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BIOMECHANICAL BASIS OF REHABILITATION PROTOCOL DEVELOPMENT AND TIMELINES

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Introduction

Combining the fields of veterinary medicine, biomechanics, kinesiology, anatomy and physical therapy to produce equine rehabilitation protocols is important. Evaluation of the whole horse mechanics is not only a means to obtain quality healing, but is also a way to prevent injury from reoccurring, or from occurring. The problem solving begins with a thorough examination and diagnosis of the horse, which is followed by an organized rehabilitation plan.

The development of rehabilitation protocols is a long process and there are always those individuals that fall outside of the average response to rehabilitation. However, these caveats should not stop the development of protocol design. The formation of a rehabilitation protocol 'skeleton' onto which practitioners can begin to add their expertise and experience seems to be a useful exercise.

A rehabilitation plan not only looks at the site of the current pain and physiological dysfunction, but also focuses on the compensations that occur when the body attempts to deal with the mechanical problems. A physical therapist needs the information provided by a thorough medical examination, however the rehabilitation plan may first focus on compensation issues rather than pin pointing the site of the diagnosis. For example, a stifle injury may initially include physiotherapy to the sacral lumbar region to correct any hypertonicity that is producing asymmetrical loads on the stifle resulting in pain.

The purpose of this paper is to discuss the author's experience in equine rehabilitation and offer some clinical guidelines. These guidelines are meant to open up discussions on how rehabilitation timelines are used in clinical practice, not to be a definitive final recommendation.

The research behind the concepts discussed in this paper can be found in *The Proceedings for the 11th Annual Promoting Excellence Symposium, 2015* written in collaboration with Dr. Michael Butcher. This paper will focus on expanding the concepts previously presented, and discussing the application of these ideas into clinical practice.

The whole horse body mechanics must be evaluated even when the diagnosis of pathology is a specific bone, muscle, tendon or ligament.

The rehabilitation practitioner, prior to any evaluation of a horse, will have communicated with the attending veterinarian about the current diagnostic evaluations and treatments of the horse. In addition, the practitioner will also discuss with the attending veterinarian any rehabilitation recommendations.

The rehabilitation clinician performs the first evaluation of the horse by watching the horse stand in the stall, or on crossties, without interacting with the horse. This allows the practitioner to observe the passive stance of the horse and how the horse's body is naturally aligned. Observations by the clinician includes, any cervical, thoracic or pelvic rotations of the dorsal spinal processes relative to the sagittal plane, and the preferred weight-bearing leg(s). A gentle pressure, which will move the horse from side to side, will allow the practitioner to observe how the horse rebalances to their preferred body alignment. Evaluation of the limb angles, from the sagittal plane, as well as anterior/ posterior positions, will also be observed. For example, it should be noted if the olecranon of the forelimb, or the patella of the hind limb, is positioned medial or lateral in comparison to the contralateral and/or ipsilateral limb. The foot to ground balance of the hoof is another important element to observe, and the evaluation of all joint angles of the limbs during stance is performed.

Next, the entire body of the horse is palpated to note the level of musculoskeletal tenderness, numbness, asymmetry and static range of motion. Then the horse is walked away from, and toward, the practitioner to determine the medial/lateral swing pattern and the alignment of the head, neck, shoulders, thorax and hips. Of particular note are the asymmetrical medial or lateral swing of the limbs and any rotation of the thorax from the sagittal plane. Joint flexions have been performed by the attending veterinarian and can be reevaluated if applicable.

In general, when the horse is walking away from the practitioner, any hind limb swing pattern that places the hoof in an incorrect medial or lateral position during the stance phase is noted. An incorrect hoof placement is designated by the print of the hind hoof landing more than an inch medial or lateral to the print of the front hoof on the same side. This specific asymmetrical placement of the hind hoof may or may not be biomechanically significant to the ability of the limb to weight bear, but should be noted as a possible cause. Once the contact of the hoof with the ground is observed, then any abnormal joint rotations during the swing phase of that limb is noted.

The same medial or lateral deviations of the stance and swing phases discussed above are noted with the front limbs when the horse is walked toward the practitioner. The clinician uses these observations to best determine if the deviations from symmetry seen are due to the abnormal biomechanical position of the front, or hind limbs, or both.

Typically, when a hoof is placed medial to the ipsilateral limb the horse is using this medially placed limb for increased weight bear, and most likely reducing the weight bear on the contralateral limb. In general terms, the limb placed more medial is the stronger and therefore typically more coordinated limb, because the horse is more willing to weight that limb. The opposite limb is therefore considered “weaker” and/or less coordinated. In human rehabilitation “weakness”, as described by the patient, can be the result of incoordination, hypertonicity of the muscle, or lack of range of motion of the limb. Therefore, weakness may be the result of a motor system abnormality (Reeves and Swenson, 2004). The only way to determine what “weakness” in the horse is, will be to encourage the horse to weight bear that limb during dynamic movement and observe how the horse responds. The author challenges the “weak” limb to increase weight bear during 3 separate movement evaluations over a minimum of 3 days to help better determine the basis of the weakness. The exercises to accomplish this weight bear are discussed later.

Watching how the hoof contacts the ground, noting any toe out or toe in deviations, and how these deviations translate up the limb, is also important. As during the static evaluation, upper limb deviations are observed as potential causes or results of lower limb abnormal stance and swing phase positions.

The other major movement patterns to observe at this time are:

1. The trunk rotation relative to the sagittal plane, noting any tendency to hold the trunk more to one side of the sagittal plane than the other

2. Positioning the dorsal spinal processes to the right or left of center

3. Asymmetrical pelvic lift and cranial/caudal pelvic asymmetry

All parameters are also viewed at the trot to see if the addition of speed and, if the change in limb sequence as the gait changes influences the movement pattern observed at the walk. Any improvement in the movement pattern is evaluated as a positive sign because, when the horse's balance is challenged, an improvement in balance occurs.

Observation of the horse walking and trotting from both sides allows another view of the entire horse to determine if there is any range of motion abnormalities. The extension/flexion of the spine is observed, including observation of the position of the neck and tail, as well as the dorsal and ventral flexion of the vertebrae.

Side to side or lateral flexion is then observed on circles, to the right and left, in hand or during longeing. The size of the circle is important and should be about 20 meters in diameter to observe dynamic movement patterns that mimic performance, in the author's opinion. Smaller circles are useful to better evaluate the reluctance to weight bear the limb and to intensify range of motion movement patterns.

Hard surfaces can be useful to determine if the musculoskeletal issue is predominately a swing phase or stance phase issue. A stance phase problem will be more evident on a hard surface indicating a higher possibility of a weight bear issue with the limb, rather than a range of motion problem.

If possible, riding the horse is next in the dynamic evaluation process. Or, if riding is not possible, and the horse is trained under saddle, longeing can be the alternative. Even if no riding or longeing is possible, the saddle and bridle should be placed on the horse and the fitting of the equipment observed. During riding, the same sequence of movement observations occurs, starting with straight lines away from, and to, the clinician and ending with riding the horse in circles. If possible, the clinician will also ride the horse to add to the evaluation the "feel" of the horse to the visual observations. Riding is not necessary, and many times not advisable, but the author has found that in some rehabilitation cases, riding the horse can be helpful to organize the correct rehabilitation plan.

The Rehabilitation Timeline: Rest should be used as infrequently as possible

Research in human rehabilitation has shown that even in the acute phases of injury, early mobilization can be used successfully to produce better quality healing for muscles, tendons and ligaments (Kannus et al, 1992: Kannus, 2000). Immobilization is now minimally used, and protocols have changed from long, complete immobilization to early, controlled mobilization immediately after trauma. During rehabilitation, active joint motion and weight-bearing activities are recommended earlier than ever before. Continuous passive motion or range of motion exercises are advised immediately after surgery or injury in most rehabilitation protocols. Kannus, 2000: Stoffelen et al, 1998; Jung et al, 2009).

Immobilization may be necessary with wounds, fractures and severe ruptures so that enough mechanical strength can develop before mobilization. However, muscle, tendon and ligament tissues require regular, appropriate loading during healing to maintain their strength and function (Sharma and Maffulli, 2005: Bigard and Fink, 2003; Rubin and Lanyon, 1987; Lister, 2008) .

The concern that early mobilization may affect the quality of long-term healing and result in more frequent reinjuries has not been substantiated, when the appropriate mobilization process is utilized. Research has shown that correct early mobilization is a better alternative to immobilization and does not lead to a higher reinjury rate (Kannus, 2001).

Horses pose specific problems, and the direct transfer of rehabilitation techniques used by human practitioners is difficult. Early mobilization of a limb that is painful to a horse will not be easy, and the use of tranquilizers is not widely recommended in rehabilitation. Therefore, specialized mobilization techniques and modalities that are comfortable to the horse are necessary (Sharifi et al, 2008; Schils, 2009; Denoix and Pailloux, 2005; Goff and Stubbs, 2007; Porter, 1988).

The Rehabilitation Timeline: Veterinary diagnosis and treatment followed by physical therapy

Treatment of the cause of the injury, including pain management is the first step in any quality rehabilitation program. However, if incorrect movement patterns are what caused the injury, and these issues are not addressed, the symptoms are likely to return. An evaluation of the movement of the horse and the discussion of incorrect movement patterns and how to improve the quality of the movement is an important next step to healing. The determination of which exercises are beneficial and when, is a specialized area of expertise and those with riding and training backgrounds are naturally better able to communicate this information to the rider. However, there are some important guidelines that every practitioner can add to their repertoire to address these issues. The focus of this paper will be an outline of how to use movement to improve healing. It is important to emphasize that, although the exercises discussed here are similar to the exercises used for improvement of performance, the goals of rehabilitation do not necessarily mimic the exercises, nor the order of the exercises, used for performance enhancement. The rehabilitation specialist is not a horse trainer. The physical therapy exercises discussed here are simply guidelines to help improve the movement patterns and balance of the horse so that they can then be trained for performance in a way that decreases the likelihood of breakdown.

The Rehabilitation Timeline: Straightness is of primary importance.

Straight lines should be emphasized in the early stages of rehabilitation, as well as during the initial warm up phase in the later stages of rehabilitation. Correct spinal symmetry is the primary goal for rehabilitation and it is a well accepted by human researchers that increased spinal torsion is one of the most important reasons for the procession of low back pain (Adams and Roughley, 2006; Farfan et al, 1970; Gordon et al, 1991).

Of course, the practitioner must be flexible and sometimes what doesn't work with one horse is exactly what works with the next horse. Experience with dressage type exercises for both the practitioner and rider is beneficial at this stage, but not necessary. Rehabilitation can be done successfully with a young rider or an experienced Olympic rider. The goals and outcomes of the rehabilitation plan will vary, but the ability to improve the horse is highly likely with a good rehabilitation protocol. It will be the <u>degree</u> of improvement that will generally depend on the abilities of the rider and horse

Biomechanically correct distal limb movement is also important to the overall quality of movement. Anterior Cruciate Ligament (ACL) injuries and the relationship of injury to incorrect joint movement has been studied extensively in human rehabilitation. The knee joint is a complex combination of rotational, rolling and gliding movements, therefore the actual cause of the injury can be multifaceted (Boden et al, 2009). However, ACL injuries have been found to occur at the highest rate when two factors are present; deceleration, and changing directions. Internal rotation (torsion) of the tibia relative to the femur and compressive loading during landing were correlated with a higher risk of ACL injury (Meyer and Haut, 2008). A major focus in the training of young athletes to reduce injury is to educate them on how they position their limbs during sport.

Knee adduction or abduction and the role of muscle interaction as a prelude to human ACL injury, has been debated in the literature (Yu and Garrett, 2007). However, the current research is trending in the direction that landing with the knee rotated inward or, abduction, that is due to a lack of neuromuscular control, is a risk factor for ACL injury (Hewett et al, 2005). Training programs to reduce abduction of the knee have also been shown to reduced ACL injury (Hewett et al, 1999). Reducing abduction by as little as 2 degrees has been shown to be protective (Chaudhari and Andriacchi, 2006).

It is unusual to be able to only ride straight lines in rehabilitation, therefore some type of turning is typically necessary to connect the straight lines. To reduce the pathological rotational joint movement and torsion, the straight lines should be connected by turns that look more like the corners of an octagon rather than a continuous curve. A series of straight lines connected by smooth, shallow turns is a better strategy than riding a constant arc at the onset of the rehabilitation protocol. Human research has shown that during walking, people need three strides to reach a steady state of balance (Miller and Verstraete, 1994). Therefore, a minimum of three strides would be a reasonable number of strides to remain on a straight line before changing directions so the horse will have time to rebalance before the next turn.

In addition, allowing the tempo of the horse to slow down so that the limb placement can be more precise is valuable at this phase of rehabilitation. Research has shown that, when limb acceleration is reduced, the ability to position the foot for correct foot contact with the ground is increased (Jansen et al, 1993).

Watching the horse coming and going in a straight line will determine if the hind hooves are tracking into or within a couple inches of the track of the front hooves. A crooked horse, even when only walking, will not improve during rehabilitation to the degree of a horse that has correct biomechanical movement. Having the horse in correct balance on all four limbs is extremely important, so that the horse does not over load any limb, or rotate any joints incorrectly. In addition, alignment of the footfalls of the horse is an easy indicator for practitioners and riders alike to see and evaluate regardless of their experience.

Typically, adjusting the horse’s hindquarter position to improve straightness is the first correction attempted, rather than adjusting the position of the shoulders, because most horses will respond more easily to those aids. Positioning the haunches in or out relative to the position of the shoulders will help to align the footfalls of the horse, and works well for many horses. At times, flexion in the thorax and neck are also necessary to get the desired movement of the haunches. Several exercises may need to be tried to find the one that best positions the horse, and also can be performed by the rider. Renver is a favorite exercise of the author to help with alignment, if the rider and horse are able to accomplish this more advanced exercise.

If the horse does not respond to displacement of the haunches to improve the straightness of the body, then displacement of the shoulders to the right or left is the next movement to try. As the rehabilitation protocol advances both displacement of the haunches and displacement of the shoulders to straighten the horse typically becomes a part of the program. This is due to the fact that any exercise, which is over performed, even if the exercise was initially beneficial, will tend to be detrimental to the biomechanics of the body. A periodic review of the overall balance of the horse is essential not only in the early stages of the rehabilitation protocol, but also to maintain the improvements obtained.

Extending the period of time the movement is performed is essential to obtain the changes in muscle memory, which is necessary if improvement in the overall balance of the horse is a goal. In addition, maintaining a steady gait in the beginning of the rehabilitation process is important due to the stresses placed on the tendons and muscles when changes of gait occur. Equine biomechanical research on the muscle-tendon stresses and elastic energy storage showed that changes in gait increased both tendon and muscle stresses more steeply than did steady-state trotting (Biewener, 1998). These data support the concept that changes in gait should be minimized during early rehabilitation.

In summary long, straight lines with shallow turns should be used in the early stages of rehabilitation. The focus at this point is on limb placement and making sure that the weight bear on all four limbs is a equal as possible. In addition, during this phase of rehabilitation, quick starts and stops should be reduced and steady-state movement should be emphasized.

The Rehabilitation Timeline: Longitudinal flexion follows straightness

Strengthening the body from back to front, or caudal to cranial, is called longitudinal bend or flexion. The horse's body relative to the sagittal plane remains symmetrical, and a distinct change in the dorsal/ventral flexion, and extension, is observed during correct longitudinal flexion. It should be emphasized that both dorsal and ventral movement should be encouraged, or the horse can begin to use rigidity of the muscles rather than flexibility of the muscles to obtain stability. Longitudinal flexion should be obtained in the horse before asking for distinct lateral bend on long curves and circles. Correct longitudinal flexion helps the horse to continue to become more stable in the top line due to the focus on symmetry relative to the sagittal plane. When asking the horse to bend longitudinally, if the horse is not symmetrically balanced on the sagittal plane, then biomechanically incorrect rotations will be observed and the horse will typically position the hindquarters or shoulders more to one side of the sagittal plane.

If the horse moves in the correct symmetrical frame, the horse then has the best opportunity to use all limbs as equally as possible for balance. When the horse is asked to bend from side to side too early in the rehabilitation process, before the stabilization of the thorax, lumbar and pelvic region are adequate, there is a good chance of producing incorrect joint movements, which is one of the major causes of musculoskeletal breakdown (Bisschop et al, 2013; Burkhart et al, 2003a; Burkhart et al, 2003b; Dines et al, 2009; Garrison et al, 2012; Myers et al, 2006; Wilk et al, 2011)

During rehabilitation, keeping the overall position of the horse as "neutral" as possible and not specific to any sport is the best. This "neutral" frame typically places the bottom of the horse's nose no lower than the base of the neck (where the neck meets the chest) while keeping the poll the highest point of the arch of the neck and some flexion of the neck at the atlanto-occipital joint. The correct degree of longitudinal flexion from front to back should be determined based on the training of the horse.

It is important that the horse not change the rhythm of the gait when flexing from front to back. If the tempo or rhythm of the gait changes, this is usually an indicator that too much flexion has been asked of the horse at this particular stage of rehabilitation.

In general, longitudinal flexibility is encouraged first by shortening, rather than lengthening, the horse's frame from front to back. This will encourage the dorsal lift of the horse and reduce the incidence of the longitudinal flexion encouraging rigidity in the back, rather than stability. In the author's opinion, it is much easier for the spine of the horse to move ventrally, when compared to dorsal movement.

Some muscles seem to be more prone to injury than others and eccentric (lengthening) muscle action is frequently the cause of injury (Brockett, 2004). In humans, the hamstrings are a common site of muscular injuries with the biceps femoris muscle being the most frequently injured. In one study, the biceps femoris was the muscle injured in 83% of 154 hamstring injuries (Connell, 2004). It has been proposed that this high injury rate could be due to the biarticular function of the muscle making this muscle more prone to injury (Whiting and Zernicke, 2008). In addition, proximal and lateral injuries to the biceps femoris muscle bellies are common in humans (Garrett et al, 1989) and it has been proposed that this is due to the fact that these muscles have their length determined by the coaction of two joints (e.g. the hip and knee) (Thelen et al, 2005). For example, with the combination of hip flexion and knee extension, the hamstrings are placed in a maximally lengthened state predisposing it to injury (Whiting and Zernicke, 2008).

For example, transitions within the same gait, and between gaits, will increase the spinal flexion and extension from front to back. Transitions within the same gait are asked of the horse first before transitions between the gaits are emphasized. Transitions within a gait simply means the horse will slow and speed up the tempo while maintaining the same gait or rhythm. The first steps of the horse in and out of the transitions within a gait are good indicators of the mastering of this exercise. When the horse can maintain a steady frame and rhythm, the degree of difficulty is increased and the horse is then asked for the within-gait transitions more frequently. For example, at first the horse is asked to slow and speed up the tempo once on a 20 meter circle and then is steadily asked to increase the transitions so that 4 transitions are asked on one 20 meter circle. Next the quickness of the response to the aids to slow down and speed up the tempo are ridden more quickly, while always maintaining a steady frame and rhythm of the horse. Finally, the transitions are asked for between gaits such as walk to trot and trot to walk, progressing to transitions where a gait is skipped such as from walk to canter and halt to trot. Again a steady frame is emphasized during all these transitions. The steadiness of the head and neck is a good indicator of the ability of the horse to stabilize the thorax and lumbar region during these exercises. The horse should not swing the head and neck dorsal and ventral during the transitions because this is a good indicator that the horse is keeping the thorax and lumbar region rigid. The head and neck should remain as still as possible while the thorax and lumbar regions of the horse move dorsally and ventrally during the transitions.

Turns should be gradual and consist of shallow turns connected by straight lines. "Clipping" the 90-degree corners off a rectangle or square is one way to describe the types of turns performed at the early levels of rehabilitation. The head and neck of the horse should not be positioned to the inside of the sagittal plane of the horse. If it is necessary to keep the horse from falling to the inside of the circle, the horse's head and neck can be positioned slightly to the outside of the sagittal plane during the early stages of the rehabilitation program. However, positioning the head and neck on the sagittal plane without the horse falling to the inside should be emphasized.

In summary, the focus at this stage of rehabilitation is first, that the spine of the horse is positioned over the limbs as symmetrically as possible in the sagittal plane. Second, the musculoskeletal improvements emphasized at this stage should be on improving the longitudinal flexion or dorsal/ventral movement of the thorax and lumbar regions. Riders should first be instructed to slow or speed up the horse's tempo while maintaining the same gait to encourage longitudinal flexion from front to back, not side to side. The head and neck of the horse should remain steady and in a position that requires some longitudinal flexion based on the training of the horse. The horse should first be asked to slow the tempo and almost makes a gait transition and then ask the horse to gradually resume the original speed without changing gaits. These exercises are asked for more frequently and then more quickly as time progresses. The last exercises at this stage of rehabilitation include transitions between gaits such as walk to trot, followed by more difficult transitions where a gait is skipped such as halt to trot.

The Rehabilitation Timeline: Lateral flexion is next. Steady curves should be avoided in the early stages of rehabilitation

Lateral bending or flexion is referred to as bend in the horse from side to side relative to the sagittal plane. Lateral movement is a complex combination of muscular actions and is basically the result of unilateral co-contraction of the epaxial muscles, the iliopsoas and the oblique abdominal muscles (Denoix, 2014). When the horse can flex longitudinally from front to back willingly, while maintaining a straight, even and active gait, then the horse is typically stable enough to begin exercises that require a lateral bend. Because of the increased chance of incorrect rotation of the vertebrae when bending from side-to-side, this movement is asked for later in the rehabilitation program. As discussed previously, research has noted that incorrect side-to-side rotation is one of the leading causes of the negative progression of an injury. To gradually increase the lateral flexion, one exercise that has been used successfully by the author, is to incorporate large 20-meter octagon shaped “circles”. Once the horse can consistently maintain balance and rhythm on the octagon, change the exercise to a constant, curved line of a “true” 20-meter circle. This series of exercises will gradually increase the lateral bending demands and should help reduce the tendency of the horse to rotate the dorsal spinal processes off the midline in an attempt to comply with a degree of lateral bend the horse cannot perform.

The horse should not bend more in the neck than the circumference of the circle. One good indicator is to observe that the ears of the horse stay level relative to the ground as the horse is asked to flex to the inside laterally. If necessary to keep the horse from falling in on the circle and overloading the inside shoulder the horse can be bent in the neck slightly to the outside of the circle. Gradually the horse will be able to maintain their tempo and rhythm in balance with the lateral flexion of the neck in relationship to the curve of the circle.

Asking the horse for side-to-side movements such as leg yielding and half pass are good exercises next to increase the demands of the horse's balance during lateral bending. Again, if the tempo or the rhythm of the gait changes, the degree of lateral bending or the exercise may need to be changed because these changes could be an indication of a lack of stability and may result in pathological rotation of the spine.

There are times when lateral bending is asked for before longitudinal bending. During rehabilitation, for horses that have more difficulty trotting, it may be beneficial to focus first on front to back, or longitudinal, bending. For horses that have more difficulty cantering, side-to-side, or lateral, bending can be focused on first. This is due to the sequence of footfalls and vertebral flexions that each gait places on the spine, which will be discussed next.

In summary, lateral flexion exercises should follow longitudinal exercises in a rehabilitation protocol. The degree of lateral bending will be based on the previous training of the horse and the horse specifically should not be asked to obtain more lateral flexion in the neck when compared to the overall flexion of the rest of the body. Care should be taken that no rotation of the dorsal spinal processes off the sagittal plane occurs when lateral flexion is obtained.

Rehabilitation Time Line: The trot is a more stable gait, than the walk or canter, and can be used to improve trunk and lumbosacral stability

The sacroiliac joint is a gliding joint and its most important function is for stability, therefore the joint is more susceptible to shearing than to compressive forces (Dalin and Jeffcott, 1986a; Dalin and Jeffcott, 1986b). Pain in the sacroiliac joint has been associated with instability of the joint (Jeffcott, 2009), although the movement in the sacroiliac joint is relatively small and the movement of the sacroiliac joint is accompanied by movement of the lumbosacral region (Degueurce et al, 2004). In addition, the sacroiliac joint is responsible for lateral movement and rotation (Dalin and Jeffcott, 1986a; Dalin and Jeffcott, 1986b).

One study found that the activity of the muscles of the back increased with an increase in speed at the trot and showed a decrease in flexion, while extension remained unchanged as speed increased. This is an indicator that the back muscles have a more stabilizing role at the trot as speed increases, rather than inducing movement (Robert et al, 2001). In addition, one preliminary study of 3 horses found that the greatest magnitude of segmental vertebral motion occurred during the canter and the least amount of motion occurred during the trot (Haussler et al, 2001). The trot is such a stabilizing gait that, even when compared to the walk, the trot was found to produce more vertebral stability than the walk. Another equine study evaluated motion at the equine sacroiliac joint using pin-mounted sensors and found that the mean walk values for flexion/extension, axial rotation and lateral bending were significantly ($p < 0.05$) greater than the values at the trot (Goff et al, 2010). These studies could indicate that the trot is the best gait to use when stability of the spine is important and would not be the best gait to use if flexibility of the spine is important to the progression of the rehabilitation protocol. In addition, the walk and canter may be the best gaits to improve flexibility of the spine and reduce rigidity.

Interestingly, in jumping a similar result was found, where too much flexion in the lumbosacral junction as the hind limbs clear the fence can be an aspect of poor performance. Good jumpers show increased extension at the lumbosacral junction. In poor jumpers, increased flexion of the lumbosacral junction and thorax was noted before take-off and during flight. Therefore, lumbosacral extension was less over fences and resulted in poor jumping performance (Cassiat et al, 2004). Another equine study supported this work and found that the rearward extension of the hind limbs, produced through extension at the lumbosacral junction, was one of the kinematic variables found in good jumpers (Bobbert et al, 2005).

In summary, exercises to develop trunk stability and extension in the lumbosacral region, and perhaps the thorax, would be useful for horses with weak back muscles or muscles that are rigid due to overuse. These exercises would include trotting at faster speeds to activate the muscle groups that support trunk stability. However, for horse with a rigid back with muscle spasms (hypertonicity) the canter and walk would be better gaits to improve flexibility. A lower and longer frame of the horse will position the center of gravity further forward and, in the authors' opinion, to counter this the horse will increase tension in the lumbar region, which would be beneficial for lumbar stability. However, if the center of gravity is pushed too far forward this position may increase the forces on the forelimbs and over stress the lumbar muscles. For rigidity in the back the long, low frame used for loosening may actually increase rigidity in the lumbar region.

Rehabilitation Time Line: When should the canter be added to the protocol?

Looking at the differences in tendon loading across gaits, research found an increase in these parameters on the DDF tendon with a change from walk-to-trot-to-canter (Butcher et al, 2007). The strain, stress and force of the DDF tendon roughly doubled when the walk was compared to the canter. Therefore, for DDF muscle/tendon complex rehabilitation, the canter should be utilized at a later time than for SDF muscle and tendon injuries. Activating associated muscles, which could reduce the load on the flexor tendons could prove useful.

In the SDF tendon, the loading parameters were greater than in the DDF tendon at all gaits (Takahashi et al., 2010). However, in the SDF tendon, the strain, stress and force decreased by 14% from trot to canter, although it is important to note that the SDF muscle/tendon complex loading is still overall higher than the forces on the DDF tendon (Butcher et al, 2009). Other research supporting these data found the same 14% reduction in average vertical ground reaction forces when the gait transitioned from trot to canter (Farley and Taylor, 1991).

In summary, a progressive increase between gaits from walk to trot and trot to canter may not be appropriate for all injuries. For example, rehabilitation protocols for injuries to the SDF muscle/tendon complex could introduce the canter before the trot to reduce the muscle and tendon loading parameters. In comparison, the addition of the trot into the rehabilitation protocol, may achieve greater strain by the SDF muscle/tendon complex. Therefore, the traditional progression of walk to trot and then canter may not be the best sequence for all injury rehabilitation plans.

Rehabilitation Timeline: What about concussion, how does that relate to healing?

In one study looking at the effects of falling, human subjects were told to "keep their hands as far away from the ground as long as they could" (increasing elbow flexion) during falling and the results were compared to the forces measured when the subjects were allowed to "arrest the fall naturally". Subjects were able to reduce the force of impact by 27% by flexing their elbows (DeGoede and Ashton-Miller, 2002), which reduced the velocity of the hands hitting the ground as a result of increasing the time over which force was applied. When subjects were then told to fall with "stiff-arms" the forces were increased by 40% when compared to falls were the elbow was flexed (DeGoede and Ashton-Miller, 2002). If changes in movement patterns can reduce impact forces this significantly, the reduction in injury risk can be large. In addition, the authors cited that flexing the elbow during falling was so significant that this movement pattern change was more important than bone strength in reducing injury.

In another human study, knee angle upon landing was correlated with impact forces. It was found that the angle of the knee at contact significantly influenced both peak ground reaction forces (GRF) and acceleration of the tibia, thigh and trunk body segments. In addition, the peak forces and accelerations increased more rapidly when the angles of these body segments were close to full extension, and this is related to the decreased period of time during which the force was applied (Elvin et al, 2007a).

Translating these concepts to equine rehabilitation would indicate that evaluating the degree of flexion of joints during ground contact is important. Developing exercises that improve joint flexion will not only help reduce impact forces, but may also develop a movement pattern to reduce future chances of injury. Examples of exercises that could help lower landing velocity, include slowing the speed of the gait of the horse and then, to increase joint flexion, encouraging higher carpal and hock action. Higher carpal and hock action is also a more natural reaction when the gait is slower. In addition, flexion of the carpal and hock joints results in an associated increase in the flexion of the fetlock in the distal limb. For jumping, tightening the distances between the fences to help slow the horse, while choosing the appropriate height of the fence to obtain the desired joint flexion, could prove helpful rather than just increasing the height of the fences. Another example would be using gymnastics such as bounces, one-strides or two-strides in a gymnastic series at lower jumping heights, while keeping the speed slow to encourage more distal joint flexion, when compared to joint flexion obtained on the flat. The slower speed will also lower the magnitude of the impact forces. Evaluation of the degree of flexion of distal limb joints at stance in both the fore- and hind limbs during a clinical examination could be a valuable tool in a lameness exam.

In another study of human athletes, GRF were compared to vertical jump height. When forces on the athlete were evaluated, landing forces could be as high as 8 times the body weight of the jumper. However, in this study, there was no correlation between jump height and peak vertical ground reaction forces (Elvin et al, 2007b).

In summary, GRF are important elements to consider in rehabilitation protocols but the focus on correct point position and flexion to reduce GRFs should not be underestimated. Even in jumping, other issues rather than fence height may be important contributing factors to injury. If higher fence height improves the other biomechanical aspects of the horse's position during jumping, such as distal limb flexion, on approach, take off, flight and landing, then a higher fence height may be appropriate in earlier stages of rehabilitation. However, increasing fence height too much will override any positive outcome by multiplying GRF above acceptable levels.

Rehabilitation Timelines: What about focusing on supporting structures to the injury site to help improve the healing rate?

Research on horses has found that in the forelimbs, one head of the complex deep digital flexor (DDF) muscle flexes the fetlock in late swing and, although it is largely a positional control muscle, its fast fiber typing characteristics render it susceptible to fatigue. The DDF muscle/tendon complex stabilizes the hyperextension of the fetlock as well as assisting the superficial digital flexor (SDF) muscle to support the limb during ground contact (Butcher et al, 2007).

In comparison, the SDF muscle belly is more resistant to fatigue than the DDF and undergoes lengthening, resulting in elastic energy storage and recovery by its tendon (Butcher et al, 2009). The long, thin SDF tendon compliments the short, pennate fibers of the SDF muscle belly and allow this muscle/tendon complex to be the main source of elastic energy storage and recovery. This 'spring' effect is best realized at the bouncing trot, and it helps horses save energy, therefore reducing fatigue. The authors cited that when the DDF muscle fatigues, this requires the SDF to bear more load, especially during fast galloping (Butcher et al, 2009). Therefore, to reduce SDF injuries an increase in the strength of the DDF muscle could prove useful.

Distal limb injuries are frequent in equine athletes. Muscles of the distal limb in humans and horses were once thought to generate the power for movement. However, research has shown that these muscles perform little-to-no net mechanical work during level, steady-speed locomotion (e.g. Roberts et al, 1997; Biewener et al, 2000; Daley and Biewener, 2003), while the tendons experience high levels of strain. A consensus from these pioneering works and related studies is that when evaluating the function of the tendon, it is essential that the action of the associated muscle belly must also be evaluated (Butcher et al, 2009), and that muscular imbalances likely effect tendon function (Arampatzis, 2013). Therfore, to improve healing of tendons it is likely that rehabilitation of the associated muscles is important.

In another example, equine research has also shown that the biceps brachii muscle (and lacertus fibrosus), is an elbow flexor and has a large isometric force-generating capacity due to the large proximal moment arm making the biceps a strong contributor to shoulder movement. To counter this strong action of the biceps the triceps brachii muscle is thought to have an important stabilizing role during stance (Watson and Wilson, 2007). The development of the powerful lateral triceps of the forelimb to help control the flexion of the elbow joint (Wickler et al, 2005; Hoyt et al, 2005) could be of assistance to compliment the tension in the SDF and DDF muscle/tendon complexes. This tension could then help support the carpus and control hyperextension of the digit (Butcher et al, 2009).

Translating these concepts to equine rehabilitation would indicate that during rehabilitation of the SDF and DDF muscle/tendon complexes, normal function of the triceps brachii would be of initial importance. If instability is found in the triceps, improved function of this muscle would be indicated, followed by evaluation of the normal function of the biceps. Generating a more powerful movement through initial biceps strengthening without having the ability to stabilize that movement could prove to be detrimental to the healing process. The author is not familiar with research that has determined exercises for the horse that primarily develop the triceps. However, clinical observation showing hypertrophy of the triceps in racing trotters would suggest that extended periods of trotting with a gradual increase in stride length would be useful. In addition, clinical observation of horses with DDF and SDF muscle/tendon complex injuries shows decreased muscle development in the triceps.

Additionally, to improve the engagement of the hindquarter, emphasizing stronger shortening of the quadriceps femoris and tensor fascia latae muscles in exercises to flex the hip, while not unbalancing the movement, rather than emphasizing hamstring development exercises may be beneficial. Contraction of the biarticular rectus femoris head of the quadriceps femoris will flex the hip and pull the patella upward resulting in extension of the stifle. Co-contraction of the cranial muscles of the leg must also occur so that the flexion of the hock is achieved at the same time as flexion of the hip. In addition, lumbosacral flexion will allow the more distal limb flexion to occur. (Denoix, 2014a). Examples of exercises would include hindquarter flexion movements such as piaffe and passage tendencies of the trot, and slower, more stationary canter strides. For both of these, conceptualize exercises that produce a “duck walk” position in the horse’s hindquarters. Of course, sustaining this limb flexion too deeply or for too long of a period of time will be detrimental.

In summary, focusing on individual muscular development alone may not be as useful in rehabilitation as emphasizing the exercises which produce the desired movement patterns. For example a balanced triceps and biceps development may be useful in the rehabilitation of SDF and DDF tendon injuries due to the movement pattern produced through the activation of those muscle groups.

Rehabilitation time line: What if the horse seems worse at some point during the rehabilitation?

Make sure the horse is “warmed up” to evaluate the quality of the movement accurately. Many times the horse will start out with a reduced range of motion and then will “loosen up” and the stride becomes normal. When new muscles are being recruited to change incorrect movement patterns, the horse may initially become a little “stiff” or may look different in their movement pattern as they adjust to the new movement.

Some stiffness or lack of complete range of motion is typically lpart of the rehabilitation protocol, and is to be expected. To thoroughly evaluate the horse’s movement; change the gait of the horse, change the direction of movement, change the bend in the horse’s body and give the horse several minutes while observing the horse moving in both directions. In addition, observing the willingness of the horse to move, or “attitude” can help determine if the change in movement pattern is a result of increased pain. If the conclusion is that the horse has become slightly worse in their movement, then return to previous level of activity, but do not regress more than one stage of the protocol. If the deterioration of the movement continues or does not progress but lasts for more than 2-3 days, then the attending veterinarian needs to re evaluate the horse.

In summary, a rehabilitation protocol will not always be a steady progress of improvements. If the horse shows a decline in the preferred movement pattern, this may only be a transitional phase as the horse becomes more coordinated in different movements and stronger in new muscles. Initially, further demands should not be made on the horse to progress in the rehabilitation protocol, rather the horse should remain at the current level of activity. If in 2-3 days the horse does not return to their previous level of performance, a reevaluation of the rehabilitation protocol should occur.

Conclusions

The topics discussed in this paper focusing on the development of protocols and timelines for equine rehabilitation, are listed below.

1. The whole horse body mechanics must be evaluated even when the diagnosis of pathology is a specific bone, muscle, tendon or ligament.
2. “Rest” should include precise and active early mobilization
3. Straightness and symmetry of body mechanics is of primary concern
4. Muscles that are in a lengthened state are more prone to injury.

5. Quick starts and stops should be reduced during rehabilitation with the emphasis on:
    a. changes of speed within the gaits
    b. gradual changes of speed between the gaits
6. Steady curves should be avoided in the early stages of rehabilitation with the emphasis on:
    a. turns should look more like octagons
    b. turns should be a series of shallow turns and straight lines.

7. Longitudinal flexion should be obtained before distinct lateral flexion is obtained
    a. If the frame of the horse is shortened, or lengthened, and the horse cannot keep the shoulders or hips aligned, this is a good indicator of a lack of symmetry.
    b. It should be emphasized that both dorsal and ventral movement should be encouraged, or the horse can begin to use rigidity of the muscles rather than flexibility of the muscles to obtain stability.
8. Slower tempos allow for better control over limb placements
9. The trot is a more stable gait, than the walk or canter, and can be used to improve trunk and lumbosacral stability.
10. The canter produces more vertebral movement than the trot, and can be utilized to improve flexibility in the top line.
11. Canter work could be introduced earlier in the rehabilitation of the SDF muscle/ tendon complex than during rehabilitation of the DDF muscle/tendon complex.
12. Exercises for rehabilitation of weak back muscles or for back spasms (hypertonicity) due to overuse include:
    a. exercises to improve trunk stability
        i. lower, longer frame of the horse will increase lumbar tension to help provide trunk stability
        ii. lower, longer frame may also increase forces on the front limbs and over stress the lumbar muscles if the center of gravity is positioned too far forward
    b. trotting at faster speeds.
13. Concussion is a consideration but may be as important to healing as good body mechanics
    a. Fence height should promote good jumping form.

14. Exercises that improve joint flexion will help reduce impact forces include:
    a. on the flat
        i. slow the speed of the gait
        ii. higher carpal joint and hock action
    b. during jumping
        i. tighten the distance between fences to slow the horse
        ii. use gymnastics to slow the horse
        iii. select fence height that increases joint flexion.
15. Exercises that improve strength and 'spring' in the hindquarters include:
    a. on the flat
        i. a "duck walk" appearance through piaffe and passage tendency work at the trot
        ii. slower more stationary canter strides
    b. during jumping
        i. very slow approaches to fences with shorter strides
        ii. shorter distances between fences
        iii. increase joint flexion.
16. Exercises for triceps strengthening which can support SDF and DDF rehabilitation include:
    a. extended periods of trotting
    b. gradually increasing the speed of the trot.

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