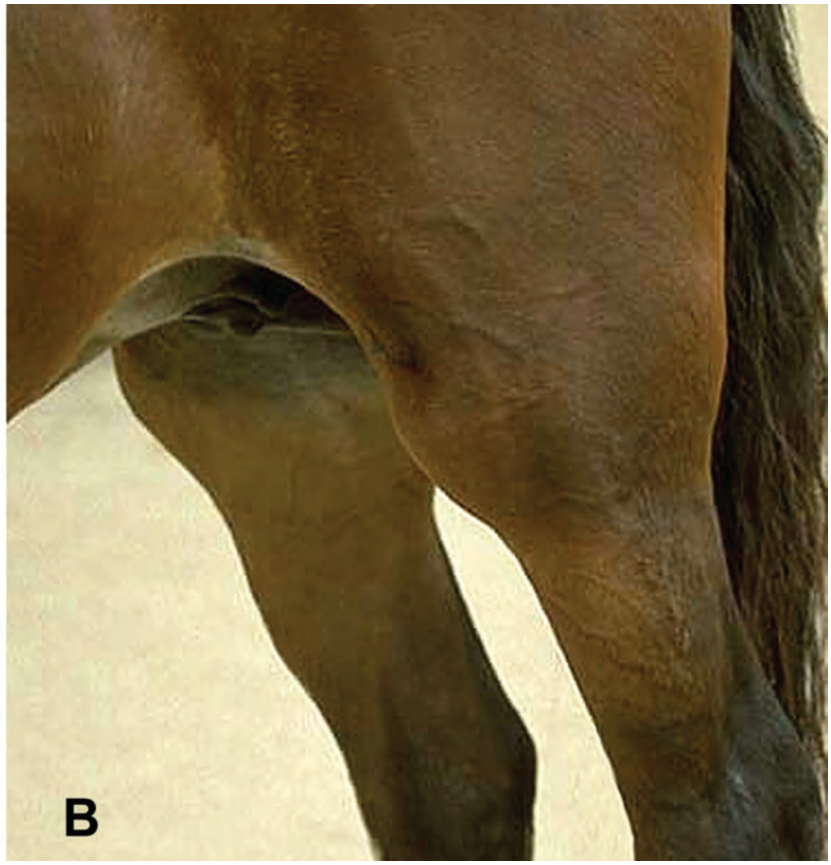
FIG. 14. Sequence frames of a Morgan park horse trotting. This style of movement requires more flexion of the hind joints than is typically seen in dressage, hunter, jumper, racing, or Western pleasure. Despite this, the hind limb joints must still be opened twice in every trot stride (red star in frames 5 and 8). At these moments, the patella may be pulled high enough to rise above the medial epicondyle and thus could potentially catch.

catch. The job of the TFL is to raise the PPC unit above the medial epicondyle hook at just the right moment and then hold it there for just long enough to permit flexion to begin (Fig. 12). The TFL then relaxes and the PPC unit is pulled downward in the patellar groove as flexion of the joint continues.

A little calculation highlights how important it is that this sequence occurs on time, every time, with each stride, and how small the window is for effective TFL contraction. A moderate trot proceeds at about 80 beats per minute, that is, either "clip" or "clop" will be heard about once every three-quarters of a second. If we consider only one hind limb, that limb will cycle from full protraction (with the joint opened wide) to full retraction (with the joint again opened wide) 40 times per minute, and the stifle joint will thus be fully opened in that limb 80 times per minute. This means that the TFL in each hind limb needs to contract once every three-quarters of a second for so long as the horse continues to trot!

Rather than asking why the stifle joint occasionally "catches" in some horses, on this basis, it would seem more reasonable to ask why it does not catch more often. The answer lies in two important areas. First, the horse's amazing neuromuscular integration, which allows for the precise coordination of the firing of the quadriceps, TFL, and flexor musculature as pictured in Fig. 12. Second, the horse's degree of collection—which is measured by flexion or coiling of the lumbo-sacral joint—greatly assists in preventing UFP and DPR, and in facilitating normal, healthy hindlimb function generally (*review our previous article on the subject of "The Biomechanics of Collection," October 2021*). Coiling of the lumbar and lumbo-sacral joints facilitates flexion of all the major joints of the hind limb, widening the window of time during which the TFL can effectively raise the patella. This is a major sustainable benefit of teaching the horse to round its back in movement. Saddle seat enthusiasts of today can benefit by studying champion performers in the era before 1930 (Fig. 17) whose horses were magnificent and expertly trained to move in collection. ■





OPPOSITE PAGE, BOTTOM: FIG. 15. Stifle joint dysfunction. **VIEW A.** Upward fixation of the patella ("hard locking" or "hung stifle," abbreviated UFP). The animal cannot bend either the stifle or the hock joint when the stifle is locked. **VIEW B**. Delayed patellar release ("rubbing stifles" or "sticking stifles," abbreviated DPR). This feels to the rider as if the horse has "tripped" or "stumbled" behind. Be it noted that rider technique and skill level contribute to the likelihood of DPR: unfortunately, this rider is not very skilled or experienced, and does not know how to help her horse achieve collection, which would offer him some protection from DPR. Horses that are prone to DPR are enormously helped by being taught to step back one-step-at-a-time, lateral work, and slow arena figures that alternate the bend (suppling exercises).

ABOVE: FIG. 16. A. A mare with "post-legged" conformation, in which the stifle and hock joints are open to nearly their full extent when the animal stands. Horses built like this can be prone to DPR and/or UFP. **B.** Chronic DPR, often called "catching," "rubbing," or "sticking" stifles, irritates the cartilage lining of the PPC unit, resulting in fluid accumulation and distension of the joint capsules (gonitis).

RIGHT: FIG. 17. I have colorized this image directly from the original photo in order to bring it to life. The mare is Liberty Girl, by Rex Peavine out of Liberty Lady, foaled 1914. Though an American Saddlebred this mare has 35 crosses to Justin Morgan in the first six generations of her pedigree. She was World Grand Champion five-gaited horse (all sexes) at the Kentucky State Fair in 1919. The rider is the owner, Mr. John P. Crozier. The quarter-boots are not weighted (that had not gotten started yet); the hoofs are of a normal length and shape; the shoes are not weighted, and the tail is not braced. The gait is a springy, collected trot, almost a passage; it is full of life and energy. Incidentally, this mare won her championship in a time of 2 hours, 22 minutes, the day after she won the mare stake in 1 hour, 44 minutes. Habitual correct collection indemnifies horses against performance injuries.